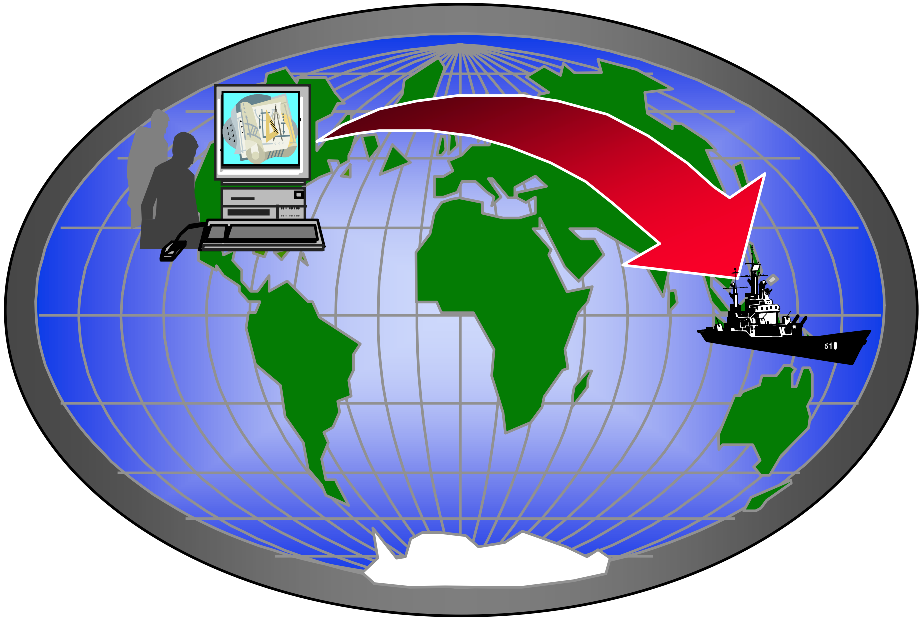
Horizontal Integration based upon: Decentralized Data Fusion (DDF), NetCentric Architecture (NCA), and Analysis Collaboration Tools (ACT)



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Horizontal Integration (HI)

*Definition**

Processes and capabilities to acquire, synchronize, correlate, and deliver National Security Community data with responsiveness to ensure success across all policy and operational missions.

*** Approved by the HI Senior Steering Group, 18 October 2003**

Technology Enablers for HI

- **NetCentric Architecture (NCA)**
  - A Network Architecture that gives component platforms access to multi-level security information and communications over a two-way encrypted connection.
- **Decentralized Data Fusion (DDF)**
  - A framework which includes a solution to the data fusion problem.
  - Two components of the proposed framework are:

