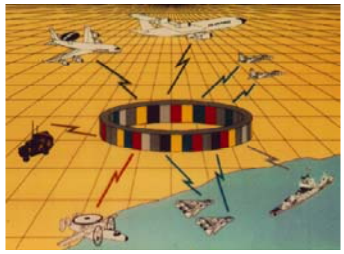
Silver Bullet Solutions, Inc.



Data & Information Fusion

Enterprise & IT Architecture

Combat & C4ISR Systems Engineering

> *"There is no silver bullet" so the well-known cliché goes. Indeed many apparent "silver bullets" turn out to solve what the famous computer scientist Fredrick Brooks' called "accidental" problems in a much bigger "essential" problem. Worse, apparent "silver bullets" often take focus off the essential problems and the difficult-to-see "tar pits" inherent in them. If there is a real silver bullet solution, it is in knowing the essence of the problem and how to navigate through the tar pits safely.*

SBSI specializes in data and information fusion, enterprise and IT architectures, and Combat and C4ISR systems engineering. We conduct research, analysis, and design and develop software, databases, and tools. SBSI addresses the essence of problems, discerning common patterns within problem sets and bringing to bear experience with the strengths and limitations of solution types.

1. Data and Information Fusion

SBSI conducts research and develops algorithms, databases, and software for data fusion for command and control, battle management, and intelligence, surveillance and reconnaissance. These include ontology-based fusion, multiple-hypothesis databases, and real-time command and control databases.

- Level 1 Correlation, Target ID & Behavior Estimation
- Level 2 Object and Event Associations
- Knowledge Assisted
- Formal Ontologies & Taxonomies
- Semantic Data Integration
- Taxonomy tools
- Data translation tools

2. Enterprise and IT Architectures

SBSI is well-recognized across the Department of Defense for leadership and expertise in enterprise architectures. A principal part of the work has been the design, development, and deployment of EA data models, databases, and software. SBSI has supported several DoD component CIO offices for over 10 years. We also conduct and support EA development and employment projects.

- Frameworks & Methodologies
- Development
- Analysis
- Databases & Data Sharing

3. Combat and C4ISR Systems Engineering

We take a unified approach to requirements analysis and formalization, acquisition, systems engineering, and configuration management that provides traceability across the entire system life-cycle. We also employ tools and techniques to make the life-cycle tractable and focused on key technical challenges.

- Acquisition System Engineering and Architecture Artifacts
- MOE's and MOP's
- Functional Designs and Specifications
- Performance and System Specifications
- Technical Requirements Documents

Type of company	Woman Owned Small Business
Locations	Washington, DC and San Diego, CA
Ownership	All United States, no foreign ownership
Average annual revenue for past 3 years	$1,500,000
Number of employees	12
NAICS Code(s)*	334220, 334511, 334513, 334519, 336413, 336419, 336999, 517910, 518210, 519190, 541330, 541380, 541511, 541512, 541611, 541614, 541618, 541690, 541712, 541990
Number of years in business	13
Name and address of points of contact	Ms. Elizabeth McDaniel 1901 Ft. Myer Drive, Suite 501 Arlington, VA 22209 (703) 892-6062 bethm@silverbulletinc.com
Other	1. Cleared personnel and facilities 2. DCAS audited and approved CPFF rates 3. Current and recent DoD contracts and subcontracts available for reference

Sensor / Data / Information Fusion

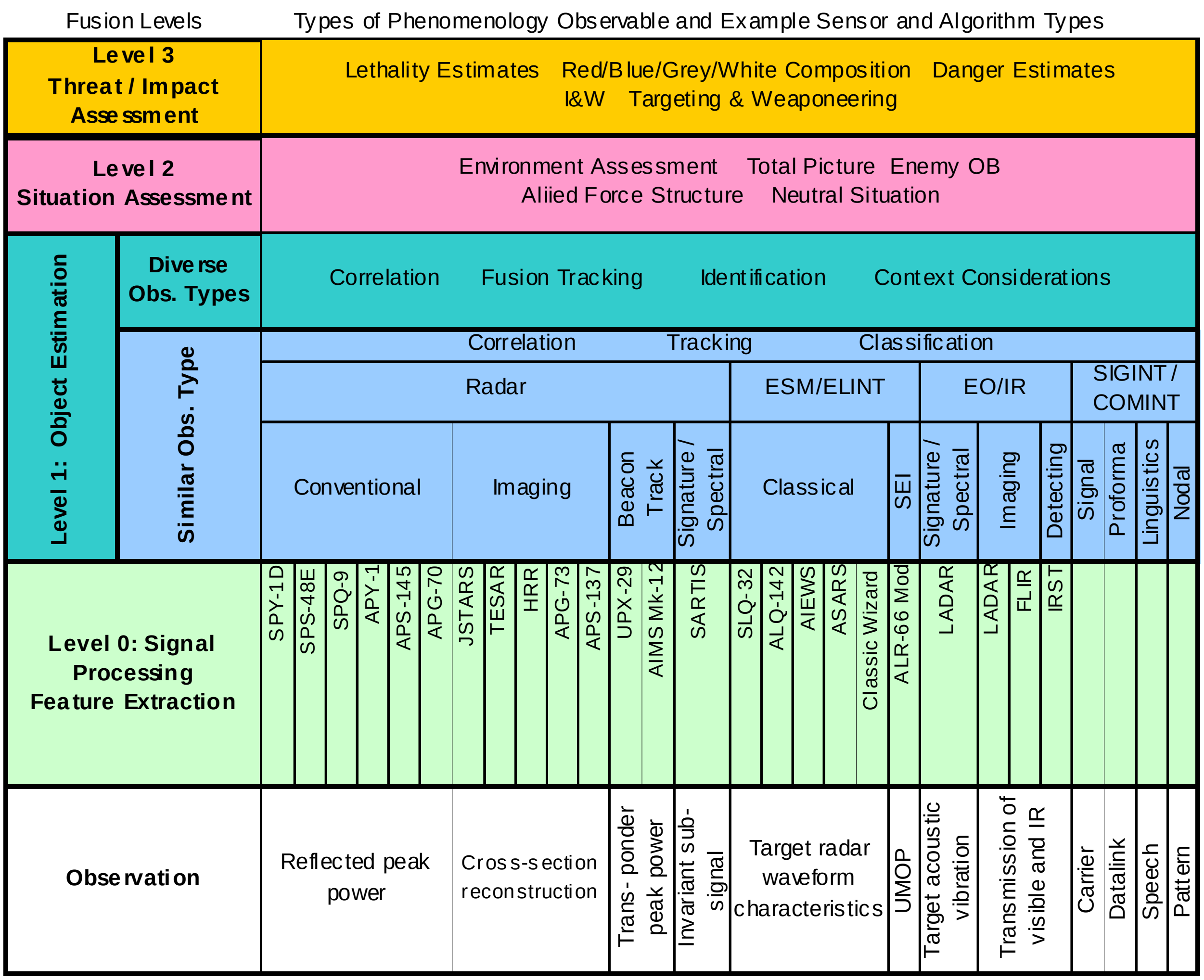
Variously called and related to "sensor data fusion", "sensor fusion", and others, it is defined in DoD as,

> *"The synergistic process of associating, correlating, and combining Hostile, Friendly, and Neutral Forces data and environmental factors to derive information and knowledge, tailorable to support the warfighter to effect and expedite command and control." (AC2ISRC, 1999)*

Particular techniques and tools deal with optimal estimation (current), smoothing (past), and prediction (future) of information of interest based upon various multiple sources of related information, including measurements, derivations, and references.

Three major themes underlie much of Silver Bullet's R&D work: (1) a reversal of the fusion paradigm, from sensor-driven, to information requirements-driven; (2) semantic, ontologic model, taxonomy foundations of fusion; and (3) formal use and modeling of heuristics in information integration and fusion.

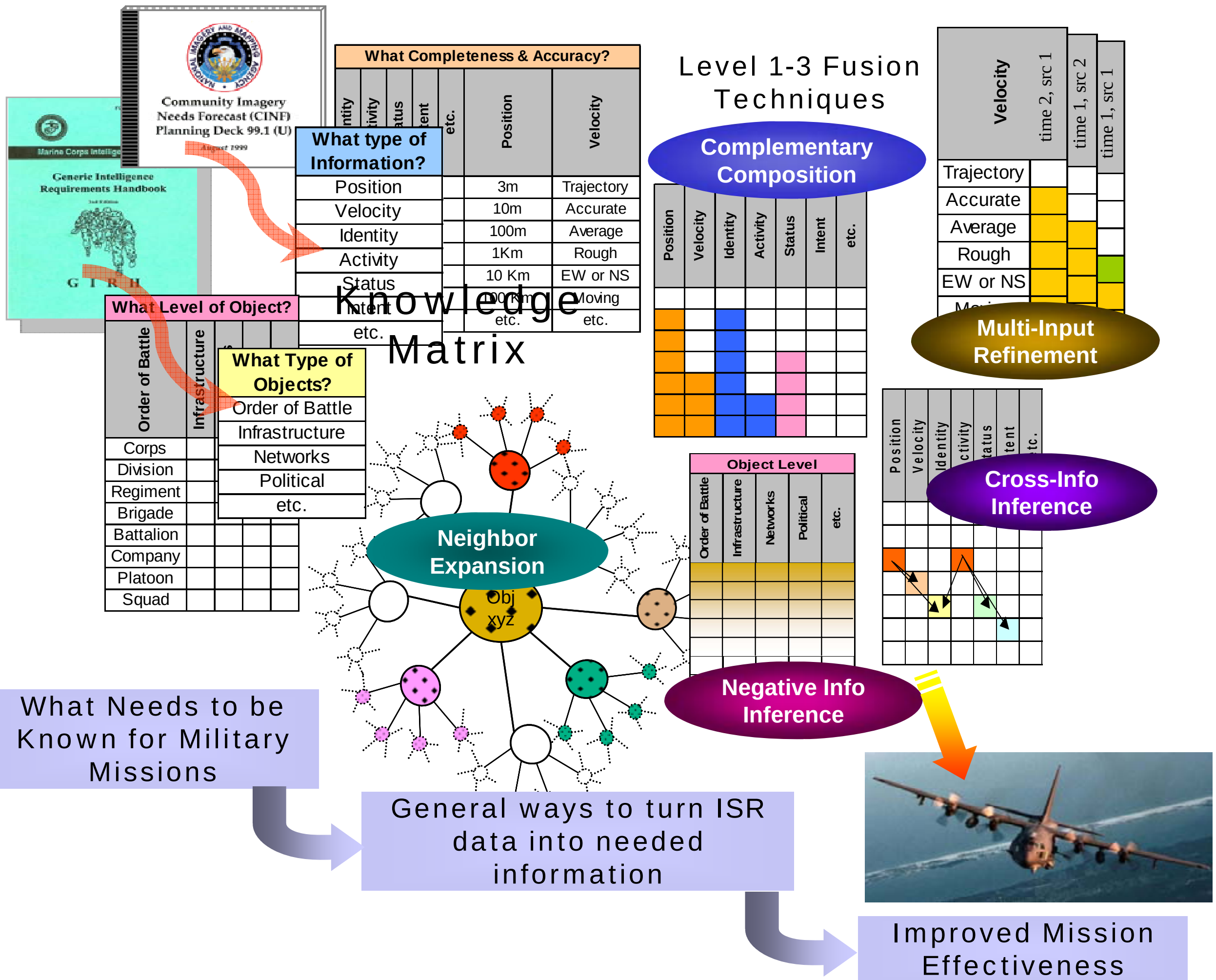
SBSI personnel have an understanding of the wide range of observables, priors, sensors, algorithms, and information levels, shown in the figure below



We have used this wide understanding to synthesize the information fusion process to the fundamentals:

- Dimensions of information
- Basic types of inference

The figure below shows these points.



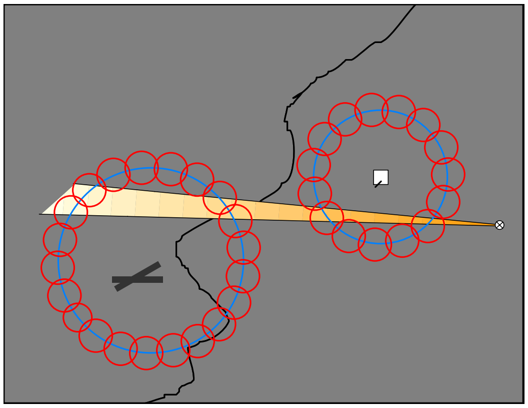
In the upper left is a user (or use) that has information requirements. In this diagram, they are shown as a set of matrix samples. These came out of a DoD study group we participated in that categorized thousands of military information requirements according to what type of information and what type of objects. This went further into detail along taxonomic and meronymic lines. The group called the multi-dimensional matrix, "the knowledge matrix. The remainder of the diagram categorizes data fusion processes into the five types shown in the center of the diagram:

1. Complementary Composition. Different sources (the different colors) may contribute different types information, e.g., radar contributes kinematics well but ESM contributes target type and activity well.

