Signal Processing Evaluation, Analysis & Research (SPEAR) Testbed at AFRL Rome Research Site

Jeffrey Tyler – Black River Systems Company, Inc.
William Baldygo Jr. – AFRL/SNRT
Robert E. Bozek – Black River Systems Company, Inc.
Todd Cushman – ARFL/SNRT
Mark Novak – AFRL/SNRT
Walter E. Szczepanski - Black River Systems Company, Inc.

Email: tyler@brsc.com
Phone: (315) 732-7385 Ext.33

Outline

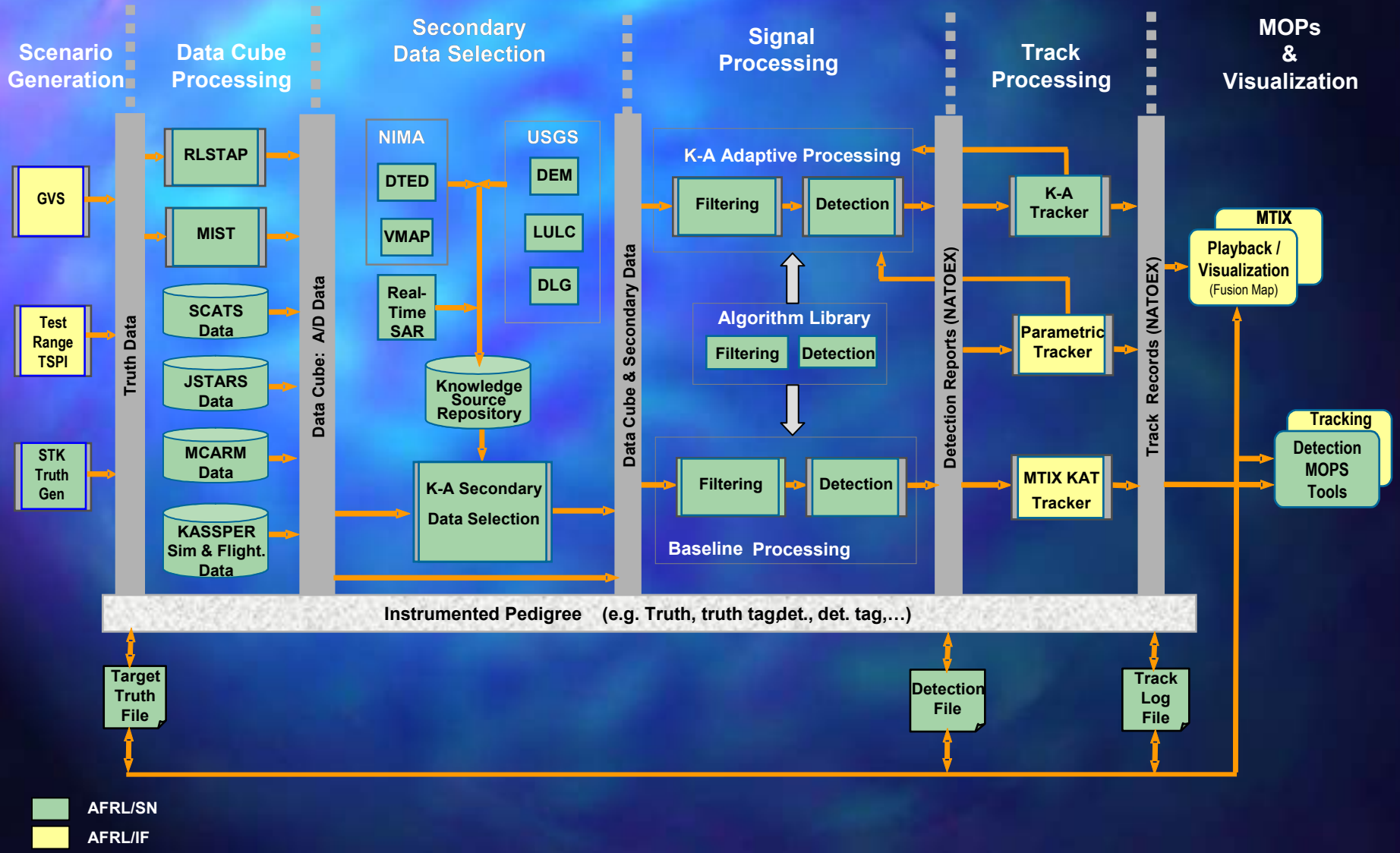
- SPEAR Overview
- SPEAR Architecture
- SPEAR Operations
- Interface Control Document
- End-to-end Evaluation
- Conclusions

Why SPEAR?

- Effective Demonstration of Relevance for Transition to Warfighter
  - Precise Quantification of System Benefits
    - End-to-End Performance Analysis (Filtering, Detection & Tracking) & Appropriate Metrics
    - Detailed System-specific Analysis
  - Testbed for Developing and Evaluating Radar Signal Processing Architectures Incorporating Advanced Knowledge-Aided Training Techniques
  - Thorough Analysis:
    - Many Datasets, Knowledge Sources & Algorithms not typically available to contractors
    - Variety of MOPs
    - Assessment through Tracking Stages of Radar

- SPEAR Provides:
  - Variety of Appropriate Tools:
    - Scenario Generation (i.e. GVS, STK)
    - Measured Radar Datasets (i.e. MCARM, JSTARS)
    - Simulated Radar Datasets (i.e. KASSPER)
    - M&S Tools (RL-STAP, MIST, etc)
    - Knowledge Sources (i.e. SAR Imagery, DTED, LULC/NLC, etc)
    - Algorithm Library (Filtering, Detection & Tracking)
  - Capability for Classified Development, Analysis and Evaluation
  - Real-time Connectivity to AFRL/IFEA Fusion Laboratory for Signal Processing-to-Tracking Performance Assessments
    - Detection Reports Sent in Standard NATOEX Format for Input to FusionMap and/or MTIX
    - MOPs Tool for Correlating Signal Processing MOPS to Relevant Tracking MOPs

SPEAR Processing Architecture



SPEAR Accomplishments

- Designed & Developed SPEAR Testbed
- Devised a JSTARS KA Approach (Near-Term Transition) Incorporating KA Processing Techniques.:
  - Obtained JSTARS T-3 I/Q Data for MPTE Flights 385 & 386 for JSTARS KA Algorithm Development & Analysis
  - Developed Emulation of JSTARS CSI & CFAR Processing as a Baseline Against Which to Compare KA Algorithm Performance
  - Conducted an Analysis of KA-CFAR Using JSTARS Data
  - Demonstrated Significant Improvement in Missed Detections & Subsequent Improvements in Target Tracking (more tomorrow…)
- Devised a Global Hawk MP-RTIP KA Approach (Mid-Term Transition):
  - Korean Peninsula Scenario for Stressing "Real-World" Clutter Environment
  - Several Convoys & Large Density of Background Movers
  - Global Hawk Radar Parameters
  - Demonstrated Dramatic Improvements in Detection Performance (more tomorrow…)
- Currently Developing "Eye Watering Scenario" for DARPA/SPO to Evaluate KA Signal Processing Algorithms
  - More tomorrow…

Planned Activity

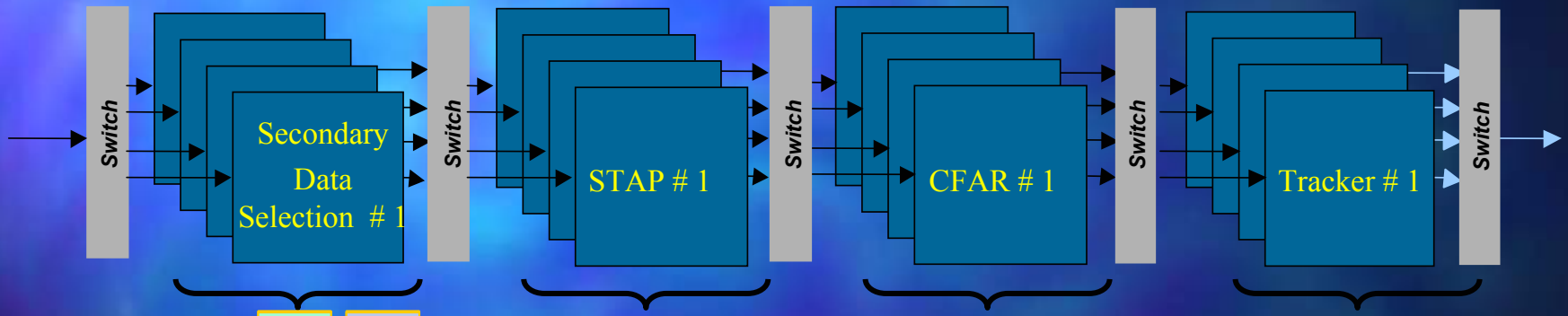
- Develop SPEAR Interface Control Document (ICD) to Aid KASSPER Algorithm Developers in Migrating Matlab Code to SPEAR Testbed
- Incorporate KA Algorithms Delivered to AFRL by KASSPER Algorithm Developers
  - Replicate Performance at Delivery
  - Generate a plan for evaluating each algorithm, what data to be used, what scenarios, and algorithm parameters, MOPs needed, and define outputs to be recorded.
  - **Run tests, generate MOPs, and analyze results.**
  - **Generate data analysis report.**
  - **Act upon feedback from contractor regarding results provided to them.**