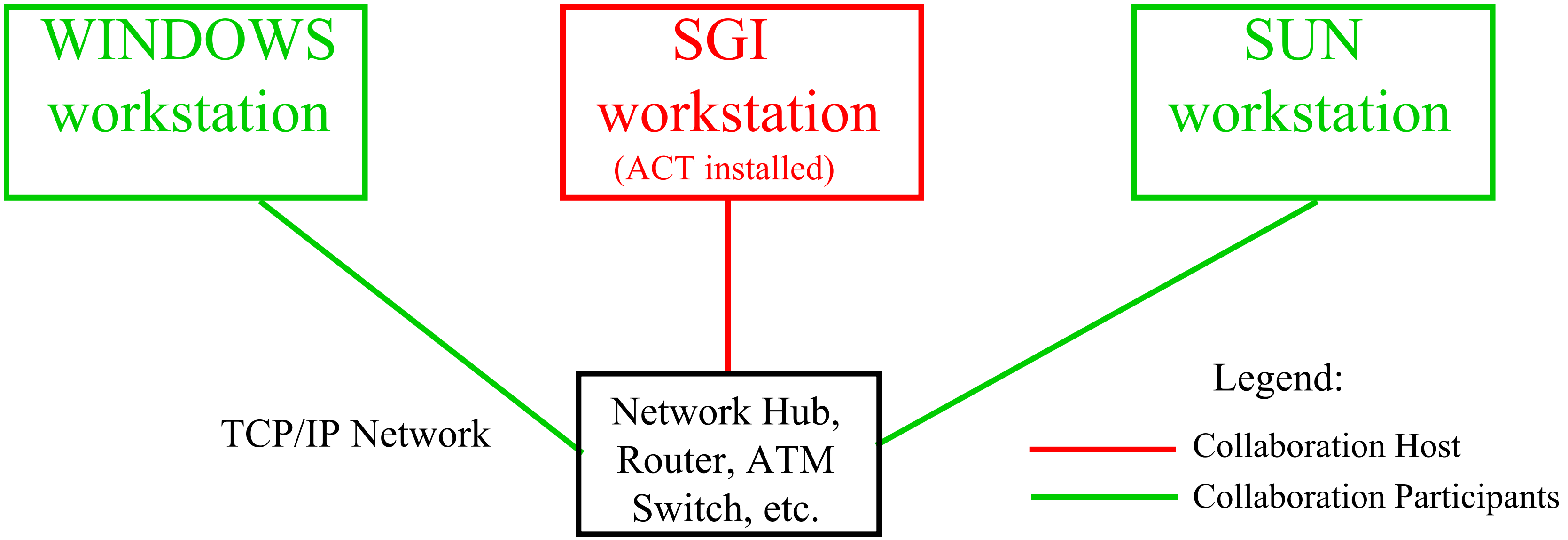
    Covariance Intersection (CI), and Covariance Union (CU)*.
- **Analysis Collaboration Tool (ACT)**
  - NRL developed second-generation tool for application sharing and collaboration between intelligence analysts.

*Julier, S. and Uhlmann, J., Handbook of Multisensor Data Fusion, 2001, edited by D.Hall and J. Llinas, Chap.12.

Analysis Collaboration Tool (ACT)

- **Objective:**
  - Leverage COTS Collaboration Technologies to enable Real-Time Collaboration Capabilities for legacy and next generation Analysis Tools.
- **Approach:**
  - Utilize SGImeeting and SunForum COTS Collaboration Tools
  - Modify, if necessary, Legacy and Next Generation Analysis Tools to accommodate Functionality of COTS Collaboration Tools

ACT Network Diagram



ACT Results

- **ACT Enables Distributed Real-Time Collaboration for Legacy and Next Generation Analysis Tools.**

- **ACT enhances SGImeeting/Sunforum/NetMeeting Collaboration Capabilities:**
  – No additional software required by participants.
  – Any X Windows based Application can be Collaborated
  – No Application Source Code Changes Required.
  – Multi-platform Collaboration: SGI, SUN, Windows (95,98,NT, 2000),

The Problem of Distributed Information

- Current ‘stovepipe’ systems are structured to support relatively autonomous nodes.
- Each node incorporates data it needs to perform its function and then processes and transmits its best available information for use by other nodes.
- In many cases information is redundant.
- In some cases information is spurious and must be purged.