2. Multi-Input Refinement. More samples will lead to refined estimates. The “more” could be over time from a single source or multiple sources.
3. Cross-Information Inference. One type of information is inferred based on some other type, e.g., inferring velocity by successive position measurements.
4. Neighbor Expansion. Something about one object is inferred based on apparent associations with others, e.g., the IED trigger man from the IED.
5. Negative Information Inference. Non-detections (“negative information”) of objects of interest in highly survielled areas means the object(s) of interest are are more likely to be in less-surveilled areas (“positive information”). Probabilistically, some of the probability mass within the highly surveilled area is re-assigned to the less-surveilled area, in proportion to the relative intensity of the surveillance. (It seeps back if the surveillance coverage becomes more even.)

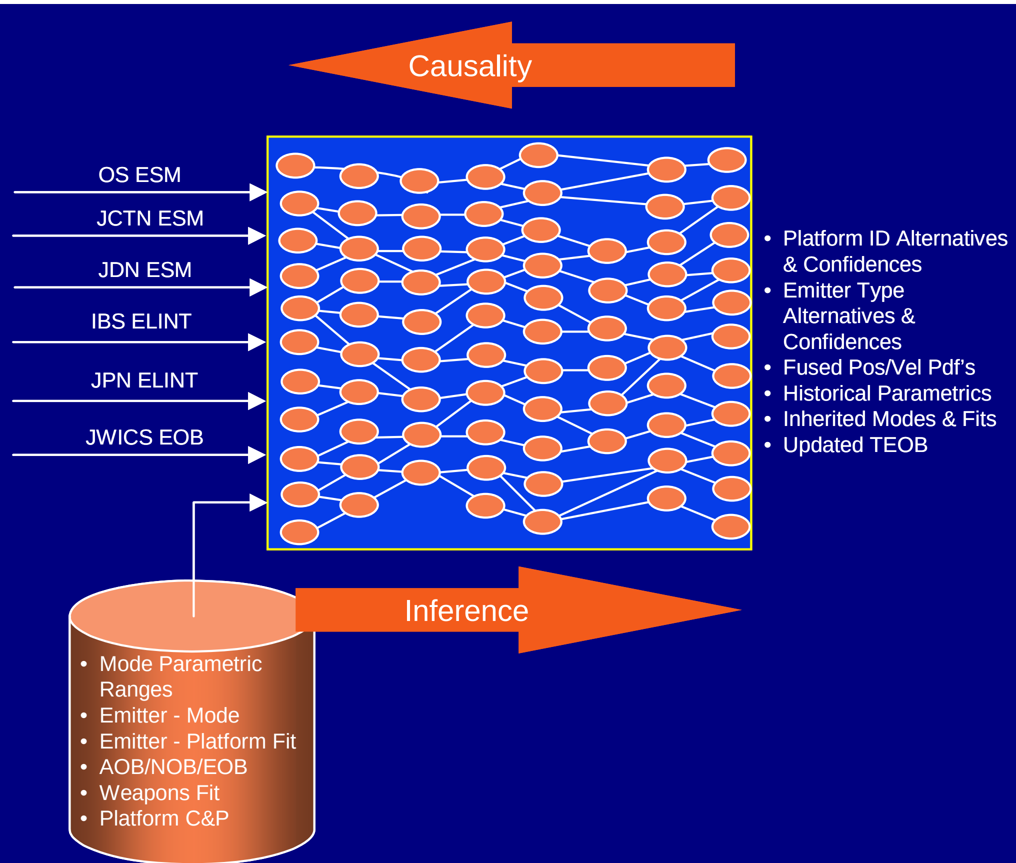
Inferencing Nets

Generalized inference provides an elegant formulation for fusing sources that have many diverse states that are nonetheless inter-related, be it in often in weak and complex ways. Indeed, levels 1 through 3 fusions can be characterized as inferring states from evidence; estimation can be viewed as a specific inference discipline. Unfortunately, the elegant inference formulation rapidly becomes intractably complex for any real-world problems due to the permutations of inter-relationships between the interacting state variables. Bayesian networks provide a way of coping with the complexity. Bayesian networks are techniques for making probabilistic inference tractable and have been in broad literature and research for quite some time. We have researched the application of the Bayes network technique to real-world large-scale fusion problem. We have experience with the many adaptations and extensions that are required and have discovered many issues that need further research.



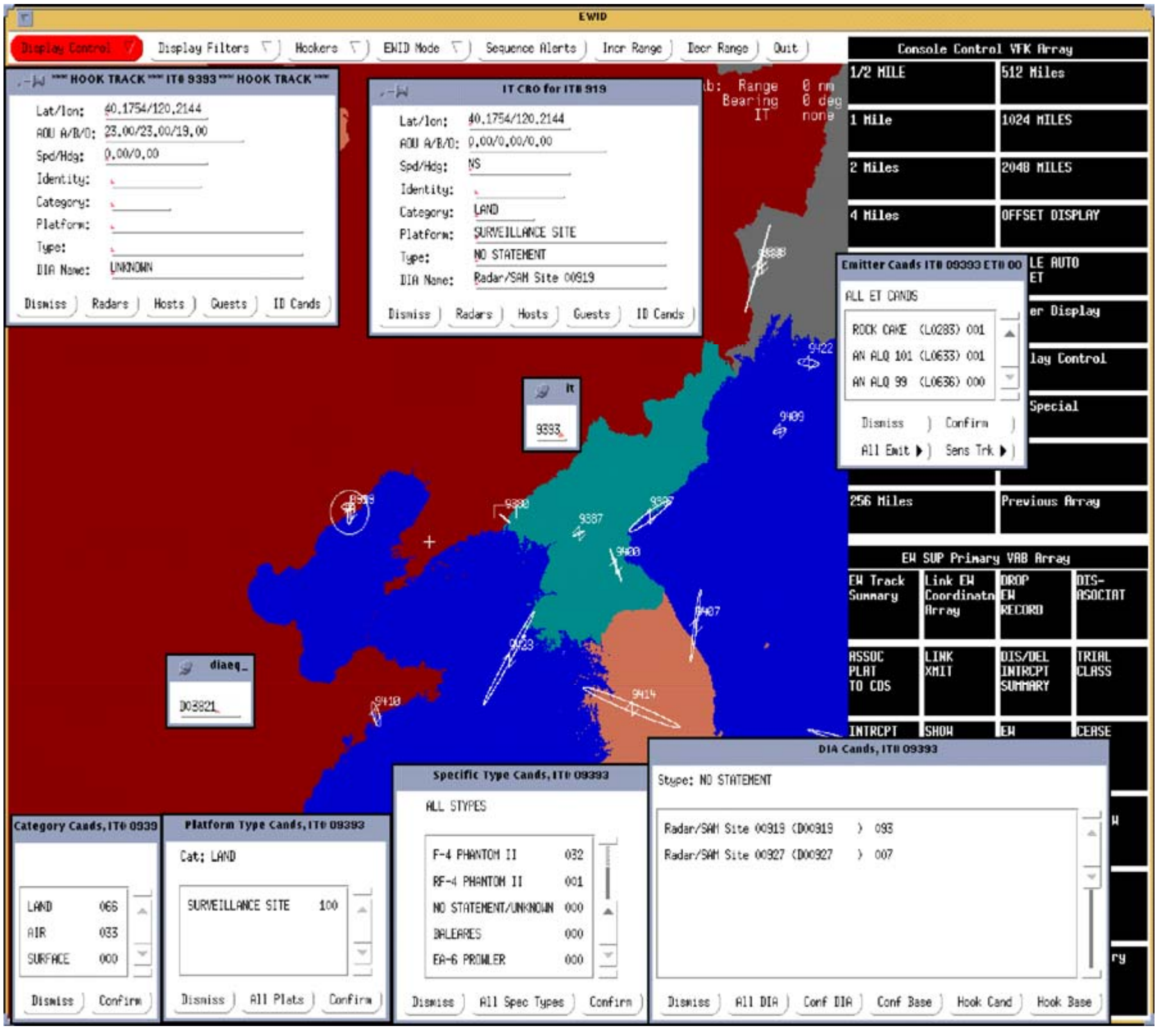
A Chain of Inference

The possible missile seeker is detected. While intercepting the missile, we’d also like to not just “shoot the arrow” but also the “archer”. We look at possible launching aircraft within launching range of the missile, thinking about what combat radius of aircraft from airbases known to have certain numbers of types of aircraft.



Basic Paradigm of Inference – Hypothesize about causes based on evidence

The “evidence” is the sensor data on the left. The hypotheses are generated from known prior knowledge of “causers” and the evidence they are known to “leave behind”.



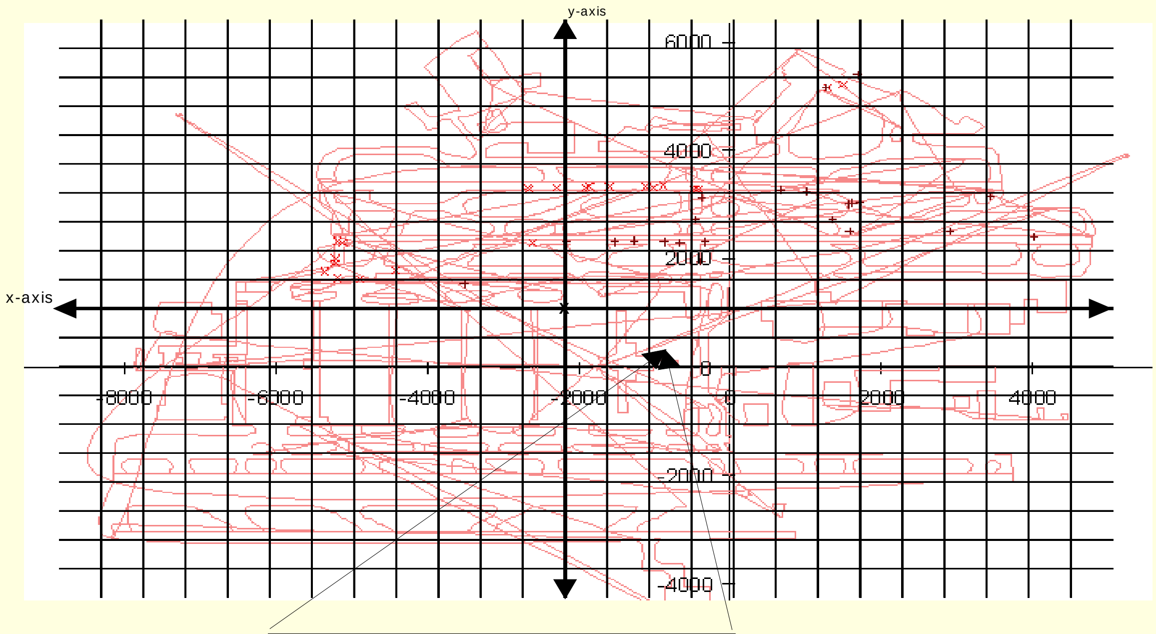
Bayesian Net Hierarchical ID Alternatives Display.

a. For the hooked track (9393), the ID Cands button was depressed resulting in the hierarchical ID alternatives popups in the lower part of the display.
b. The Bayesian Net estimates the Environment/Category as 66% Land, 33% Air and less than 1% Surface. Given Land, the only alternative is Surveillance Site (100%).
c. Normally, the Specific Type scrolling list would show the alternatives given the selected or most likely Platform but in this example the operator had selected display of "All Specific Types." This is sometimes necessary to cut across the alternatives hierarchy horizontally because branch-by-branch analysis may be too tedious.
d. Whenever a platform or emitter candidate is selected, at any level in the hierarchy, the entire set of alternatives is redisplayed to be consistent with that selection. The operator confirms the alternatives at any level.
e. Of interest to note is the EA-6B candidate which makes the list because of its jamming pod. Its probability is low however, less than a percent.

Knowledge-Assisted Fusion

The core of almost all target tracking algorithms is a digital filter such as an α/β or Kalman filter that provides a smoothed and predictive estimate based upon time-series and, in the case of fusion systems, multi-sensor data samples. A key feature of these filters is the process model that describes the underlying process being estimated. For aircraft tracking the model is usually a constant velocity model. Maneuver detection processing detects model violations and selects a resolution technique. Maneuvers do, however, have a cost to tracker performance. If the maneuver is slight but persistent (e.g., a change of course), the track will lag the maneuver due to its smoothing with historic data and then “catch up” once the maneuver is realized. In order to catch-up, the filter must shed history data which can cause a loss of some built-up “knowledge” depending on how drastic the shedding is (e.g., a “reset” vs. a gain increase.) Worse still is if the maneuver is not recognized and the original track is lost and a new track initiated. In this case, in effect all history is lost, including accumulated identification and other data that may have been attributed to the track manually or in a one-time opportunity. Despite the down sides, these types of design work quite well in most aircraft tracking applications as aircraft are in constant or near-constant velocity over a broad portion of their target lives.