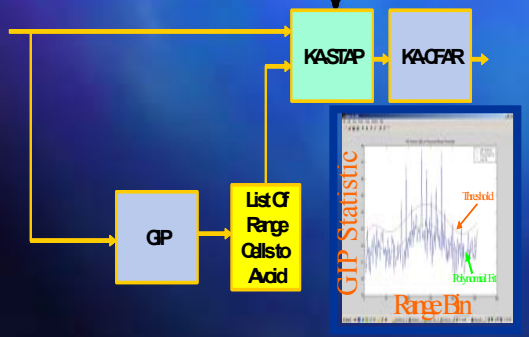
Validate ⇒ Evaluate ⇒ Critical Analysis ⇒ Inform & Report

- Complete “Eye Watering Scenario” Development

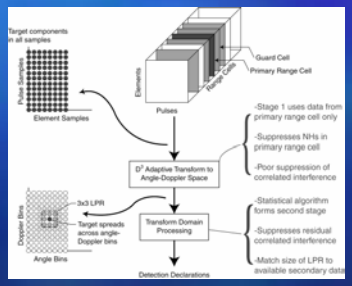
Goals of SPEAR Facility

- Evaluation of knowledge-aided algorithms in combination with different processing lineups
- Evaluation of knowledge-aided algorithms effects upon tracking for the War Fighter

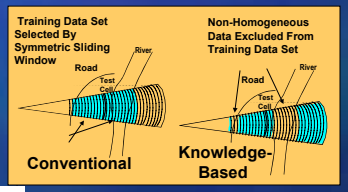




Generalized Inner Product

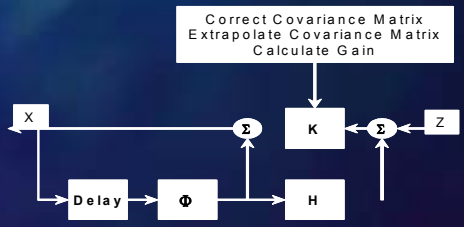


Hybrid Algorithm



ES CFAR

$$\tilde{\hat{X}} = \Phi \hat{X} + \int \Phi B u dt$$
$$\tilde{P} = \Phi \hat{P} \Phi^T + Q$$
$$K = \tilde{P} H^T \left(H \tilde{P} H^T + R \right)^{-1}$$
$$\hat{P} = (I - K H) \tilde{P}$$
$$\hat{X} = \tilde{X} + K \left[Z - H \tilde{X} \right]$$



Parametric Tracker

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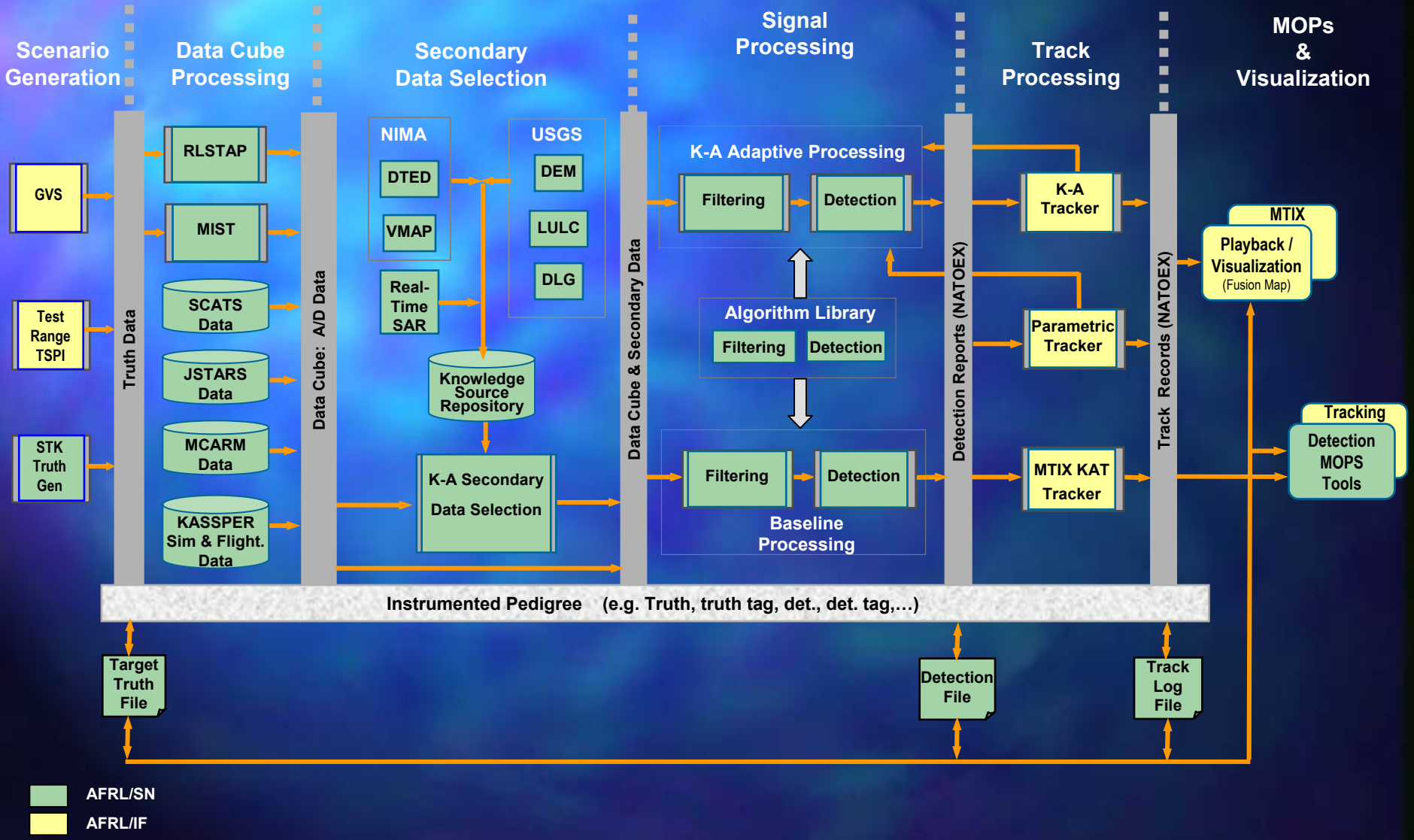
SPEAR Processing Architecture



SPEAR Scenario & Data Cube Generation Capabilities

- Scenario Generation
  - GVS – simulated data
  - STK – simulated data
  - TSPI – measured data
- Data Cube Processing
  - KASSPER Data – (ISL)
  - Joint-STARS – (Northrop-Grumman)
  - MIST (SRC)
  - RLSTAP (AFRL)

SPEAR Radar Signal Processing Capabilities

- Secondary Data Selection
  - DTED, LULC, VMAP based approaches
  - Generalized Inner Product Approaches
  - Other KASSPER Approaches
- Interference Suppression
  - Conventional Filtering Approaches
  - Space-Time Adaptive Processing
  - Clutter Suppression Interferometry
  - Knowledge-Aided STAP
  - KASSPER Unique Approaches
- CFAR
  - Conventional Constant False Alarm Rate Processing
  - Knowledge-Aided CFAR

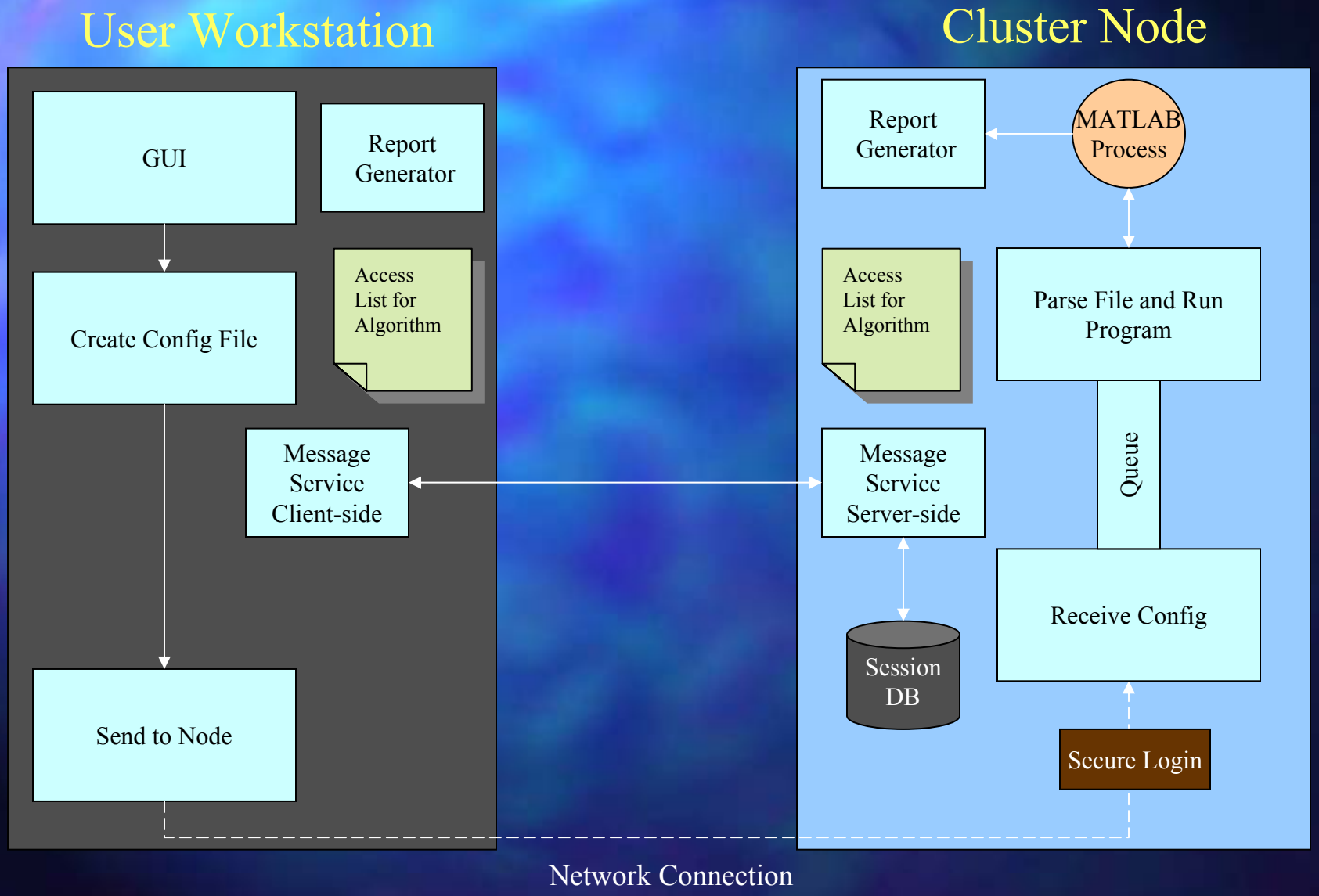
SPEAR Tracking, Visualization, and Evaluation Capabilities