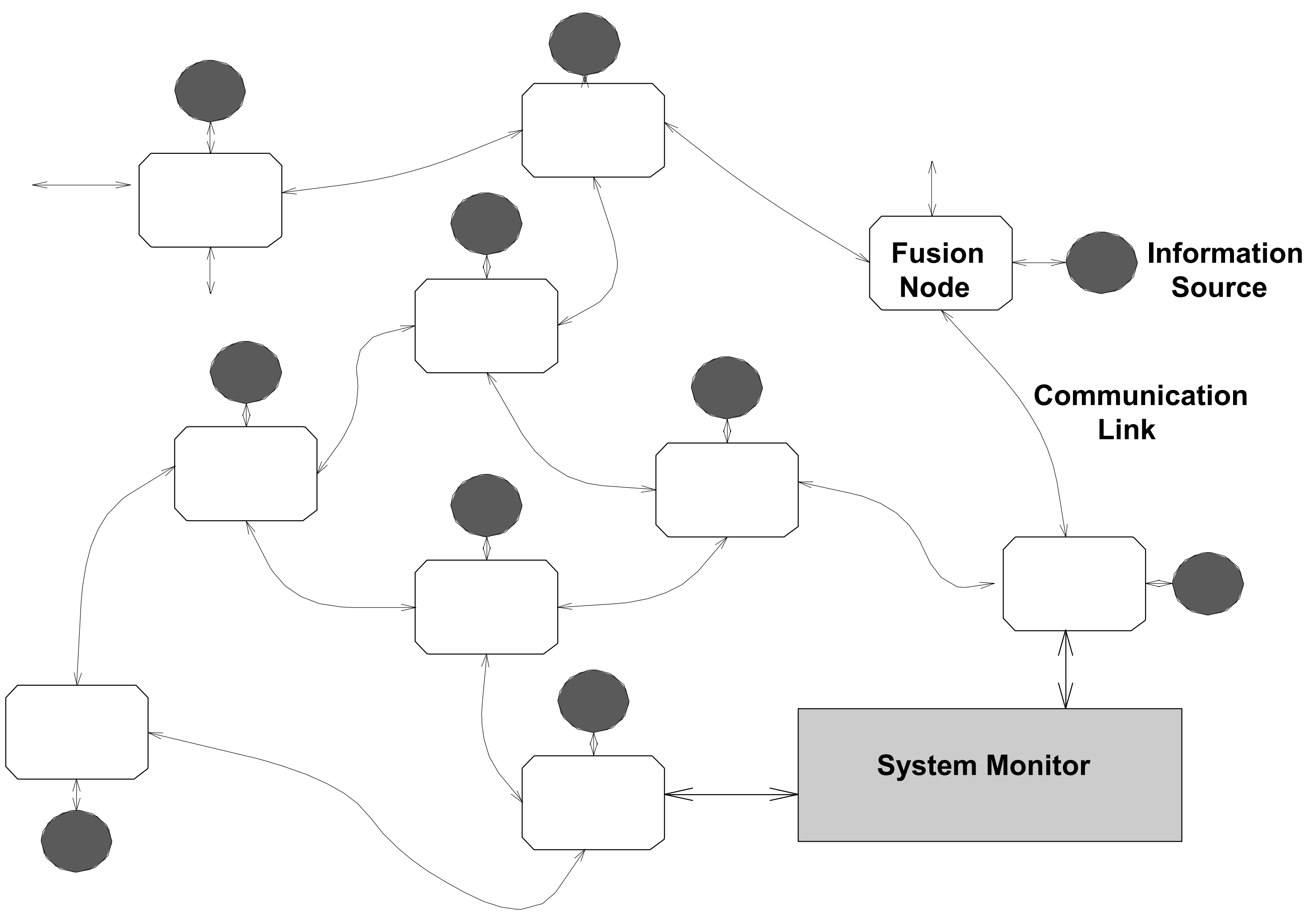
Decentralized Data Fusion (DDF)

- **A network-centric information management system includes links between a ‘global’ database and multiple local databases.**
- **A mechanism is need to fuse correlated/redundant information so that database updates are *consistant*.**
  - **Covariance Intersection(CI) is proposed.**
- **A mechanism is needed to prevent the network from being undermined by inconsistant data (deconfliction problem).**
  - **Covariance Union (CU) is proposed.**

Key Requirements for DDF

1. The information (reports) must have a well-defined measure of uncertainty and confidence.
2. The fusion process must ensure that the database updates maintained by all entities are consistent.
3. The data fusion method must be robust to failures in the network caused by, for example, communications disruptions.
4. The connectivity of the nodes can be dynamically changed.
5. The data fusion framework must be efficiently scalable, e.g., to networks having many nodes.