Unfortunately, in the airport surface regime, drastic non-constant velocity motion is frequent. Turning off ramps, accelerations, decelerations, and so forth cause maneuver detections frequently. For the U.S. Federal Aviation Administration (FAA), Silver Bullet came up with an alternative design, taking advantage of some of the unique features of the surface fusion problem. The design uses knowledge base techniques for intelligent fusion that are implementable as simple table lookups and that serve as sets of adaptive parameters to reduce maneuver responses by predicting expected aircraft behavior. For example, any human estimator would certainly use knowledge of Hartsfield’s runway, taxiway, and terminal area layout to predict where aircraft and ground vehicles are likely to move. This is hard to encode for computers and very few fusion algorithms dare to yet it is easy to show it has significant effects. We know how to encode and we know ways to use the encoding in rigorous mathematical algorithms.



Segment, Track, Bias, P_{ft}, and P_d Hash Table

Δx	x-bias	
Δy	y-bias	
$P_{ft}^{3,cw}$	P(false target | ASDE, clear weather)	
$P_{ft}^{3,bw}$	P(false target | ASDE, bad weather)	
$P_{d}^{3,cw}$	P(detect | ASDE, clear weather)	
$P_{d}^{3,bw}$	P(detect | ASDE, bad weather)	
$P_{d}^{T,cw}$	P(detect | ATIDS, clear weather)	
$P_{d}^{T,bw}$	P(detect | ATIDS, bad weather)	
seg_1	1st segment in this cell	*S*
seg_2	2nd segment in this cell*	*P*
⋮		*E*
seg_m	mth segment in this cell*	*E*
trk_1	1st track in this cell	*D*
trk_2	2nd track in this cell*	*U*
⋮		*P*
trk_k	kth track in this cell*	

* = could be via linked-list

Note: all ASDE Pd's are for one sec. integration

Note: all ATIDS Pd's are for one sec. interval

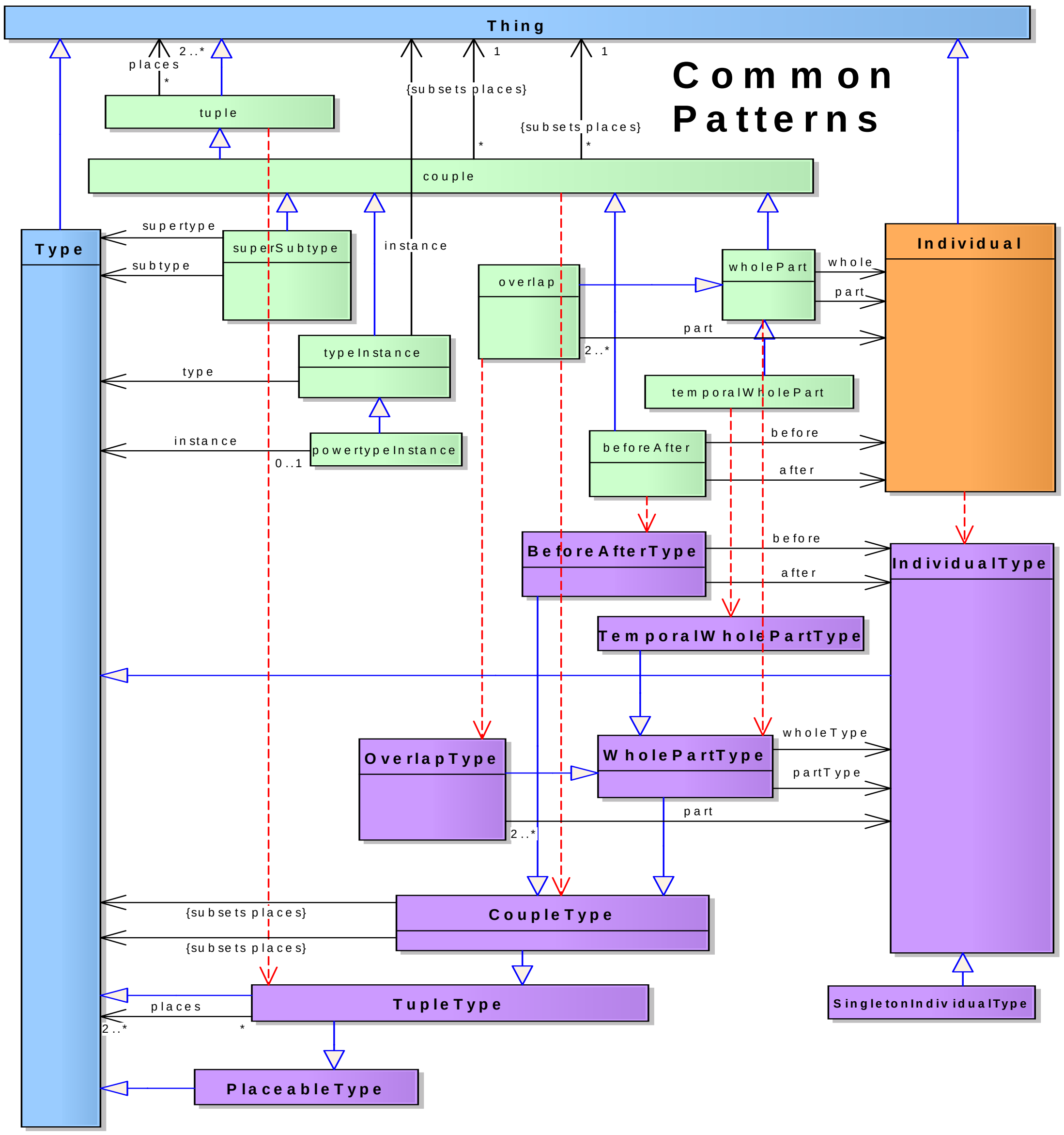
Knowledge-Based Adaptive Filtering

The grid is laid out over a major airport runway, taxiway, and terminal area. In each grid cell is shown in the left box expansion the process parameters for a (downramp, crossramp) coordinate system we adapted from U.S. Navy fire control practice. The lower table is a set of adaptive parameters for bias and sensor performance to aid in multi-sensor track association.

The figure to the right illustrates a type of theme (3), the modeling of heuristics for a sensor fusion problem. In this design, Hartsfield is overlaid with a grid of tracking, maneuver declaration, probability of false track, probability of sensor detection, position-dependent sensor registration biases, and other fusion parameters. Depending on the vehicle of interest's or sensor report's grid, the various parameters are applied, much as a human ground controller does. A quite different but fundamentally similar use of this is for data integration for data warehouses, enterprise databases, and other multi-source data systems. In these applications, heuristics are applied to de-bias incoming or accessed data and to model its quality characteristics so it can be deconflicted or merged with other sources or the current belief state.

Formal Ontologies to Support Reasoning Algorithms

SBSI has been and continues to be a key participant in several formal ontology projects. Unlike ontology projects focused on the transfer and / or storage notation such as OWL, SBSI's interest has been in the mathematics of knowledge representation. The top-level of one such project is shown below.



Like many ontologies, it starts with a root called "Thing". There are three types of things: things that have spatio-temporal (4D) extent ("Individual"), things that are sets of things ("Type"), and things that represent ordered relationships between things ("tuples"). This ontology intertwines the mathematics of Individuals (meronymy theory) with the mathematics of sets (set theory) to be able to represent a wide array of physical and social activity.

It deals with issues of states, powertypes, measures, space -- what is truly knowable vs. what is assumed. Domain concepts are extensions to the formal foundation. Rigorously worked-out common patterns are reused. The result is higher quality and consistency throughout an implementation. For example:

Using casual "is-a" language leads to the following incorrect conclusion:

Vladimir Putin is-a human is-a mammal is-a species $\Rightarrow$ Putin is-a species

Being more precise about the mathematics prevents the wrong conclusion:

$$\text{Putin} \in \text{human} \subset \text{mammal} \in \text{species}$$

$$\Rightarrow \text{Putin} \in \text{mammal};\ ¿\ \ \text{Putin} \in \text{species}$$

The practical implications of imprecision in data structures are encountered everyday in bad database queries, degraded analysis algorithms, and dis-interoperabilities.

The imprecision is just a stage of computer science -- database design had in origins in form automation, not mathematical analysis. This was and is good for storing information to be

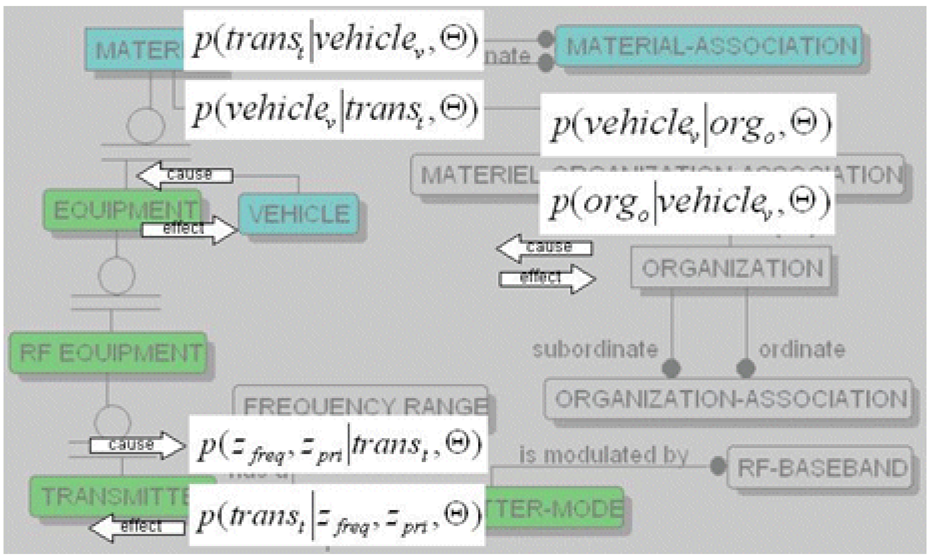


Illustration of How an Ontology can Inform a Reasoner

The underlying ontology has all the causal, taxonomic, meronymic, associational, etc. knowledge to inform the construction and execution of the Bayes Network. The diagram above is a small example for Electronic Warfare. It shows:

- The ontology states that certain transmitters have certain RF basebands which to an inference engine means once we see a certain RF, we can infer from the effect (the RF) to the cause (the transmitter).
- The ontology also states the certain vehicles operate certain transmitters which to an inference engine means that once we have belief about a certain transmitter, we can infer from the effect (the transmitter) to the cause (the vehicle).
- The ontology also states that certain organizations operate certain vehicles which to an inference engine means that once we have belief about a certain vehicle, we can infer from the effect (the vehicle) to the cause (the organization).

Under U.S. Navy sponsored research, we are working with Boeing Phantom Works and Teledyne to build a way to go from an ontology specified in Protégé to an executable Bayes Network.

interpreted and processed by humans but is inadequate for automated processing as in data fusion, data analyses, or unanticipated net-centric discovered data use.