- Tracking
  - Parametric Tracker -GMTI
  - Kinetic Auto Tracker - GMTI
  - KA-Tracker (future) – AMTI
  - Future AFRL GMTI Trackers
- Visualization and MOPs
  - Detection MOPs
  - Tracking MOPs
  - FusionMAP
  - MTIX

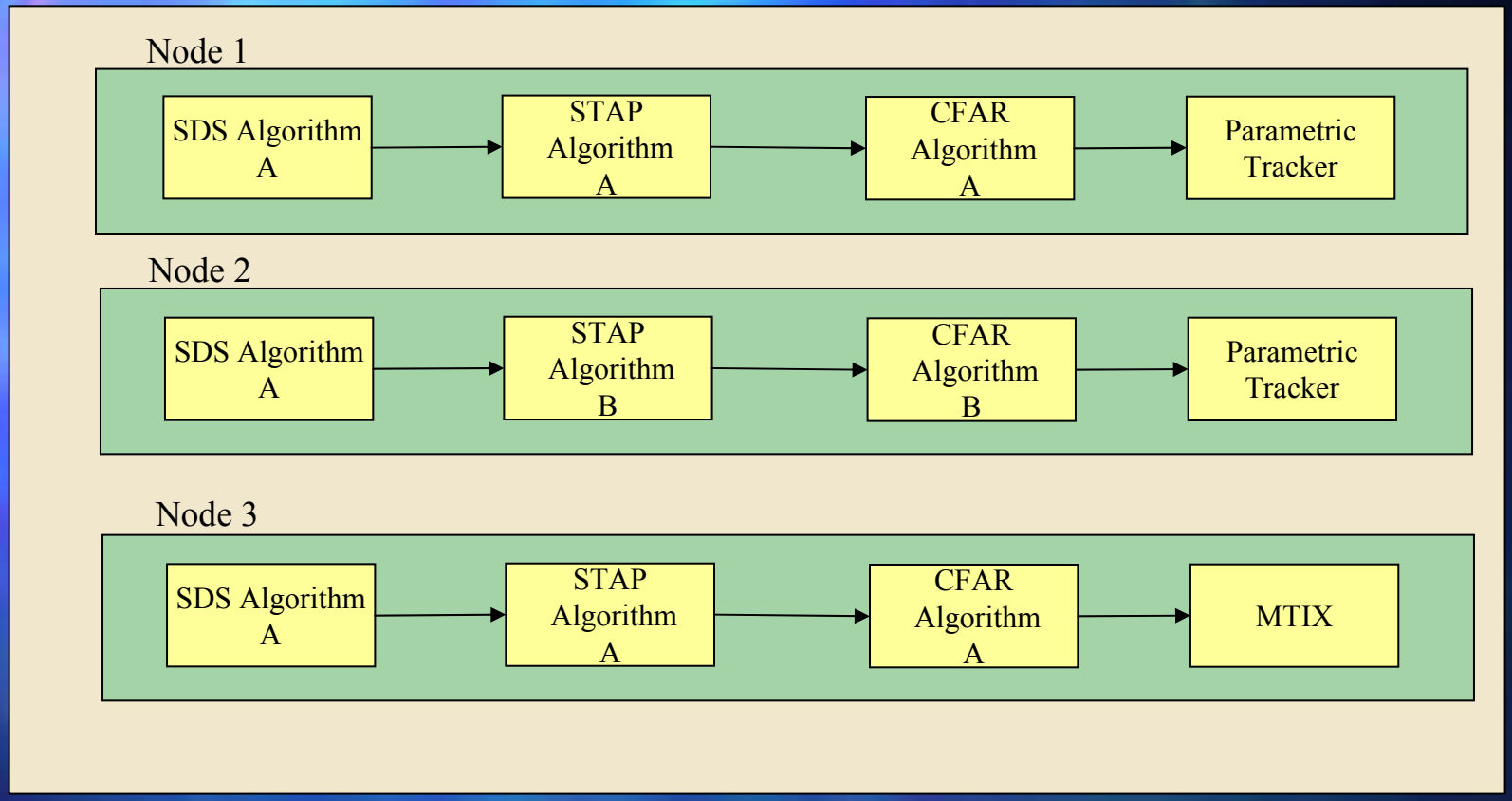
Design Philosophy

- Verifiability – ability to verify performance of individual algorithms
- Ease of Evaluation – Several analysis tools and MOPs available
- Extendibility – Ability to add new algorithms with relative ease
- Maintainability – Organized for effective maintenance
- User Friendly – Graphical User Interface and messaging system to allow for ease of use

Functional Architecture

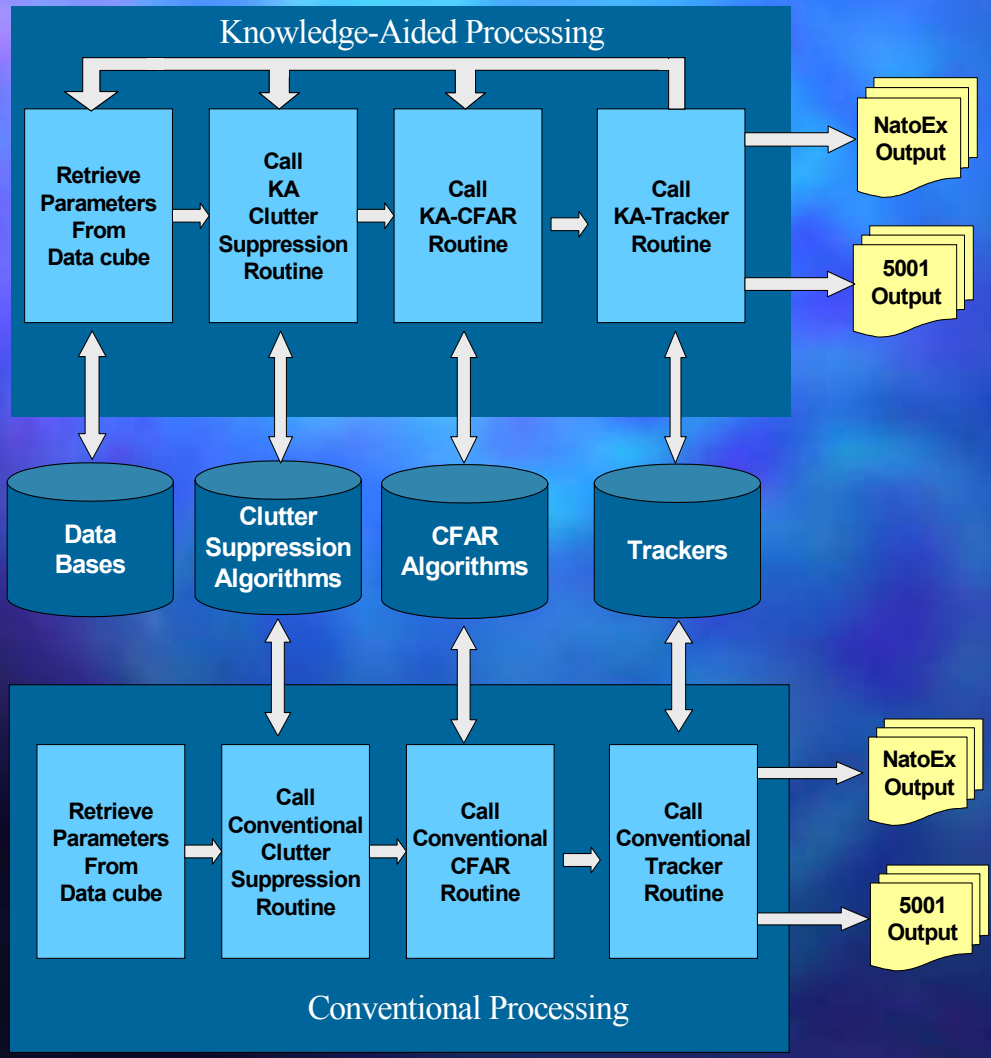


Simultaneous Testing Capabilities



- Test several algorithms at once or single algorithm with different supporting processing
- More efficient and timely evaluations