A Distributed Data Fusion Network



- Each box represents a fusion node

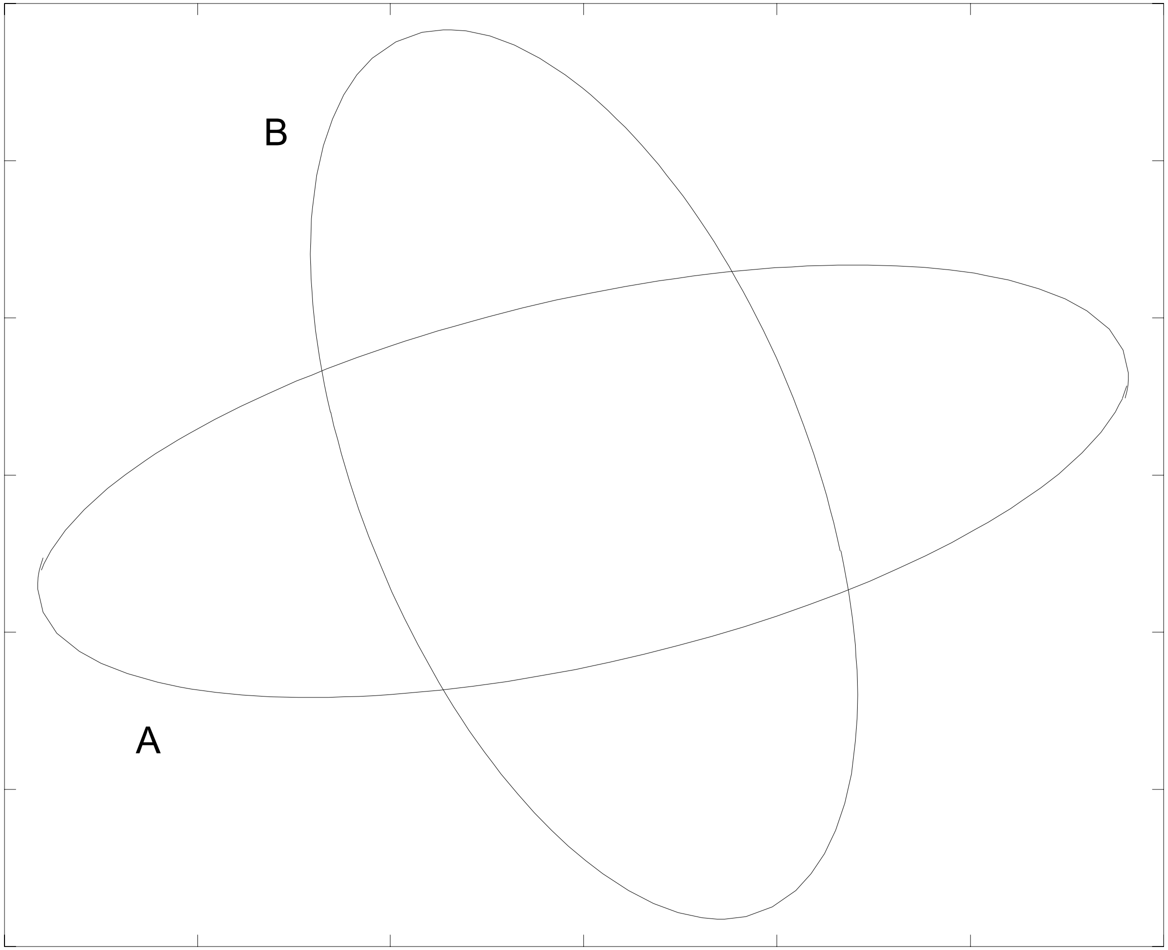
Covariance Intersection: What It Is

- **Given mean and covariance pairs (a, A) and (b, B), a fused estimate (c, C) is defined by CI as:**

$$C = (w\ A^{-1} + (1-w)B^{-1})^{-1}$$
$$c = C(w\ A^{-1}a + (1-w)B^{-1}b)$$

The parameter $0 \leq w \leq 1$ is determined by the covariance measure that is to be minimized (e.g., determinant or trace of C).