Enterprise / IT / C4ISR Architectures and Systems Engineering

Silver Bullet is nationally known for our expertise and experience with enterprise, information technology, C4ISR, and capability architecture. We routinely work for Secretarial level offices in DoD, helping to sort out issues, policies, and transformational challenges. Core DoD policies for acquisition, capabilities integration, and interoperability have our imprint. But we also work hands-on with the latest tools and client data and work side-by-side with architecture teams world-wide. Silver Bullet provides five types of architecture support:

- Policy, methodology, and data management support.
- Training and Facilitation
- Architecture Data Development Tools
- EA Taxonomies Development
- MOE's and Analysis Algorithms Development

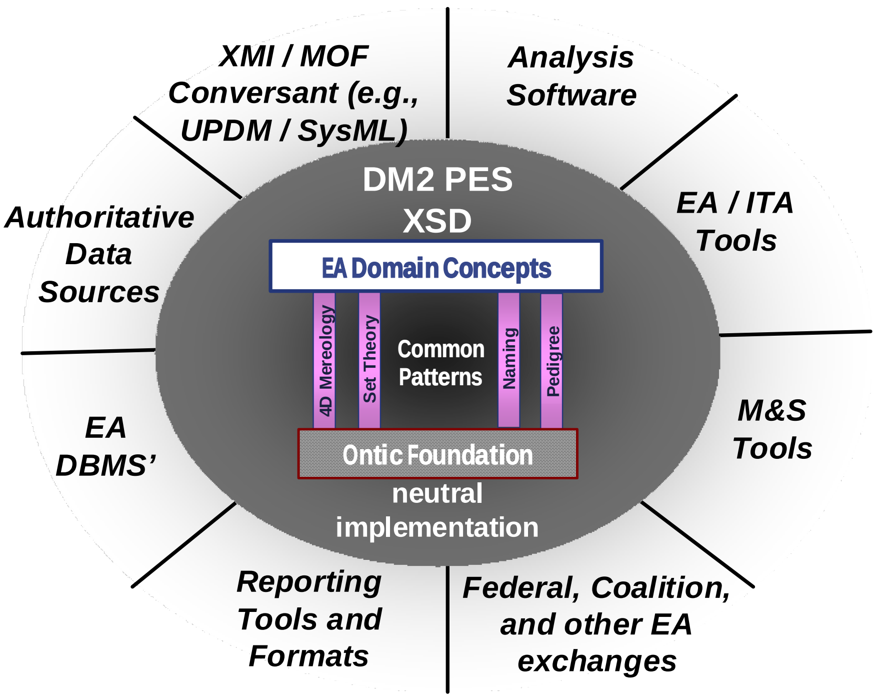
EA Frameworks

SBSI has been a part of DoD's architecture framework teams since the C4ISR Architecture Framework in 1996, then as part of the Navy team. SBSI was the Navy representative for the Core Architecture Data Model (CADM), a role that persisted through CADM's retirement 12 years later.

For DoDAF 1.0, SBSI was the Department of Navy lead representative for the DoDAF 1.0 development team. In that capacity, SBSI made key revisions that have had far reaching impact on the DoD policies. Examples are:

- The chapter on uses of architecture techniques, tools, and data in core decision processes
- The section identifying and describing the central and foundational roles of enterprise taxonomies in architectures
- Three chapters in various volumes describing architecture data and emphasizing data instead of pictures to provide analytical decision support and lead to an enterprise decision resource.

SBSI is currently a key member of the DoD CIO's DoDAF 2.0 development team, with particular responsibility for developing the DoDAF Meta Model, the replacement for the CADM. This new model is based on a formal ontology that has been developed by an international team over the past two years. SBSI is the US representative under sponsorship from OASD (NII). SBSI is developing Conceptual and Logical data model levels and a physical exchange specification. The physical exchange specification, an XML XSD, will provide a simple and neutral way to exchange EA data across the DoD for many different kinds of applications, as illustrated below.



Two big themes for DoDAF 2.0 are, 1) "fit for purpose", and 2) data-oriented architecture. SBSI is leading # 2. But SBSI laid much of the groundwork for # 1 as well as a result of EA projects SBSI was a part of.

EA Practice

There are, and have been since our inception, four important differentiators in SBSI's EA practice:

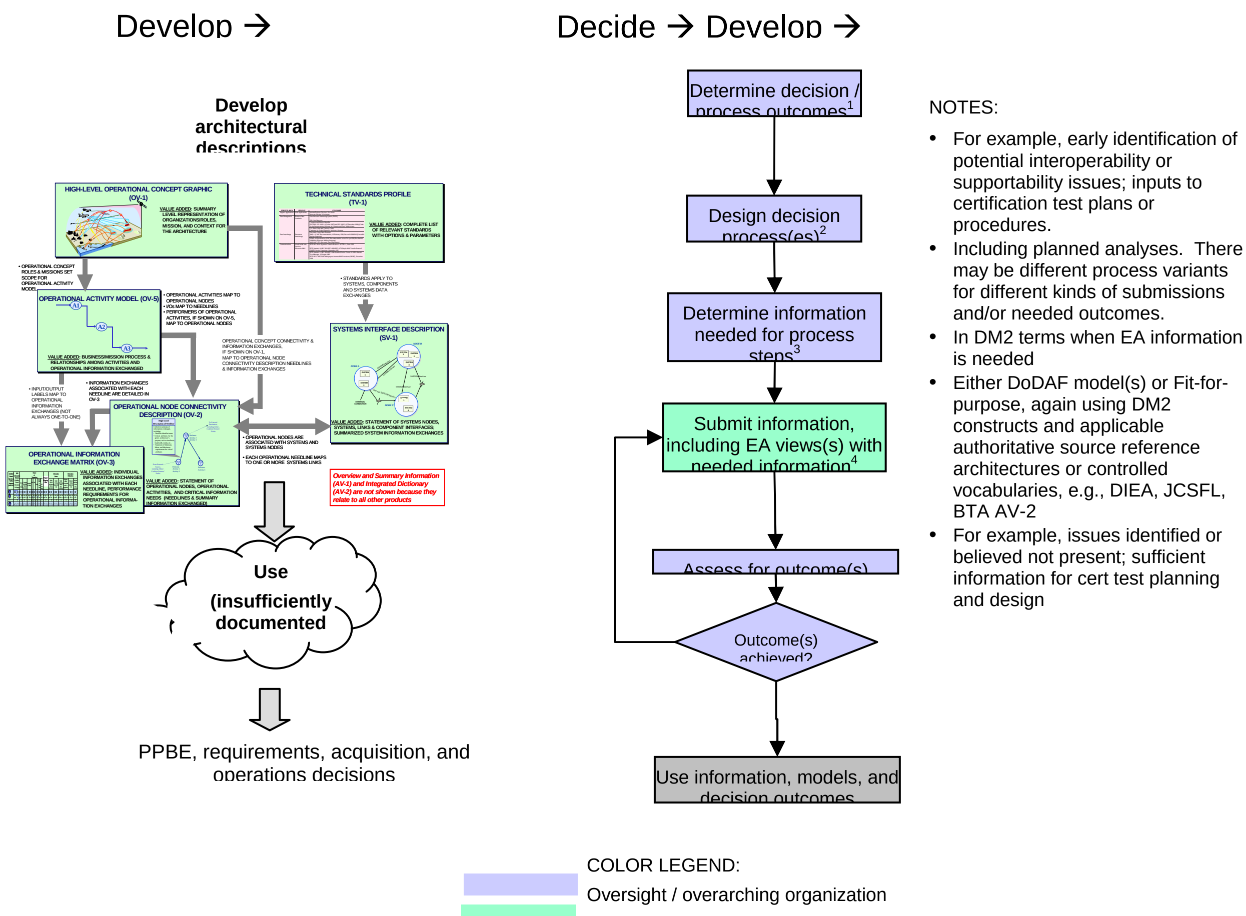
1. Purpose-focused modeling
2. Up-front EA taxonomies as model building blocks
3. EA data and databases
4. EA model data analysis

While our approaches are finding their way into the EA community, we remain a leader in ideas and experience applying these ideas. Each of these is briefly discussed below.

<u>Purpose-focussed modeling</u>

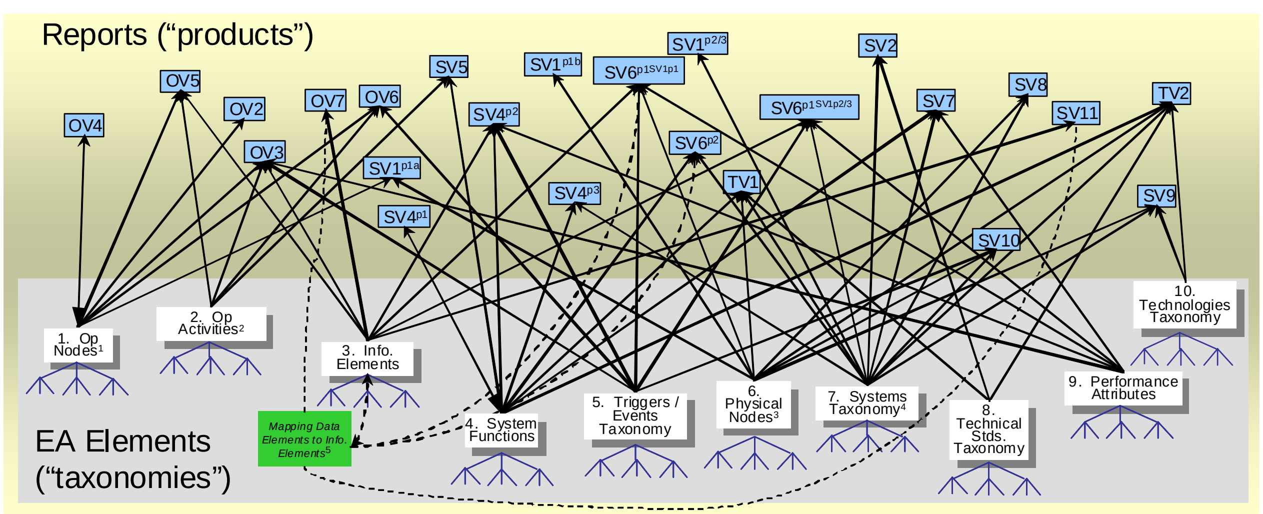
We believe much EA practice expends too many resources on methodologies and tools for building architectures, primarily architecture diagrams, e.g., debates over IDEF vs. UML, structured vs. object-oriented, Zachman vs. TOGAF frameworks, … or the debates over System Architect® vs. Metis® vs. ProVision® vs. TeamCenter®. This leads to an architecture project process like the one shown on the left of the figure below.

On the right is the approach SBSI advocates and applies on architecture projects with which we are a part or lead. In this approach, we start out by defining the capability the organization seeks, particularly in terms of measurable effects. Then we collect data and construct models necessary and sufficient to estimate those measures.

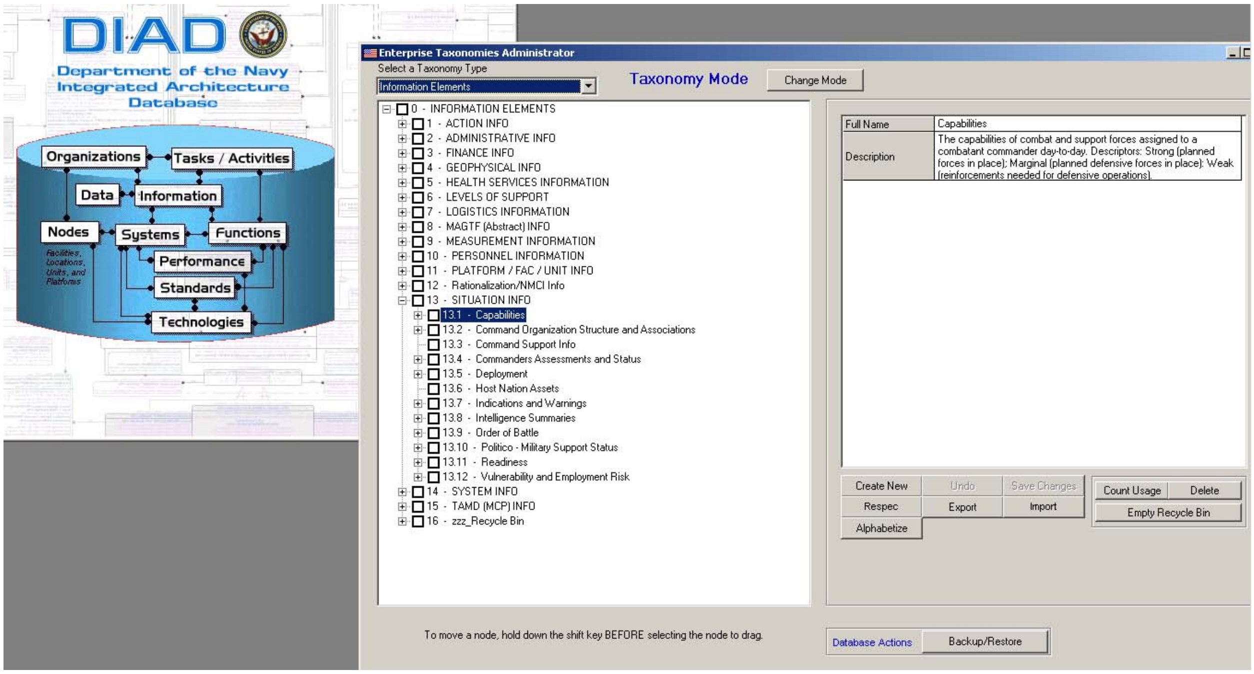


EA Taxonomy Building Blocks

SBSI has advocated and implemented EA taxonomy building blocks for over 12 years. Indeed, the current DoDAF AV-2 taxonomies were identified, defined, and written up in DoDAF by SBSI. We constructed the matrix of products to the ten taxonomies in the DoDAF as a compact version of the diagram below, which is in some ways more illustrative.



We implemented the taxonomies by building software tools on top of the EA databases such as the tool shown below, for the Department of Navy Integrated Architecture Database.