Knowledge-Aided Software Controller

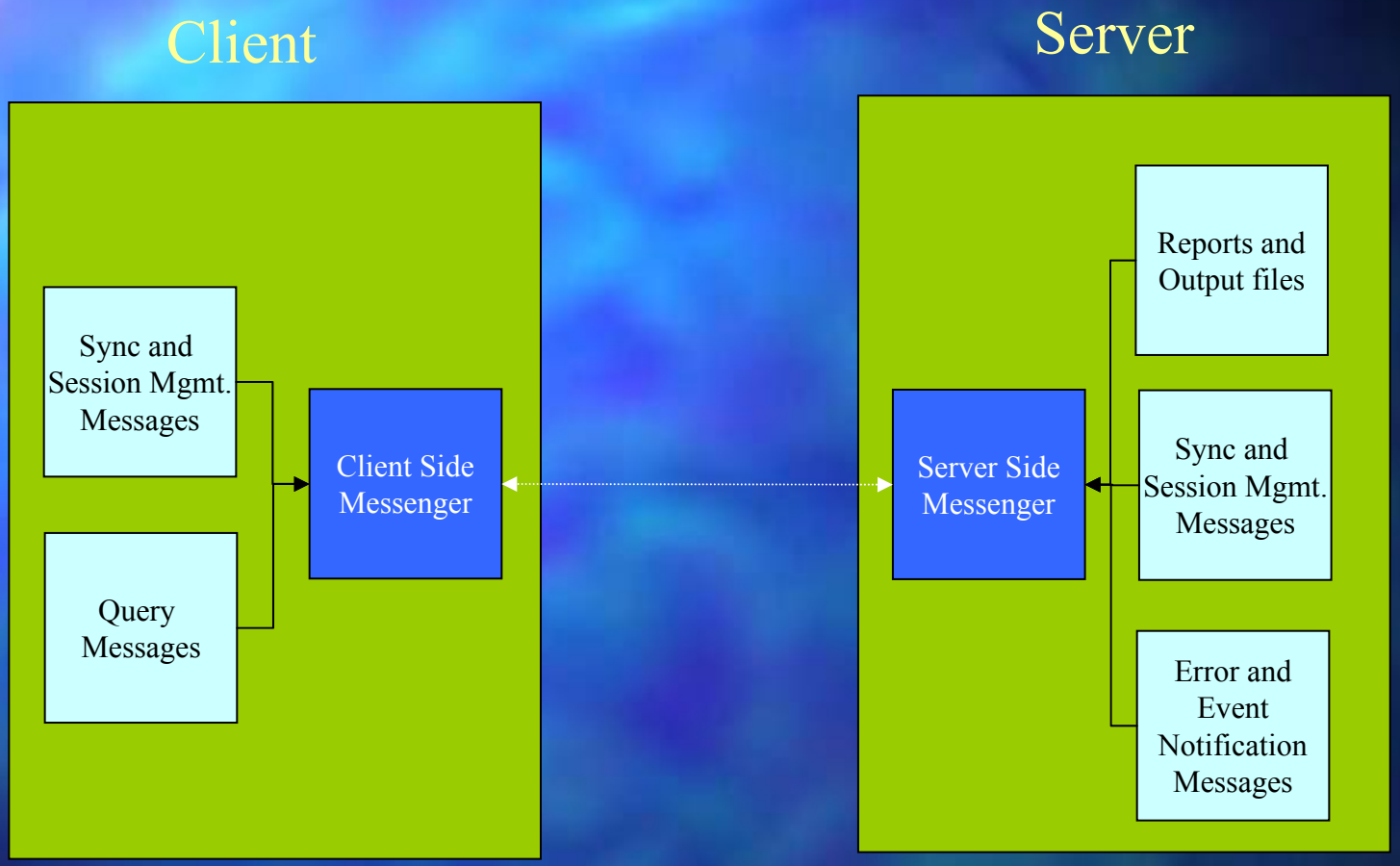


- Provide mechanism to control flow of data through the processing chain
- Organize process so that modules can be added or removed without affecting the entire system
- Provide feedback functionality for using knowledge gained by operation to influence future processing

Database Connectivity

- Geographical and Cultural Databases
  - Currently have access to DTED and LULC Level 1 databases
  - Upgrades to databases include adding NLCD data which has much finer resolution (30m x 30m)
- Data Cube databases
  - Simulated
    - KASSPER
    - MIST Generated Data
  - Measured
    - Joint-STARS
    - MCARM
  - Others to be determined.
- MySQL used to store data for easy querying

Active Message Service



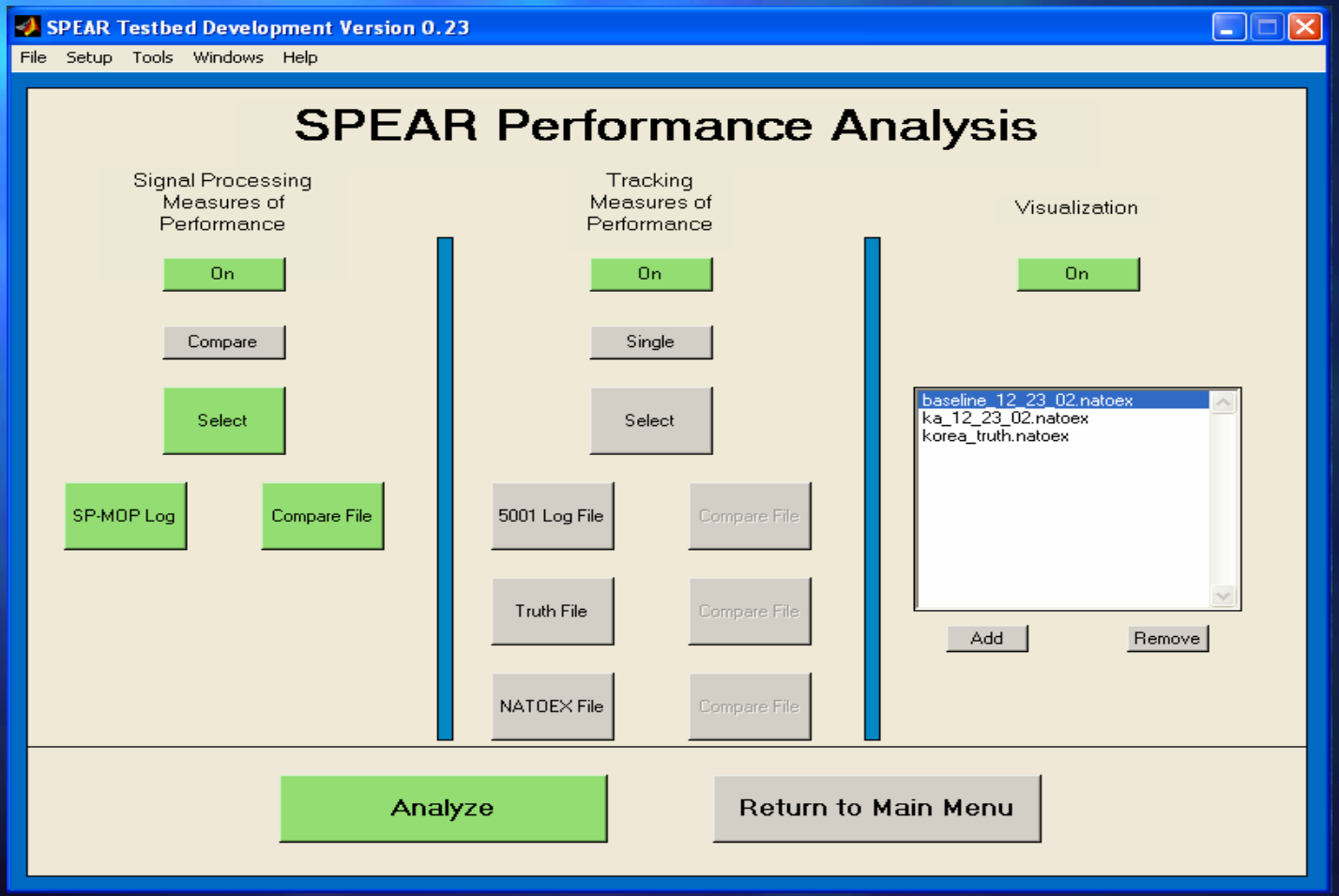
- Messages synchronize client and server
- File transfer and status queries handled