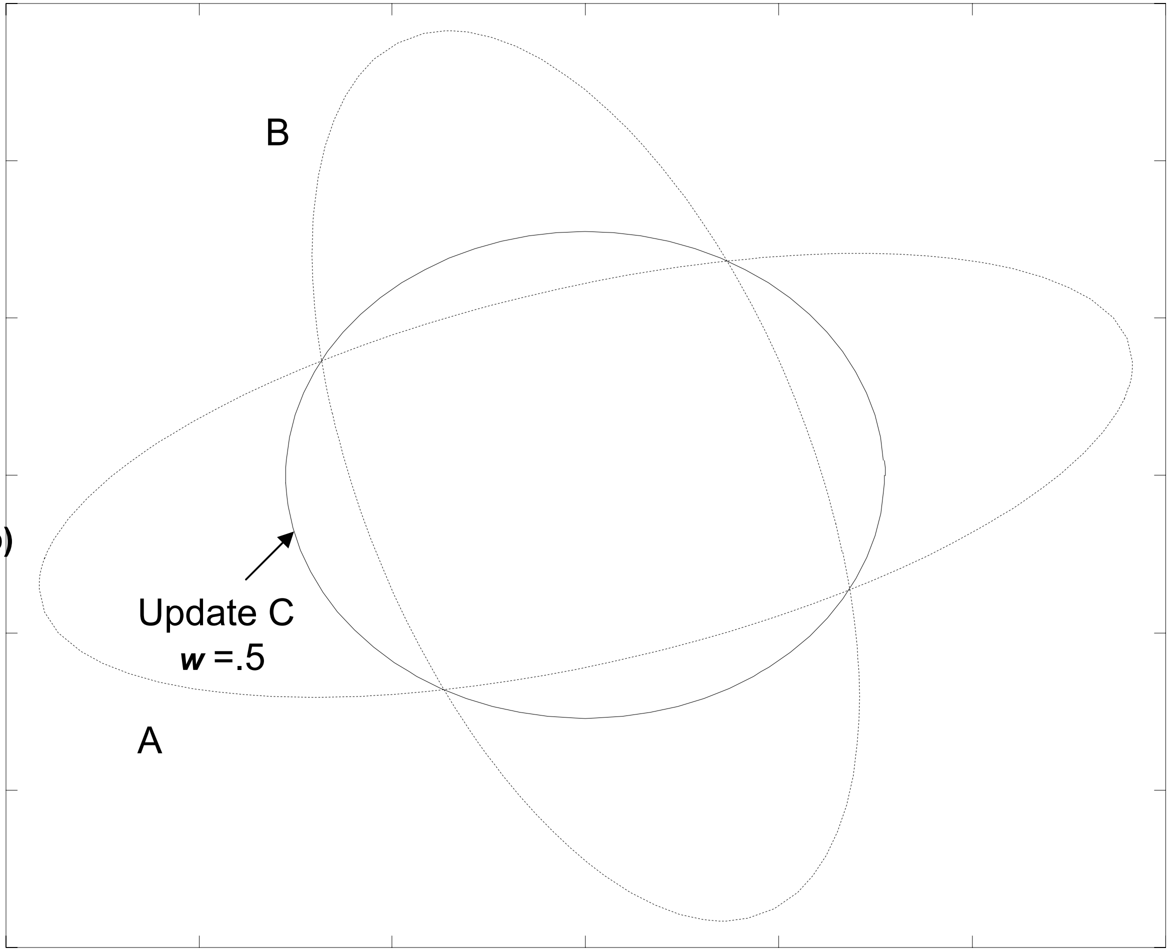
Example: Error Ellipses (cont'd.)