<u>EA Data and Databases</u>

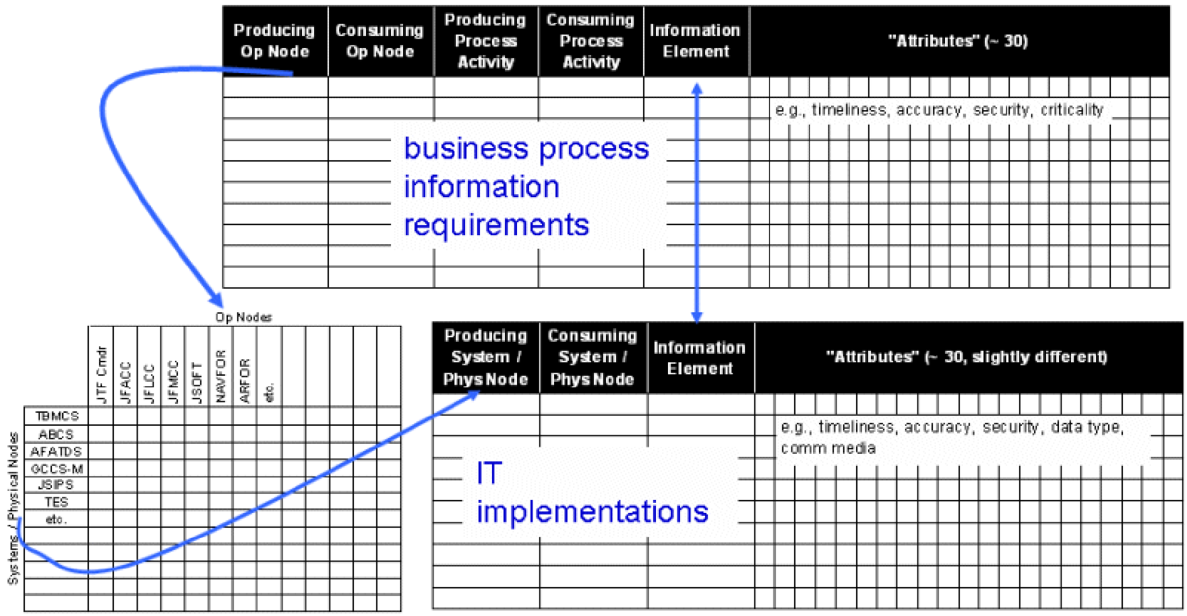
Integrated Architecture Databases are essential components of an architecture paradigm shift from stove piped architecture “products” to enterprise-sharable decision data, an essential shift based on years of lessons-learned in requirements, capabilities, acquisition, and resource management across large enterprises that will enable architecture to go from being “shelf ware” to being a technique-of-choice in addressing enterprise issues and evolution.

- We were part of small DoD panel that developed the first-ever architecture data model
- We implemented the first database to cover the entire Department of the Navy for the CIO
- We developed architecture databases for <u>many</u> DoD and Federal clients, the logo’s of a few of these databases are shown below
- We authored the architecture data model chapters for the DoD architecture framework, including the addendum on using architectures in acquisition.
- We are the lead for development of the next generation of architecture databases for DoD

<u>EA Data Analysis</u>

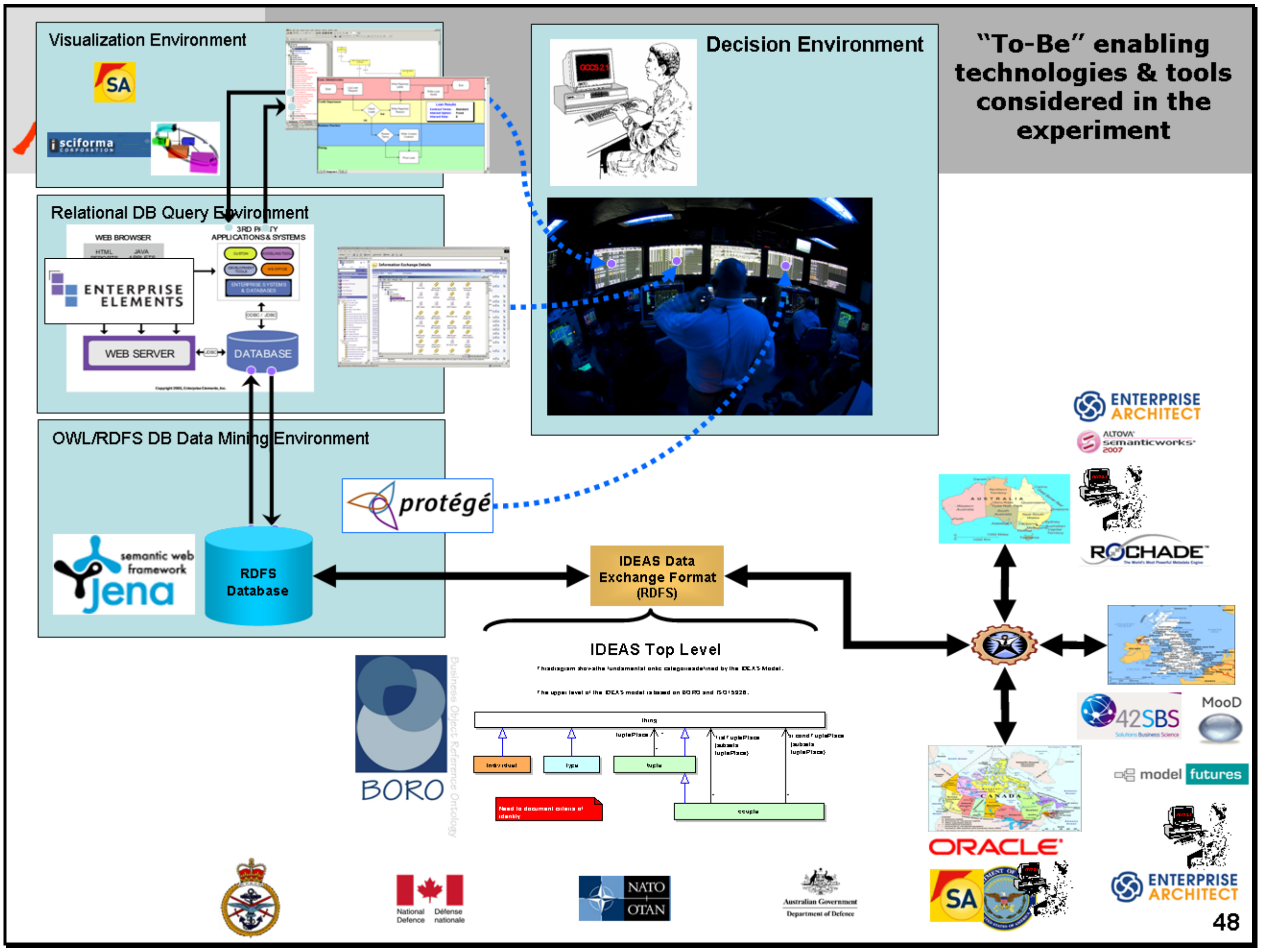
The purpose for developing the architectural description is met by analyzing the collected and assembled model data. Because our model data has consistency via the use of the building-block taxonomies, we can analyze the model data to meet the end-use purpose for the architecture project. A notional example is shown below.

Comparison of business process information requirements to IT implementations



Architecture and Systems Engineering Tools

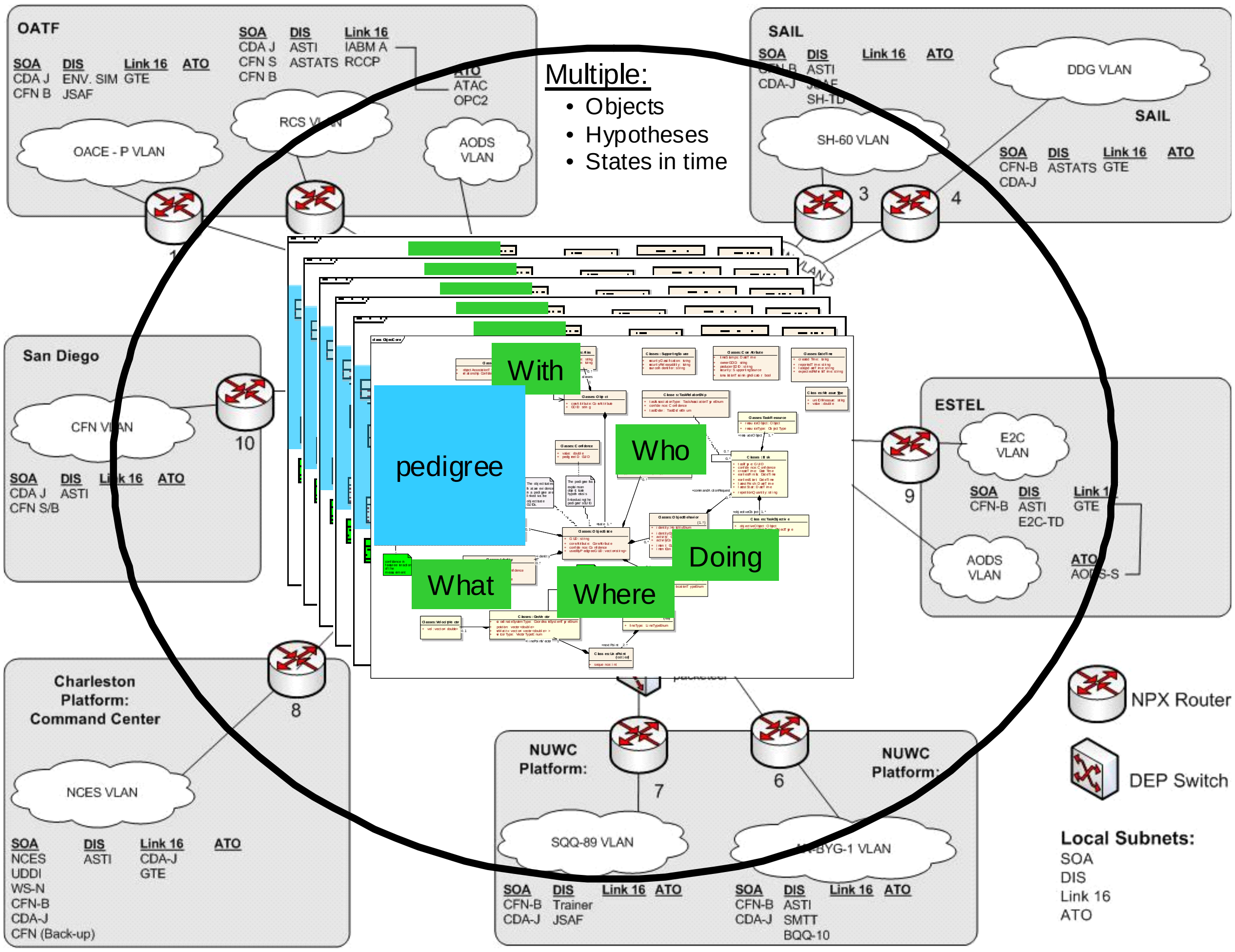
SBSI has worked with many architecture and data conversion tools including System Architect, Enterprise Architect, Enterprise Elements, and many data base management systems. We have also worked with data warehousing tools and developed many of our own. We have worked extensively with System Architect, Enterprise Architect, Enterprise Elements, and UPDM tools, e.g., Magic Draw.



Various EA and Conversion Tools in a Coalition EA Data Exchange Experiment.

Systems Engineering

The diagram below is of a Data Fusion experiment across the Naval subsurface, surface, air, and C4ISR domains using the networked Naval laboratories. The centerpiece, the situation awareness data model, was led by Silver Bullet as part of a Small Business Innovative Research (SBIR) project entitled, "Next Generation Fusion Architecture." Silver Bullet won the first phase of this research along with two other companies. Only one company was selected for the next phase, Silver Bullet. We are now working to transition this technology to Naval Combat System and C4I components.