Software Security

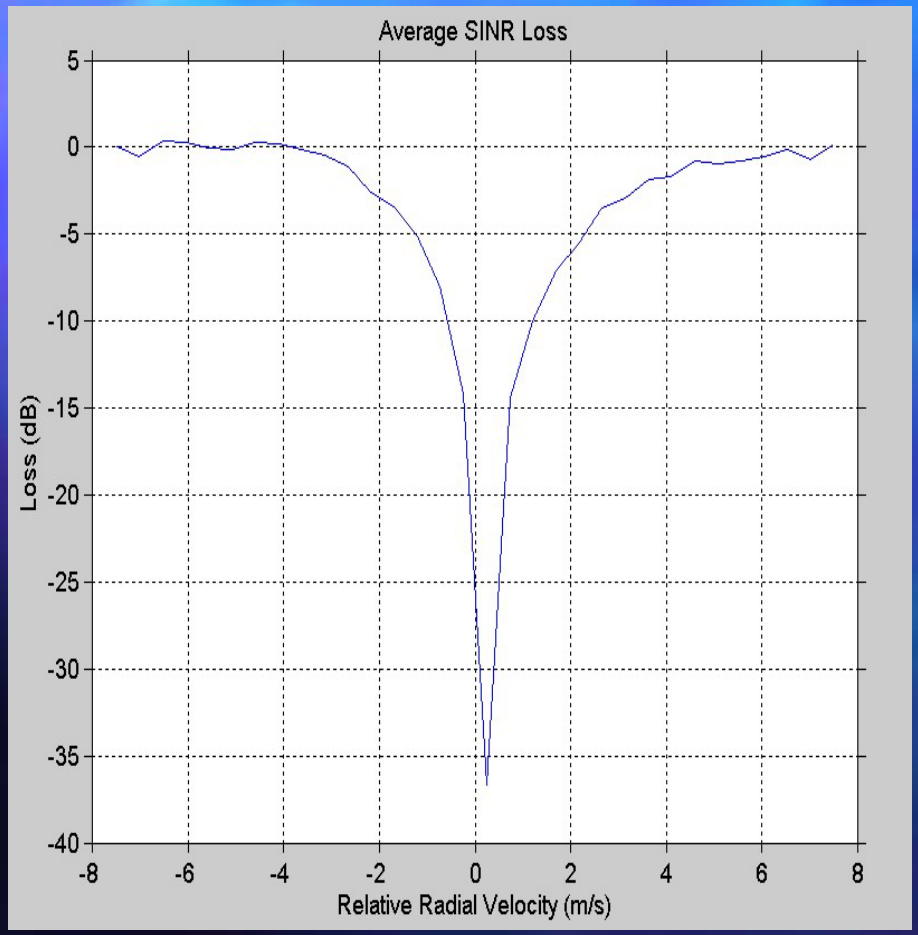
- Three Levels of Security
  - File System Level access control for viewing source and algorithm executables
  - Server authentication for using SPEAR software and control to which nodes can be used
  - Algorithm access lists to restrict access to actually run the contractor algorithms using the SPEAR software
- DoD Security
  - Classified scenarios and data will be used in evaluations
  - Classified data will be handled in accordance with DoD procedures

Measures of Performance

- Graphical analysis tools
- Figures and plots generated using output from SPEAR server



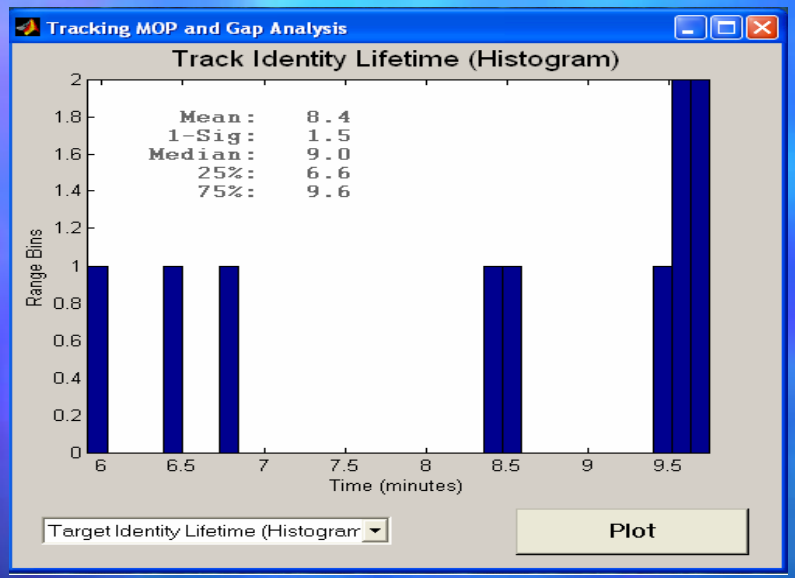
Detection Measures of Performance Examples

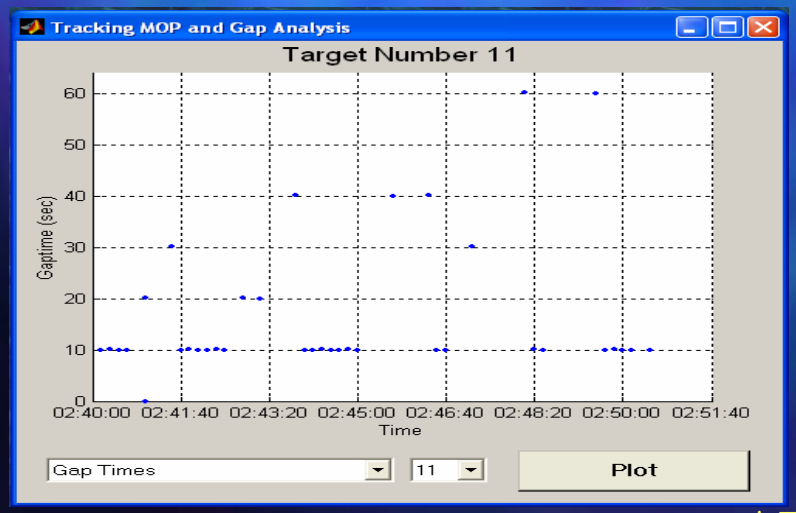


Typical Detection MOPs

- MDV
- False Alarm Rate
- Probability of detection
- Signal to Interference plus noise ratio
- SINR Loss
- Others

Tracking Measures of Performance Examples





- Gap Analysis
- Track Continuity
- Probability of False Declaration
- Track Initiation Time
- Target Identity Lifetime
- Track Purity
- Target Purity
- Average Track Life
- Complete Set of tracking MOPs available*

* Tracking MOPs provided by AFRL/IFEA Fusion Laboratory

Software Technology

- C++ object oriented software design was utilized to meet the design goals of maintainability and extendibility
- XML file format was used for configuration management, access lists, messaging service, and report generation
- XSLT (Extensible Stylesheet Language Transformation) was used in the report generation to allow users to create PDF and HTML reports for distribution and web publishing purposes respectively

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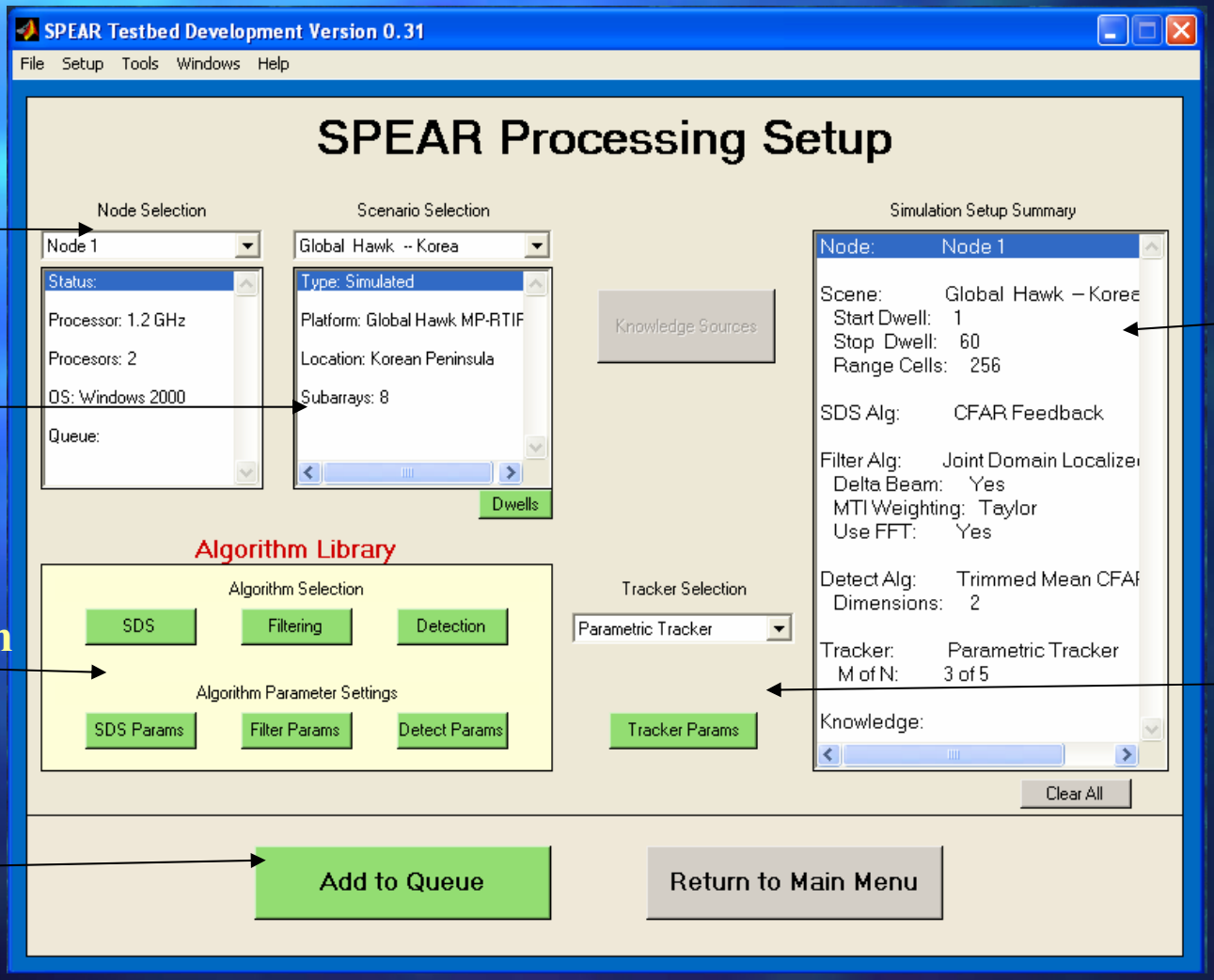
SPEAR Graphical User Interface