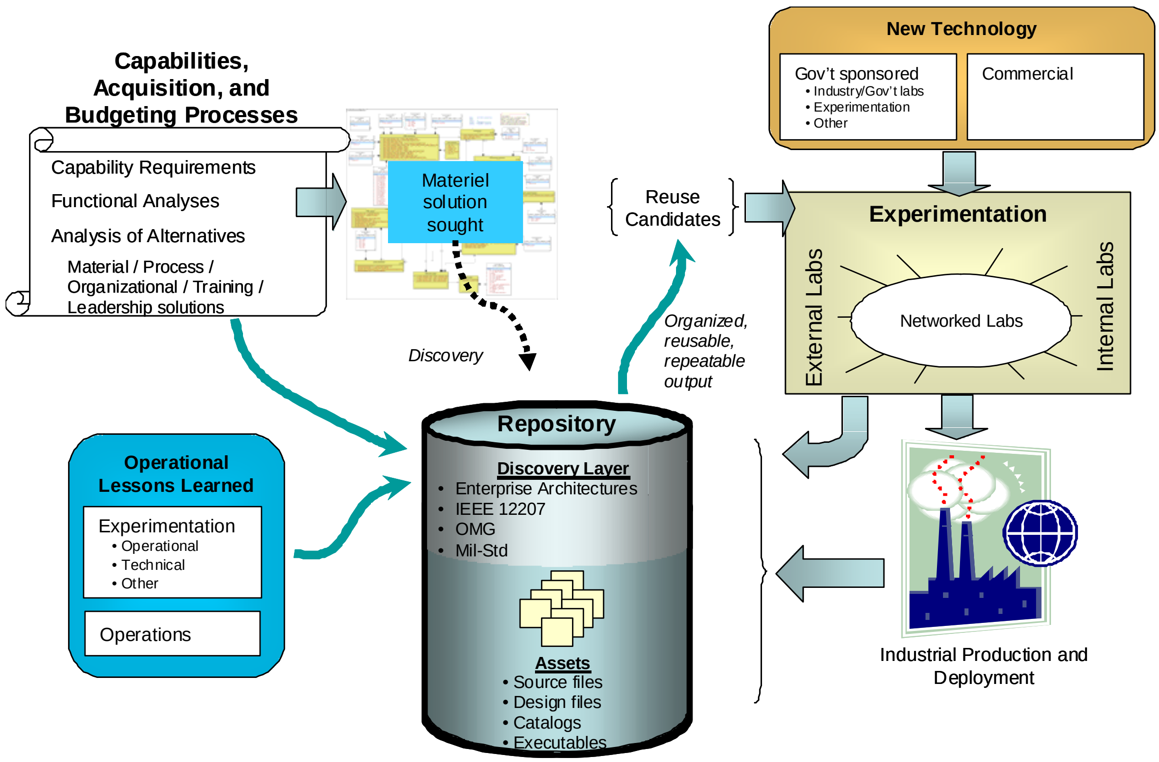


The data model is a major departure from flat “track files” in today’s command and control systems. It departs from the paradigms imprinted by yesterday’s IT constraints and models the “business objects” of the domain along with uncertainty and multiple hypotheses about them so that fusion nodes can reason and collaborate about them. For example:

- Principal interrogatives: where, what, who is it, what is it doing, and with whom
- Uncertainty and multiple hypotheses: how sure are you and what other possibilities might there be
- Pedigree: what evidence and processing or measurement technique did you use to come up with the hypothesis

In addition to designing the “common” or “joint” data model, SBSI designed the “common adapter” approach and programmed core components of the adapters.

Component Reuse



Databases and Software

Enterprise Data Integration

Using Data Abstraction to Model and Translate Diverse Domains in Data Warehouses and Enterprise Databases

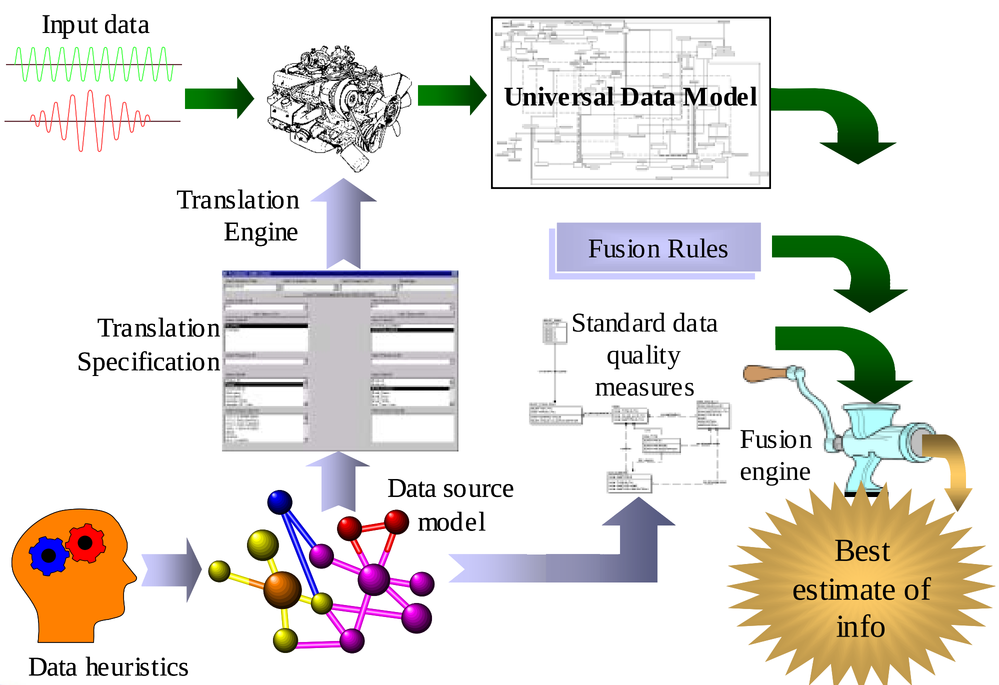
Data integration, as used herein, refers to the processes necessary for integrated data warehouses, virtual databases, enterprise databases, knowledge portals, or other forms of multi-input data to be able to be related across the multiple data sources. Translation and transformation techniques and tools are prevalent. It would appear there is an overlap between the areas of concern of information fusion and data integration. The purpose of this paper is to explore the applicability of information fusion paradigms and techniques to data integration.

Conventional approaches are ad-hoc / brute-force:

- labor intensive
- costly
- non-repeatable
- unreliable
- risky (programmatically)

What's different?

- Translation specification that feeds the translation engine
- Reference ontology for translation and normalized instance data
- Data quality augmentation
- Fusion business rules
- Combination of multi-source data using rules and data quality measures
- Treating all data as estimates (i.e., any data can be wrong)



Data Model Development

- SBSI routinely works successfully with vendor, contractor, and agency teams. We are known for our ability to facilitate many diverse communities to work together productively. SBSI currently leads the DoDAF-DM2 working group for OASD (NII) with over 214 members from industry, Government, academia, and vendors, U.S. and international. For some groups SBSI has facilitated, there have been restrictive schedule constraints in which SBSI has aided the multi-organization team and meeting the master schedule. Whether in prototypes and experiments to international working groups, SBSI has a successful track record of working with others in the Government's best interests.

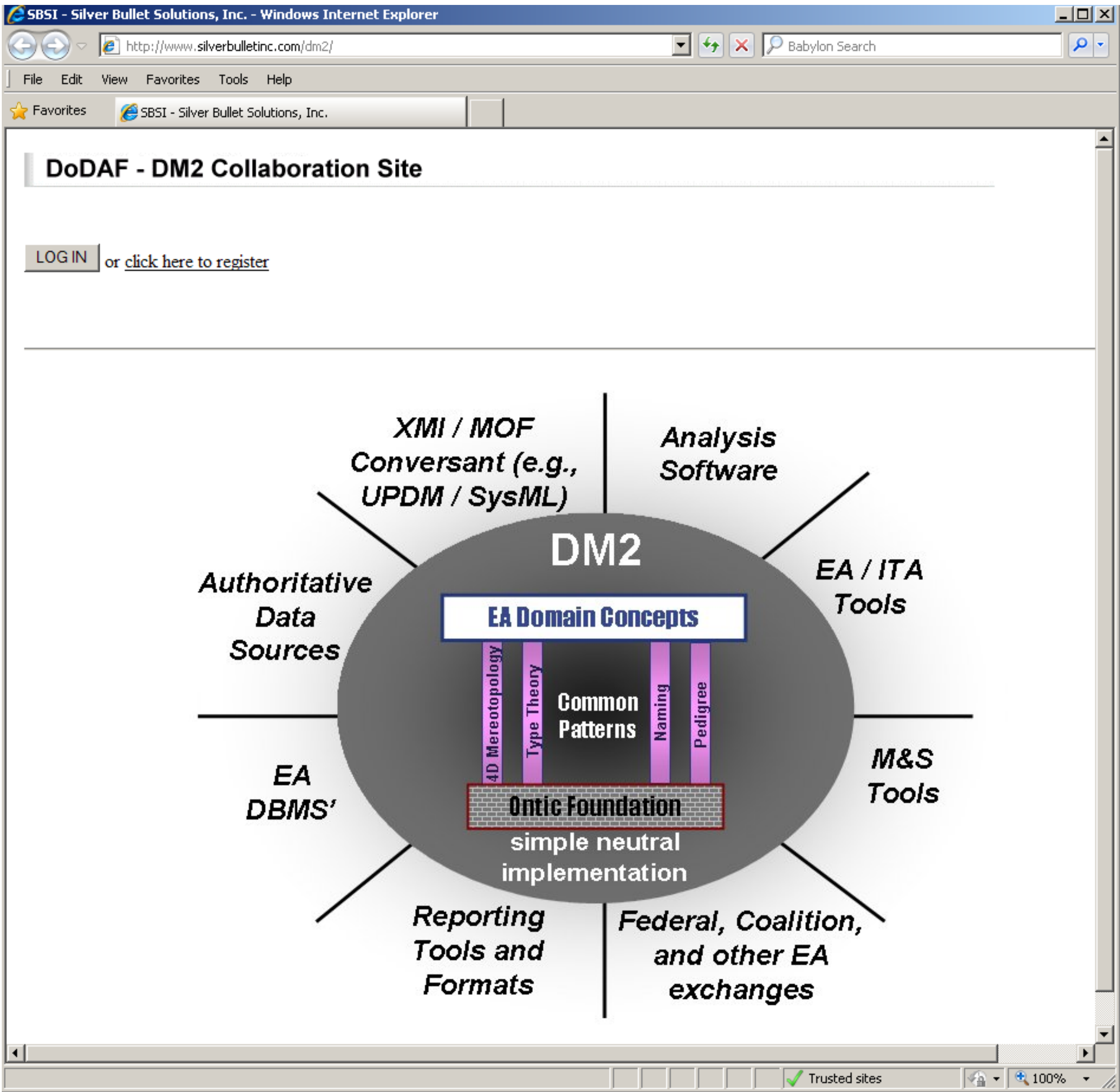
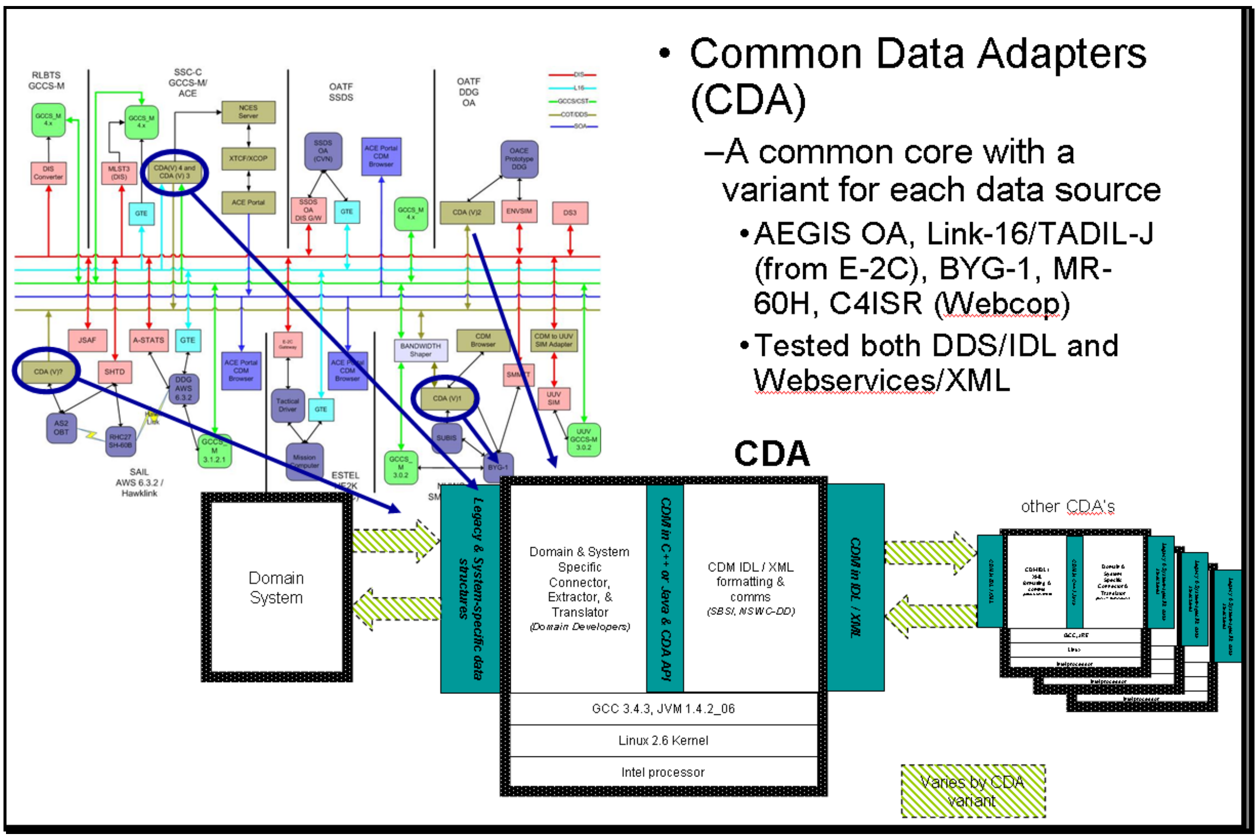


Figure 1. SBSI Operates the DoDAF-DM2 Working Group for OSD

Data Management

Data management is a specialty area for SBSI. We have been working in this area since our inception, with the idea to apply information fusion paradigms to data management and integration. (See, e.g., McDaniel, D.M., "An Information Fusion Framework for Data Integration", in Proceedings of the 13th Software Technology Conference, 2001.) We were part of the Department of Navy IPT to development the Department's data management and interoperability policies. At the implementation level, SBSI has been a key member of data interoperability experiments for Navy Open Architecture and FORCEnet for Combat Systems and C4I – cross-domain experiments that were highly successful across subsurface, air, C4I, and surface ship domains. SBSI was the data modeling lead for the Navy C4ISR data warehouse, integrating many diverse data structures. SBSI has also been a leader in this area internationally, as the DoD's lead technical representative to the International Defence Enterprise Architecture Specification (IDEAS) in which a formal ontology foundation was developed to provide a mathematical basis for complex data exchange between the U.S, U.K, CA, SWE, and AUS, with NATO monitoring for future engagement. SBSI is also DoD's lead for the DoD Enterprise Architecture Community of Interest (COI).

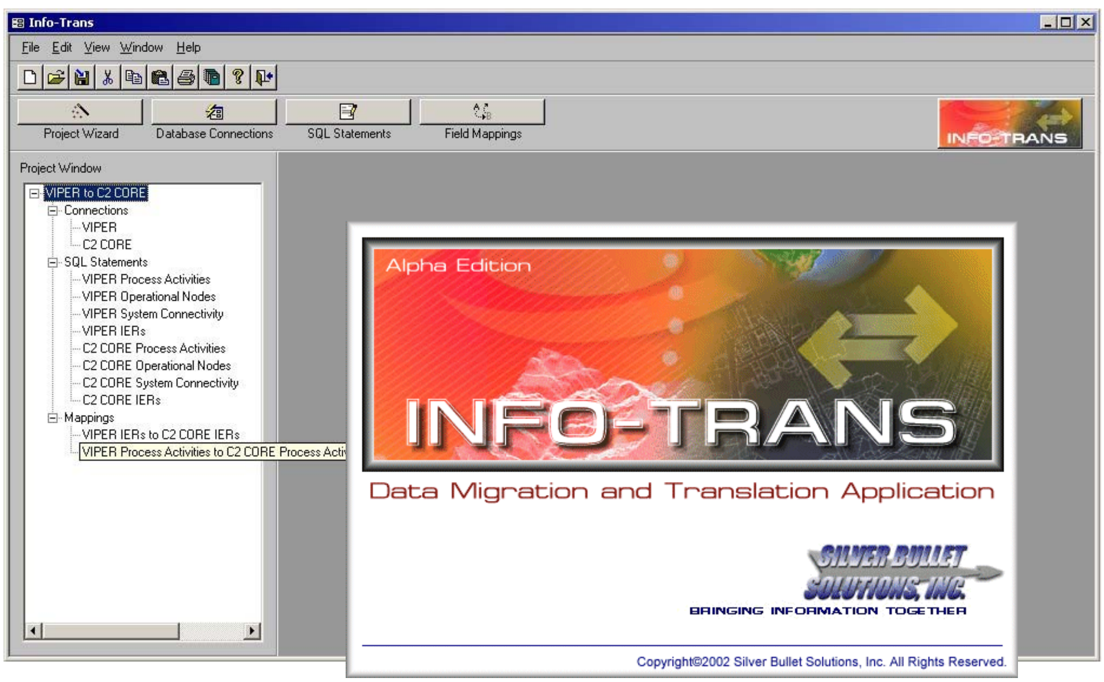


Example Way in Which SBSI Integrated Data in Legacy Systems for Navy Project

Information Translation

InfoTrans is a tool providing complex data translation based on specification of information-level affinities between sources. InfoTrans extends current table and field-level translation specification to automate many-to-many, conditional, and context-dependent translations. A translation engine operates on the specifications, obviating the need for costly and relatively low reliability custom code for these types of translations. InfoTrans is particularly useful to the complex translations typical in lower-echelon organization data sources (e.g., Operational Data Stores, (ODSs)) to enterprise data sources, typified by local to global views, legacy non-normalized to normalized structures, and / or non-abstracted to highly abstracted, perhaps object-oriented, models.

Problem: Enterprise data integration remains a manual process, requiring extensive and costly DA/DBA and programming labor, whether you're trying to interface two information assets, merge one into the other, or bring multiple semantically heterogeneous sources into a data warehouse for data mining. It takes highly knowledgeable data administrators from each information asset to study each other's designs, data dictionaries, and sample data. They have to come to understand how the data design terminologies they use are similar-to and different-from the others. The mapping from one source to the other can itself be a monumental task – before any translation queries or code is even cut! And once the translation software development starts there are the usual problems with incomplete, insufficiently detailed, or just plain wrong translation specifications. This is a major reason IT departments and CIO's are reluctant to integrate data and settle for consolidating multiple assets on reduced numbers of servers.



Our work researching these problems for the U.S. Navy led us to ideas for automation aids for data integration:

- Design step 1: Hierarchical mapping tool
- Design step 2: Congruent specification tool
- Execute: Specification parsing tool

Selected Personnel Backgrounds

Mr. McDaniel has extensive experience with R&D for multi-sensor systems for the Navy, both on full-scale development and research projects. These include the Advanced Combat Direction System (ACDS), Multiple-input TRacking and Control System (MTRACS), Electronic Warfare IDentification (EWID), and the E-2E Next Generation Fusion Architecture.

Mr. Murphy has over 30 years of experience in engineering of Combat Direction systems and sensor fusion systems. Mr. Murphy has been one of pioneers of modern sensor data fusion. He started with the Mare Island sensor fusion laboratory from which he progressed to the Advanced Sensor Integration / Tactical Distributed Processing studies on Multi-Source Track Management under which the Similar Source Integrator (SSI), Dissimilar Source Integrator (DSI), and Multi-Source IDentification (MSID) architecture originated. These studies laid the foundation for the full-scale development of ACDS Block 1 for which Mr. Murphy was the Project Engineer. Many years later, this architecture was adopted by the NAVSEA Combat System Functional Allocation Board as part of Multi-Sensor Integration (MSI) and Combat ID.

Dr. Regian has 25 years experience in cognitive performance modeling and knowledge-based software technology development, primarily for military application. Dr. Regian was Project Reliance Tri-Service Lead for DDR&E Defense Technology Objective KR-TECH (Knowledge Representation Technologies for Human Performance). He has published and presented papers on knowledge representation, knowledge management, human learning and memory, individual and developmental differences in human cognition, spatial ability and spatial information processing, cognitive modeling, skill acquisition, componential analysis of spatial tasks, cognitive automaticity, psychometrics, artificial intelligence, hypertext, hypermedia, training, computer-based training, intelligent computer-based training, and virtual reality. Dr. Regian's 15-year program of research and development was highly regarded by the DoD Science and Technology community, and was consistently ranked "World Class" by the Air Force Scientific Advisory Board. Dr. Regian was a National Research Council research adviser for ten years.

Dr. Kingbury is s fusion mathematician and is well-known for his work applying Bayes nets to ESM / ELINT fusion. He is an on-call consultant to SBSI and has a PhD in Physics.

Mr. Gardner has 18 years of experience in the design and development of Command and Control, Simulation and Training, database, and Electronic Warfare software. His software and database engineering covers the first TADIL-J implementation for EW, COTS-based realtime command and control, and database programs to integrate and augment National intelligence databases for use in Combat ID knowledge bases. Mr. Gardner has been a software engineer on systems such as ACDS, MTRACS, and

Tactical Advanced Combat Direction and Electronic Warfare Environment Generation and Control System. Mr. Gardner is extremely versatile programmer with current experience with many environments and tools.

Mr. Schaefer has been working on the leading edge of cognitive science and computer science for 10 years. He started as a valuable member of the laboratory staffs at UCSD and then gained experience in industry, applying machine intelligence techniques to natural language understanding, classification, sensor data fusion, and complex semantic heterogeneous data transformation. He been a software developer for novel techniques for data integration and fusion for the E-2E Next Generation Fusion Architecture and for surface Air Traffic Control (ATC). He is capable with most modern computer science techniques and is known for his ability to quickly learn and master many new technologies.

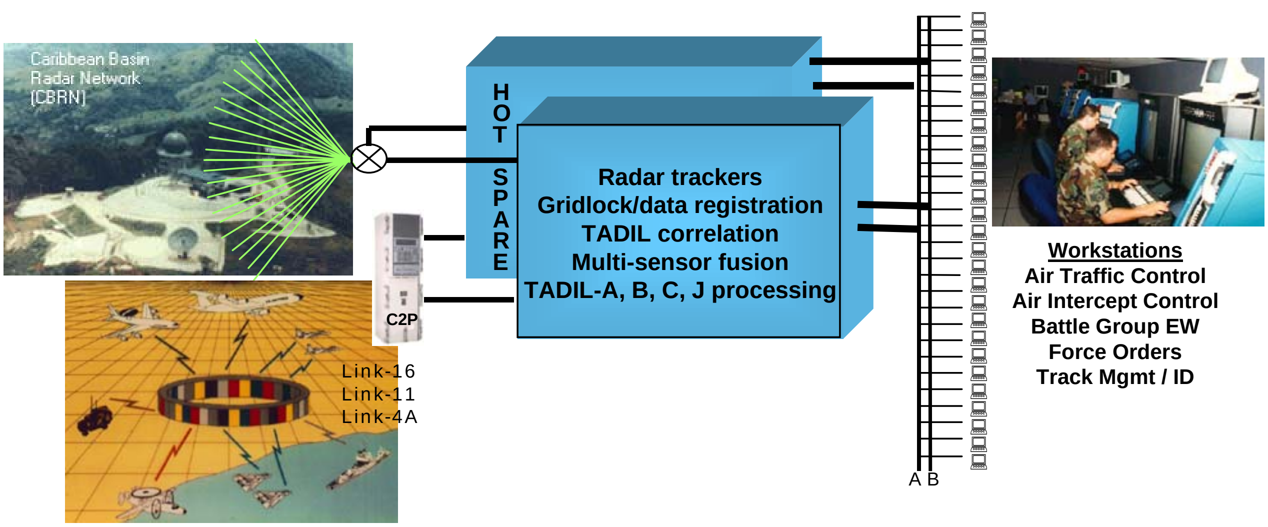
Background information on some of the projects and systems referenced in these personnel descriptions are as follows:

ACDS (SSDS)

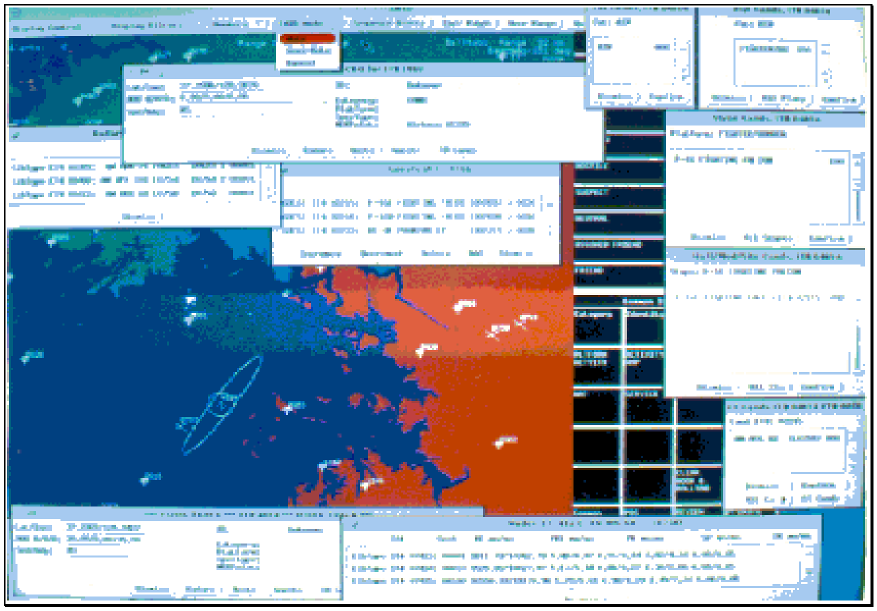
ACDS (SSDS Mk-2) is a tactical command and control system that provides functions for multi-source data fusion, automatic target identification, threat evaluation, weapons assignment, battle force planning and coordination. ACDS pioneered new concepts in data fusion with the tiers of integration shown below. Mr's Murphy, McDaniel, and Gardner worked on ACDS system engineering, software engineering, and ESM SSI and MSID knowledge-bases.