Node Selection w/descriptions

Scenario Selection

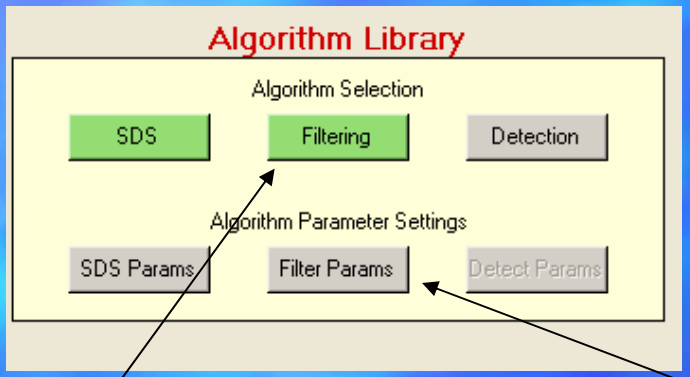
Algorithm Selection

Send to Server Node's queue

Summary Window

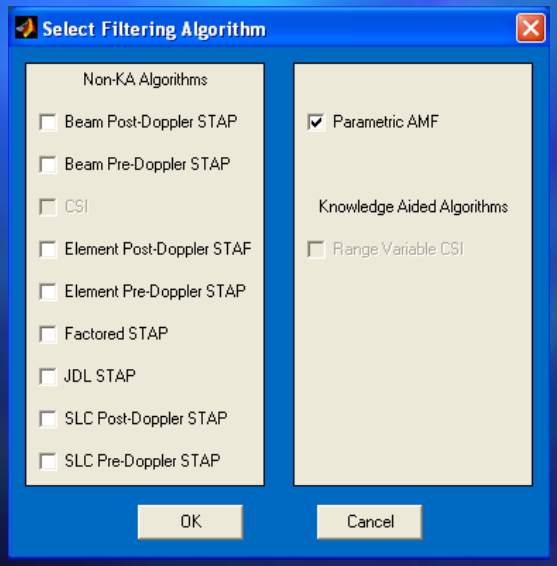
Tracking Setup

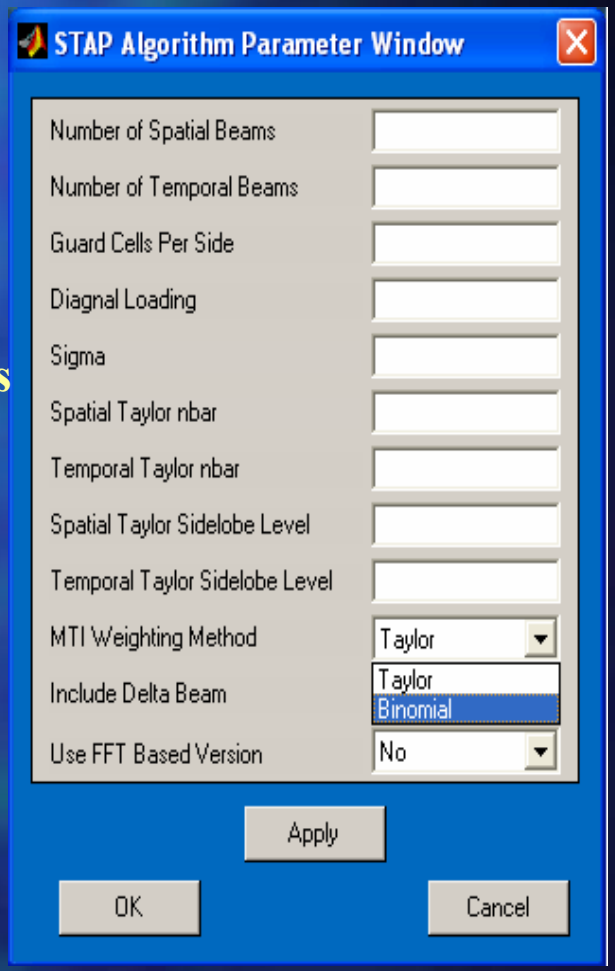
SPEAR Graphical User Interface



Step 1 -Select Algorithm

Step 2- Set Parameters





XML Configuration and Messaging

Configuration file organizes algorithms and parameters.

```
<<?xml version="1.0"?>
<testbed_config>
   <clutter_suppression>
      <algorithm>
         <algorithm_name>JDL</algorithm_name>
         <algorithm_id>11</algorithm_id>
         <vendor_name>SRC</vendor_name>
         <vendor_id>4</vendor_id>
       <parameters>
          <guardCellsPerSide>1</guardCellsPerSide>
                    .
                    .
                    .
                    .
        </parameters>
   </clutter_supression>
   <cfar>
                    .
                    ,
                    ,
    </cfar>
</testbed_config>
```

Messages are passed between client and server.

```
<?xml version="1.0"?>
<message>
   <message_type>1</message_type>
   <message_name>CLI-SYNC</message_name>
   <message_id>0000102340</message_id>
   <crypto>0</crypto>
</message>
```

```
<?xml version="1.0"?>
<message>
   <message_type>100</message_type>
   <message_name>FTP-INIT</message_name>
   <message_id>1001230000</message_id>
   <crypto>0</crypto>
   <ftp_params>
      <number_of_files>3<number_of_files>
                .
                .
   </ftp_params>
</message>
```

Future Improvements

- Wider variety of messages for Message Service
- Event Viewer for monitoring progress and significant milestones in the processing
- Priority queuing for server software to allow jobs of greater importance to proceed over less valuable ones
- Real time interaction (if desired) with processing chain

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Desired Inputs from Algorithm Developers

- Algorithms delivered in MATLAB or C
- Description of algorithm including dataset used and databases utilized
- Test input data
- Test results including charts and numerical metrics for use in validation

Secondary Data Selection Algorithms Interface

- Algorithms with feedback must specify what data is fed back through the input mechanism to the algorithm
- Databases will be available for those algorithms which require geographical and cultural data to choose secondary data.
- IQ Data preferred in Range x Pulse x Channel format
- Params structure needed to pass parameters into the clutter suppression function. A sample structure will be provided to KASSPER contractors.

STAP & CFAR Interface

- C Language algorithms preferred in mex-file format to allow them to easily be called from MATLAB. MATLAB wrappers for these functions are also encouraged.
- IQ Data preferred in Range x Pulse x Channel format
- Params structure needed to pass parameters into the clutter suppression function. A sample structure will be provided to KASSPER contractors.
- Outputs are Quiescent pattern, adaptive pattern, and estimated SINR loss. These are output in Range x Doppler format.

Additional Databases

- Must provide database itself or point of access to said database
- Querying tools, APIs, and/or interfaces should be provided to facilitate faster turnaround in algorithm integration
- Classified databases accepted
- SAR image databases should be provided along with code to utilize the imagery in the algorithms