Multiple-input Tracking and Control System (MTRACS)

MTRACS is a US Navy land-based command and control system that fuses data from many sources. MTRACS receives data from up to 30 radars. MTRACS fuses the multiple radar data with remote data received via TADILs A (Link-11), B, C (Link-4A), and J (JTIDS), and other sources. Mr. McDaniel led a team, including Mr. Gardner, developing all software related to the datalinks, including the C2P Model 5 interface, full TADIL-J implementation, and gridlock and sensor registration.



Electronic Warfare IDentification



In this screenshot, two tracks are hooked and the ID candidates for one have been requested. The candidacy is displayed as a branch in a hierarchical taxonomy, with alternatives ranked according to their conditional probability within the hierarchy.

Merging Knowledge Techniques with Statistical, Probabilistic, Evidential, and State-Estimation Techniques. EWID was a prototype workstation-based system for fusing ESM, ELINT, and multiple-source pre-engagement intelligence data (e.g., Order-Of-Battle) by applying emerging theories on probabilistic inferential reasoning. It produced target identification vectors estimating the target types. Dynamic Bayesian networks were used, in which the relationships and dependencies between network nodes were continuously computed and updated. Knowledge bases were automatically derived from National intelligence databases. Mr. McDaniel was the Principal Investigator for this research. Mr. Gardner performed programming and knowledge-base development.

Sample Recent Projects

Title	Description of Work Performed and Key Technologies Utilized	Client
International Defence Enterprise Architecture Specification (IDEAS)	SBSI is the US representative for an international architecture tool data exchange group in which ontologic features are being built in with an eye on OWL implementation.	Office of the Assistant Secretary of Defense (OASD) for Network Infrastructure and Integration (NII)
Naval Architecture Elements Data Structure	Data structure using DM2, tools, and analysis support for refurbish of architecture elements used across SYSCOMs for acquisition management by ASN RDA direction. SPAWAR is executive agent for the lists.	Space and Naval Warfare Systems Command
DoD Architecture Framework Document and Data Model Development	DoDAF 2 supports 6 DoD core processes: JCIDS, DAS, PPBE, Systems Engineering, Operations Planning, and Capabilities Portfolio Management (CPM). SBSI is writing much of the text for the DoDAF document. SBSI is leading the development of the DoD-wide data model (DoDAF Meta Model or DM2) for architecture knowledge representation as part of the DoDAF. Conceptual and logical development is with a UML tool with an ontology profile. At the physical level, SBSI is developing the XSDs. SBSI coordinates a large data model working group. SBSI is also part of the DoDAF socialization team and is aiding DM2 implementation pilots.	Office of the Assistant Secretary of Defense (OASD) for Network Infrastructure and Integration (NII)
Next Generation Fusion Architecture	This is Small Business Innovative Research (SBIR) project in Phase II for the creation of a Next Generation Fusion Architecture in support of advanced sensor and data fusion. This architecture provides a foundation for advanced fusion algorithms including non-kinematic level 1 fusion, level 2 and 3 complex assessments, and more broadly scoped Situation Awareness. The core of the architecture is a comprehensive, rigorous, and integrated domain knowledge representation. The goal is to support advanced mechanisms, such as ontology-based inference, weak evidence linking and accumulation, behavior modeling, and execution of multiple kinds of fusion algorithms interoperating autonomously, yet synergistically. As part of the research, SBSI experimented with "realtime" DBMS' implementing portions of the JC3IEDM triggering in-house Kalman filter target trackers, JVC association algorithms, and Bayes Nets. SBSI also led key components of Navy Open Architecture / FORCEnet cross-domain (air, sub, surf, C4ISR), developing the common data model and many portions of code used to interface data between the DEP labs for E-2C, AEGIS OA, BYG-1, SQQ-89, WebCOP, Composeable FORCEnet, and MH-60R. As part of this, SBSI represented PEO IWS in Joint Track Manager and Warfighter Information Processing Cycle initiatives.	Program Executive Office for Integrated Warfare Systems (PEO-IWS) / Naval Air Systems Command (NAVAIR)
Office of the Army Chief of Staff for	Developed DoDAF products and data in support of business process analyses and systems decisions. IRB support,	Office of the Assistant Chief of

Title	Description of Work Performed and Key Technologies Utilized	Client
Installations Management (OACSIM) Enterprise Architecture	measure-based decisions, data consolidation, the BTA Business Enterprise Architecture and other goals and initiatives are part of this task.	Staff for Installations Management (OACSIM)
Enterprise Architecture Development, Arnold Engineering Development Center	Developed the Enterprise Architecture, products, and integrated data dictionary for the Development Center including utilities for portfolio management and capital investment planning. SBSI is developing linkages from AEDC EA to US Air Force Materiel Command, the DOD Enterprise, and the Federal Architecture Frameworks.Air Force Test and Engineering Enterprise Architecture. SBSI is supporting the development of this architecture with the establishment of a CADM-based architecture database. SBSI is working with Arnold AFB Subject Matter Experts to develop the architecture, starting the well-defined architecture taxonomies. Key Technologies: DoDAF, CADM, taxonomies, architecture SME facilitation.	US Air Force
Department of the Navy Enterprise Architecture	Provided enterprise and IT architecture support to the DoN Chief Information Officer including technical expertise for governance formulation and architecture infrastructure support. Silver Bullet has been the Department's representative on several matters, notably the DoD Architecture Framework (DoDAF) and the Core Architecture Data Model (CADM). Silver Bullet drafted a significant amount of the modernizations and re-orientations of DoDAF. Silver Bullet participated in the design of CADM and developed a very comprehensive CADM-based architecture development toolset. Silver Bullet designed and implemented techniques for enterprise architecture data sharing and synchronization and display interfaces for management of large multi-dimensional and highly inter-related datasets. Also supported the development of policy and implementation guidance for Data Management and Interoperability (DMI) and NMCI Critical Joint Applications architecture development for end-to-end interoperability testing. Key Technologies: architectures, databases, data visualization, enterprise data synchronization.	Department of the Navy Chief Information Officer
Joint Task Force Command and Control Architecture	Developed an Integrated Data Dictionary and normalization of existing and future models of Joint Functions, Capabilities, Activities, and Mission Threads. SBSI is developing the Joint Architecture Repository System (JARS), a CADM-based database at the JFCOM. SBSI is imanaging the Joint Architecture Repository System (JARS) and facilitate integration of enterprise architectures into the Defense Architecture Repository System (DARS).Joint Command and Control Architecture. This will be used as JFCOM's staging area for upload and maintenance of the DoD Joint C2 architecture. This involves reconciliation of architecture artifacts and development of consistent and sufficient architecture taxonomies. Key Technologies: architectures, databases, data translation	Joint Forces Command (JFCOM)

Title	**DoD Architecture Framework Document and Data Model Development**
Description of Work Performed and Key Technologies Utilized	DoDAF 2 supports 6 DoD core processes: JCIDS, DAS, PPBE, Systems Engineering, Operations Planning, and Capabilities Portfolio Management (CPM). SBSI is writing much of the text for the DoDAF document. SBSI is leading the development of the DoD-wide data model (DoDAF Meta Model or DM2) for architecture knowledge representation as part of the DoDAF. Conceptual and logical development is with a UML tool with an ontology profile. At the physical level, SBSI is developing the XSDs. SBSI coordinates a large data model working group. SBSI is also part of the DoDAF socialization team and is aiding DM2 implementation pilots. SBSI is also the US technical representative for the International Defence Enterprise Architecture Specification (IDEAS) group in which ontologic features are being built in with an eye on OWL implementation. Under this contract, SBSI also is supporting the development of the DoD CIO Standard Vocabulary for DEIA. Mapping and analysis of Dept vocabularies: DoD Enterprise Infrasturcture Architecture (DEIA), JCA, DoD Primitives and Lexicon (Business Transformation Agency), JFCOM Architecture Elements lists (e.g., Joint Common System Functions List, JCSFL), others. Catalog in database and tools for comparison.
Client	Office of the Assistant Secretary of Defense (OASD) for Network Infrastructure and Integration (NII)
Prime	LMCO
$ Value	$1,200,000
PoP	Oct-08
	Sep-11
Capabilities Keywords	Enterprise Architecture, DoDAF, DM2, IT Architecture, Architecture Framework, Data Modelling, Formal Ontology, RDFS/OWL, DEIA, JCA, Core Enterprise Services (CES), Tactial Edge, Standard Vocabularies, Database Development, Database Applications Software Development
Contract Number(s)	Subcontract to Lockheed-Martin under W91QUZ-06-D-0017
POC	Mike Wayson, OASD (NII), Architecture and Standards Directorate, (703) 607-0482, Michael.Wayson@osd.mil

Title	**DISA Business Enterprise Architecture**
Description of Work Performed and Key Technologies Utilized	Analyze business initiatives, work with agency subject matter experts, and employ DoDAF Enterprise Architecture techniques and tools to development solutions and plans for achieving them in a systematic, justifiable, and repeatable manner.
Client	Defense Information Systems Agency (DISA)
Prime	Soft Concepts
$ Value	$1,000,000 (if option years exercised)
PoP	Oct-09
	Sep-14

Capabilities Keywords	Enterprise Architecture, Business Process modeling, Knowledge Management
Contract Number(s)	Subcontract to Soft Concepts under HC1047-09-F-4106
POC	Kenneth Ly, Strategic Planning & Information Dir, EA & Portfolio Management Div, Enterprise Architecture Branch, 703-681-2335, Ken.Ly@disa.mil

Title	**Context for Data Fusion**
Description of Work Performed and Key Technologies Utilized	The Context of a situation influences belief. Research project with University of Buffalo subcontractor to develop model of Context, ways to enter additional Context information, and reason about reasonableness and additional relevant information using UBuF SNePS reasoning system. Initial case was Small Boat Attack with NGA Digital Nautical Chart (DNC) database and primary initial source for contextual information. Developed trafiicability database and context ontology.
Client	Office of Naval Research (ONR)
Prime	SBSI
$ Value	$500,000
PoP	Nov-07
	Dec-08
Capabilities Keywords	Ontology, Automated reasoning, Data Fusion, Context data model, Database Development, Database Applications Software Development, Predicate logic, RDFS
Contract Number(s)	N00173-08-C-4004
POC	Wendy Martinez, Office of Naval Research (ONR), martinwe@onr.navy.mil

Recent Publications

McDaniel, D. & Schaefer, G., “Real-Time DBMS for Data Fusion”, Proceedings of the National Symposium on Sensor and Data Fusion, Infrared Information Analysis Center, 2003

McDaniel, D.M., “An Information Fusion Framework for Data Integration”, in Proceedings of the 13th Software Technology Conference, 2001

McDaniel, D.M., "Airport Movement Area Knowledge-Assisted Association and Tracking", white paper for the FAA/DoT National Procurement Conference, 2002

Woolf. B. P. , & Regian, J. W., "Knowledge-Based Training Systems and the Engineering of Instruction", in J. Dexter Fletcher & Paul R. Chatelier (Eds.), Handbook of Training Technology. New York, NY: Plenum Press, 2000

Shebilske, W. L., Goettl, B. P., & Regian, J. W., "Individual and group protocols for training complex skills in laboratory and applied settings", in D. Gopher & A. Koriat (Eds.), Attention and Performance XVII: Cognitive regulation of performance, MIT Press, 1999

Tieso, J. V., McDaniel, D., “A Roadmap for Developing Architectures in a Net-centric World”, in Proceedings of the 2004 Department of Defense Command and Control Research & Technology Symposium, 2004

Wheeler, J. L., & Regian, J.W., "The Use of a Cognitive Tutoring System in the Improvement of the Abstract Reasoning Component of Word Problem Solving", Computers in Human Behavior, 1999

Yadrick, R.M., Regian, J.W., Connolly-Gomez, C., & Robertson-Schule, L., "Dyadic vs. individual practice with exploratory and directive mathematics tutors", Journal of Educational Computing Research, 1998