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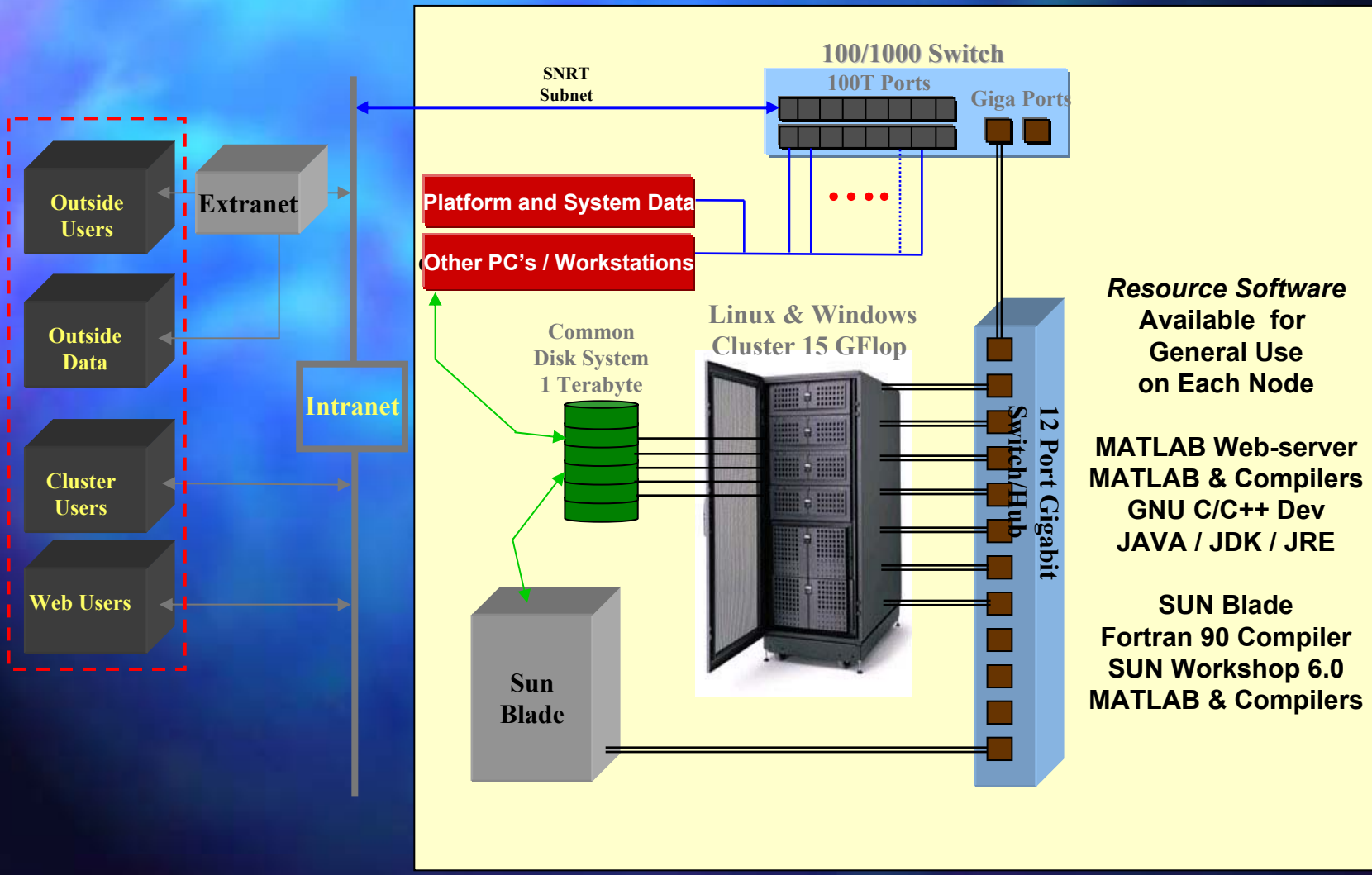
Utilizing Resources From Two AFRL Directorates

- Provides DARPA opportunity to evaluate Knowledge-aided signal processing algorithms in context of the impact on the War Fighter
- Connectivity between Bldg. 106 and Bldg. 240 at AFRL/Rome Research Site provides both AFRL/SN & AFRL/IF with extended capabilities
- Sensors Directorate will have direct access via SIPRNet to MTIX and GVS
- Information Directorate will receive feedback and high fidelity signal processing results

SPEAR (AFRL/SN) Unclassified Facility

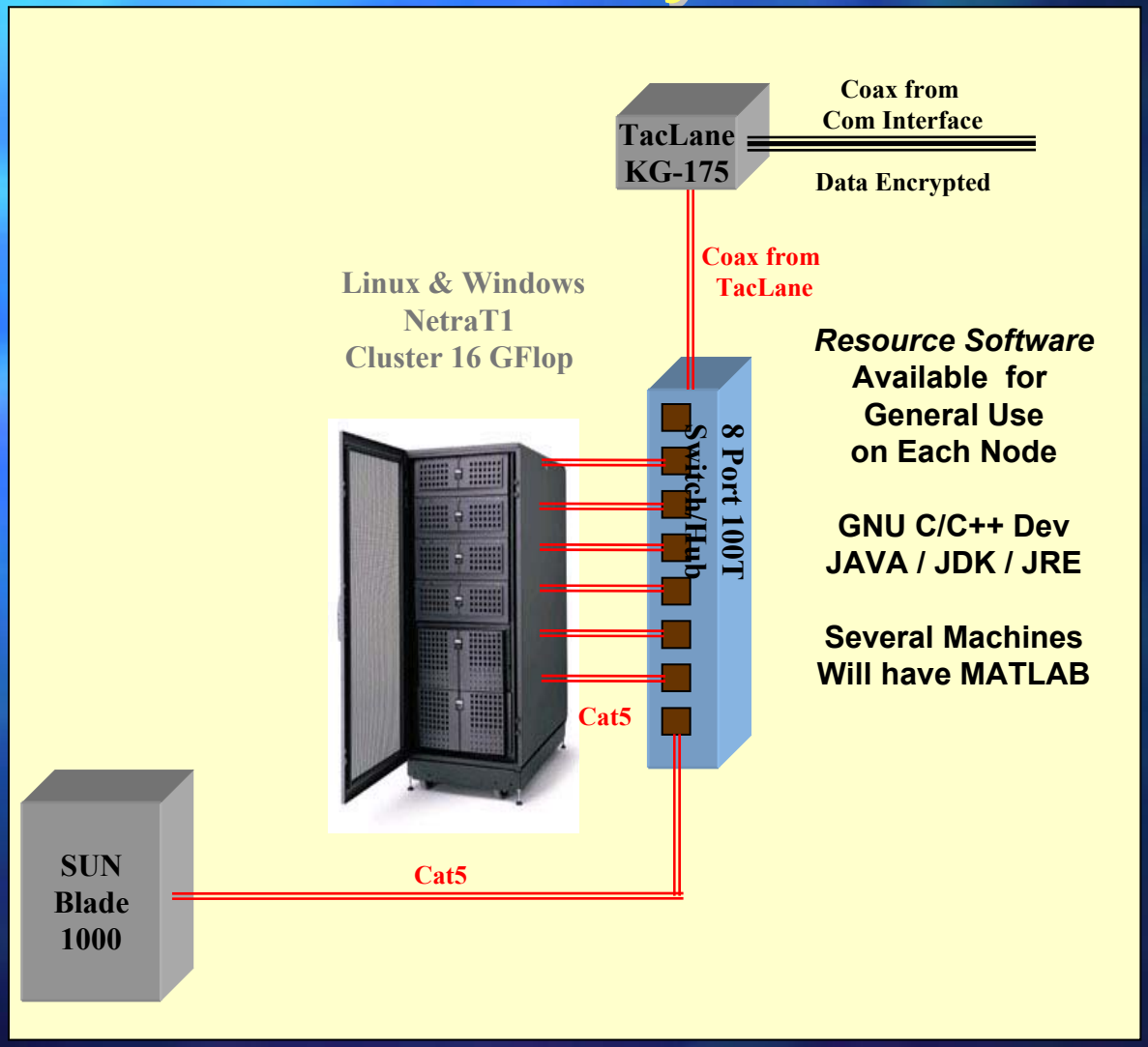


Resource Software
Available for General Use on Each Node

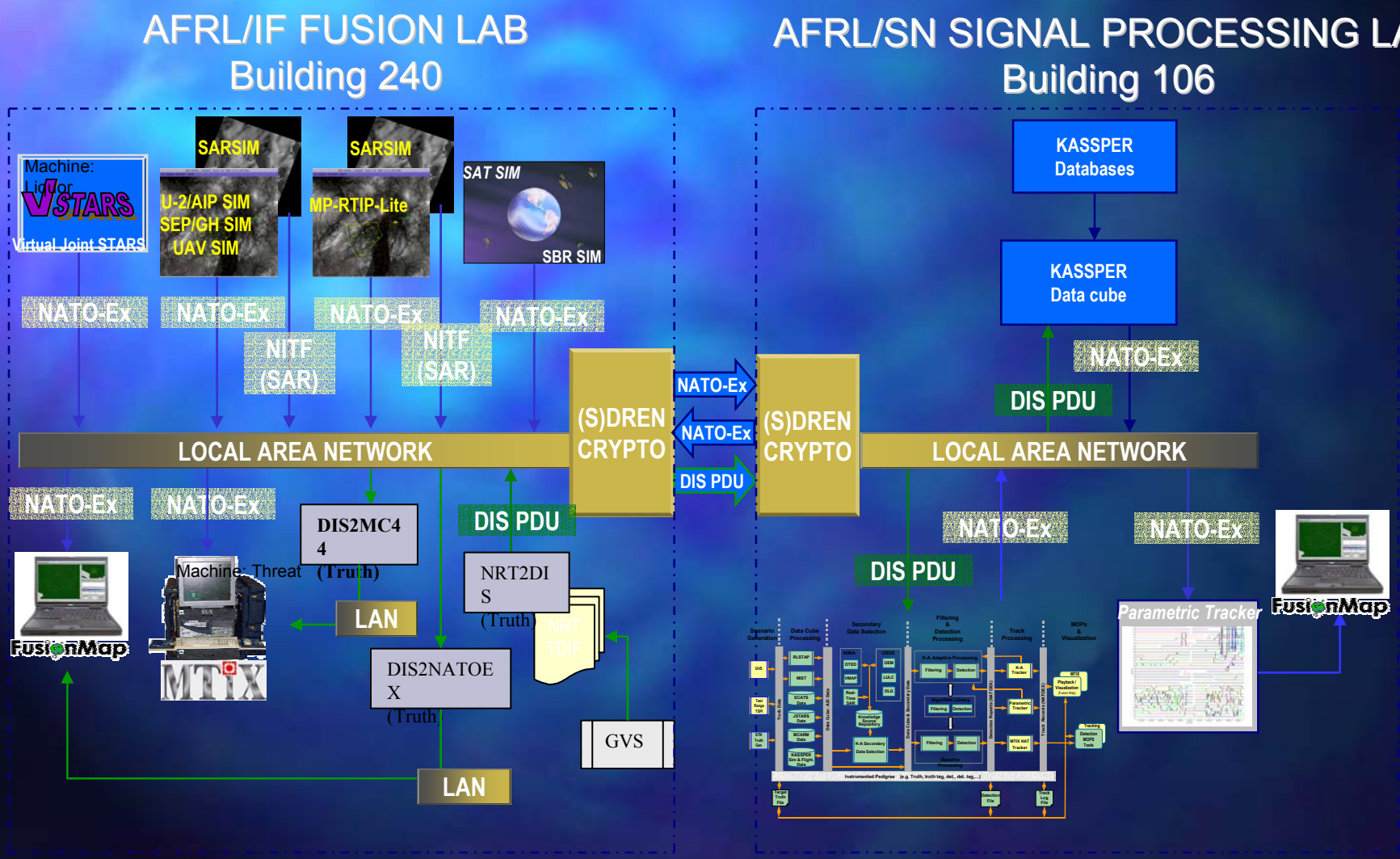
MATLAB Web-server
MATLAB & Compilers
GNU C/C++ Dev
JAVA / JDK / JRE

SUN Blade
Fortran 90 Compiler
SUN Workshop 6.0
MATLAB & Compilers

SPEAR (AFRL/SN) Classified Facility

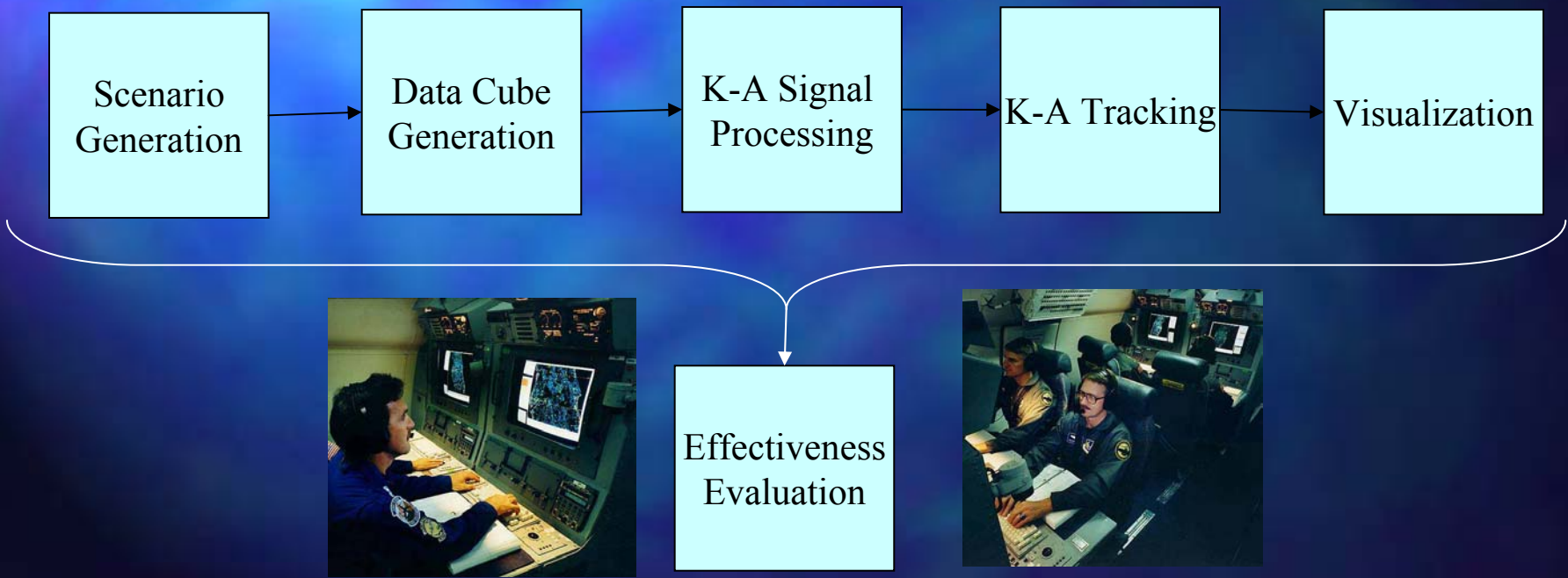


Connectivity Between SPEAR and IFEA Fusion Laboratory



Importance of End-to-End Evaluation

- Critical to recognize "big picture"
- Allows all communities to understand the impact of their algorithms and techniques on the War Fighter
- Gives results as viewed by the radar operator



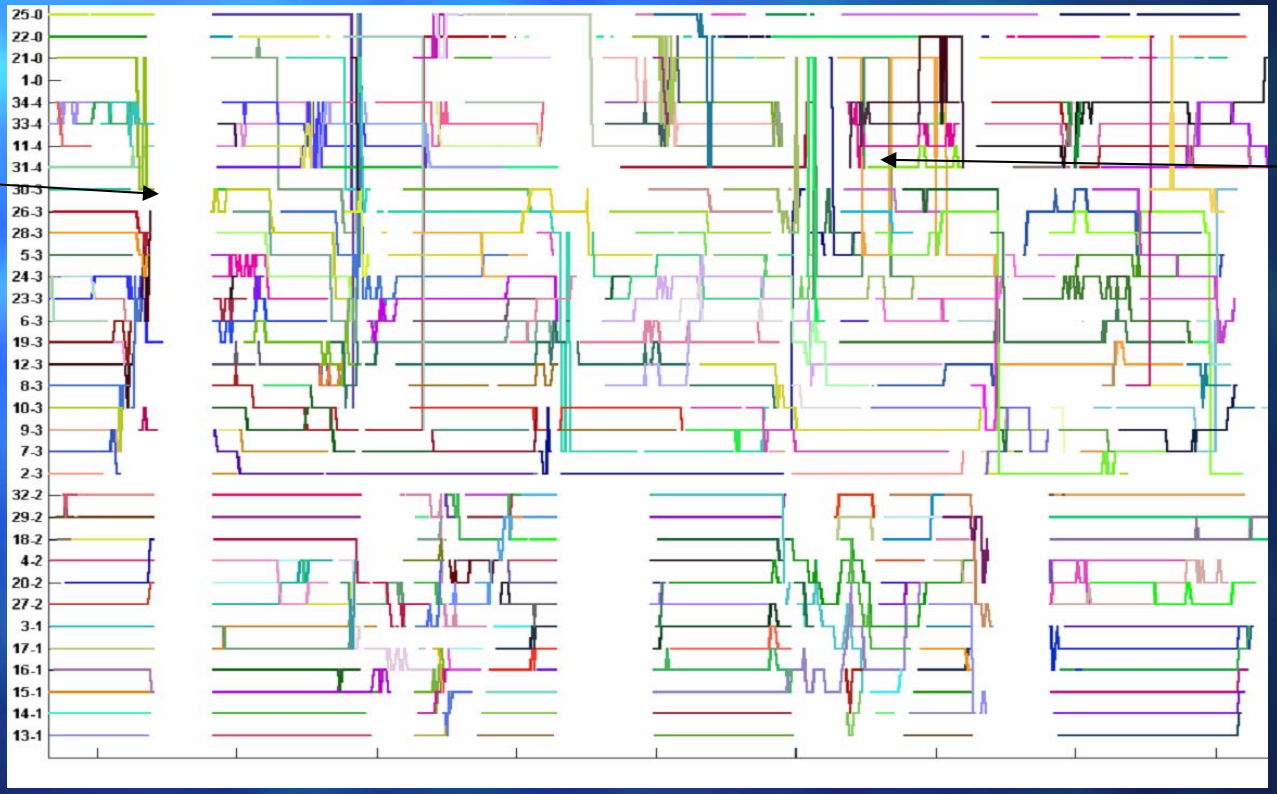
Evaluation Procedures

- Gain understanding of techniques
- Verify that results provided by contractors can be duplicated on SPEAR
- Integrate algorithm into testbed
- Conduct stressing experiments with different supporting processing and configurations
- Provide performance evaluation feedback to algorithm developer
- Produce report of results from these tests

Detection Performance Impact on Tracking

Poor signal processing = Poor tracking

Aircraft Turn around



Missed detections cause track drops and switches

Numbers on left represent target numbers
Colored lines represent individual tracks

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Conclusions – Evaluations

- SPEAR evaluation facilities nearing completion
- Evaluating Knowledge-Aided algorithm improvements on tracking performance is essential
- No detailed evaluation schedule has been established. Experiments will be conducted as algorithms are received.
- A schedule of delivery from each contractor is preferable so we can effectively plan the evaluations
- Release of algorithm performance results will be evaluated on a case-by-case basis by the DARPA Program Manager
- Encourage close working relationship between AFRL and KASSPER contractors

Conclusions – Software Upgrades

- Software will periodically be updated with improved interfaces and functionality. In the case of a significant interface change, contractors will receive a revised ICD.
- Off-site use of this software is not available. Access to processing cluster may be made available on a case by case basis in the future.
- Report generator will be equipped with encryption to add additional layer of security.

Conclusions – Results of Current Tests

- Experiments have already been conducted on testbed
- Results from both measured and simulated data sets
- Introduced tomorrow in classified session