Example: Error Ellipses (cont'd.)

$C = (wA^{-1} + (1-w)B^{-1})^{-1}$

$c = C(wA^{-1}a + (1-w)B^{-1}b)$



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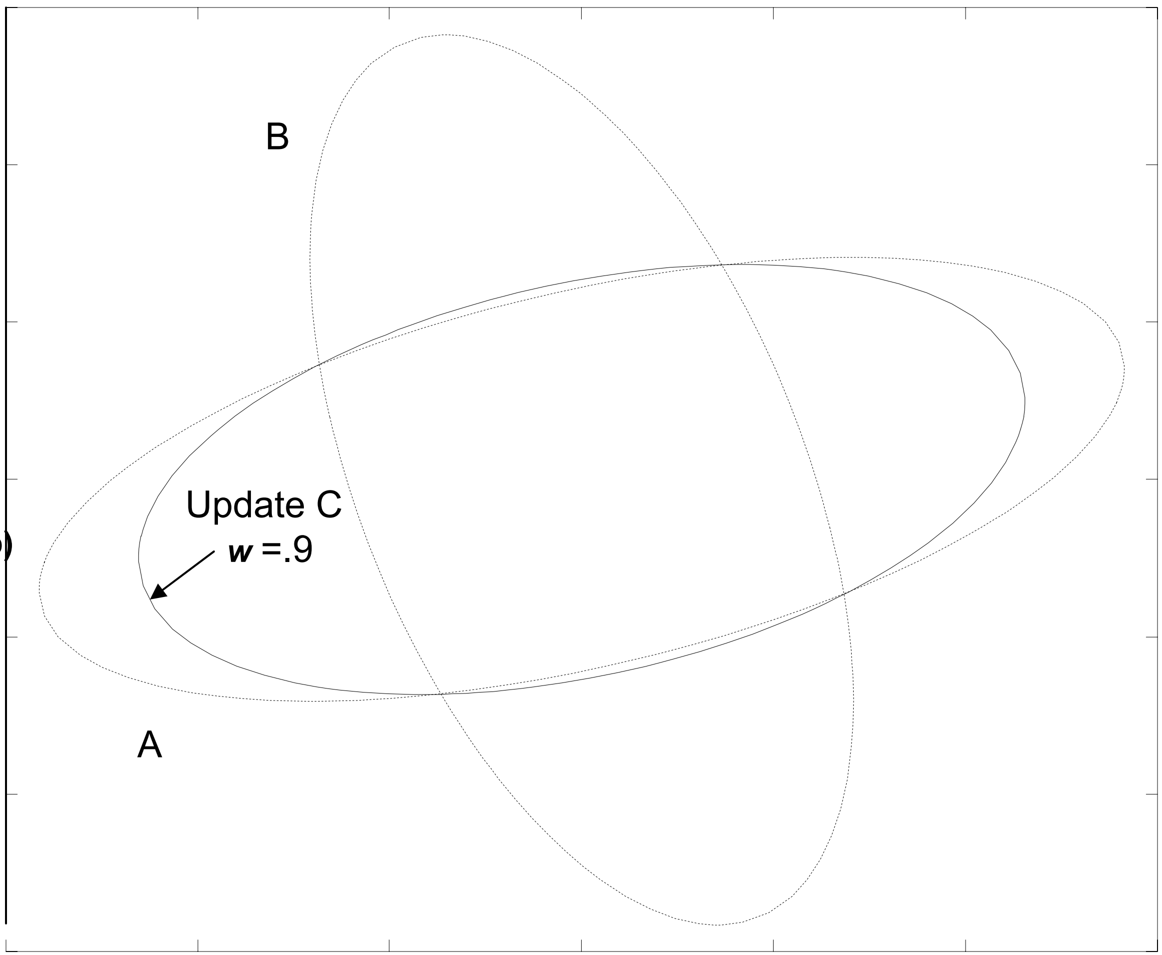
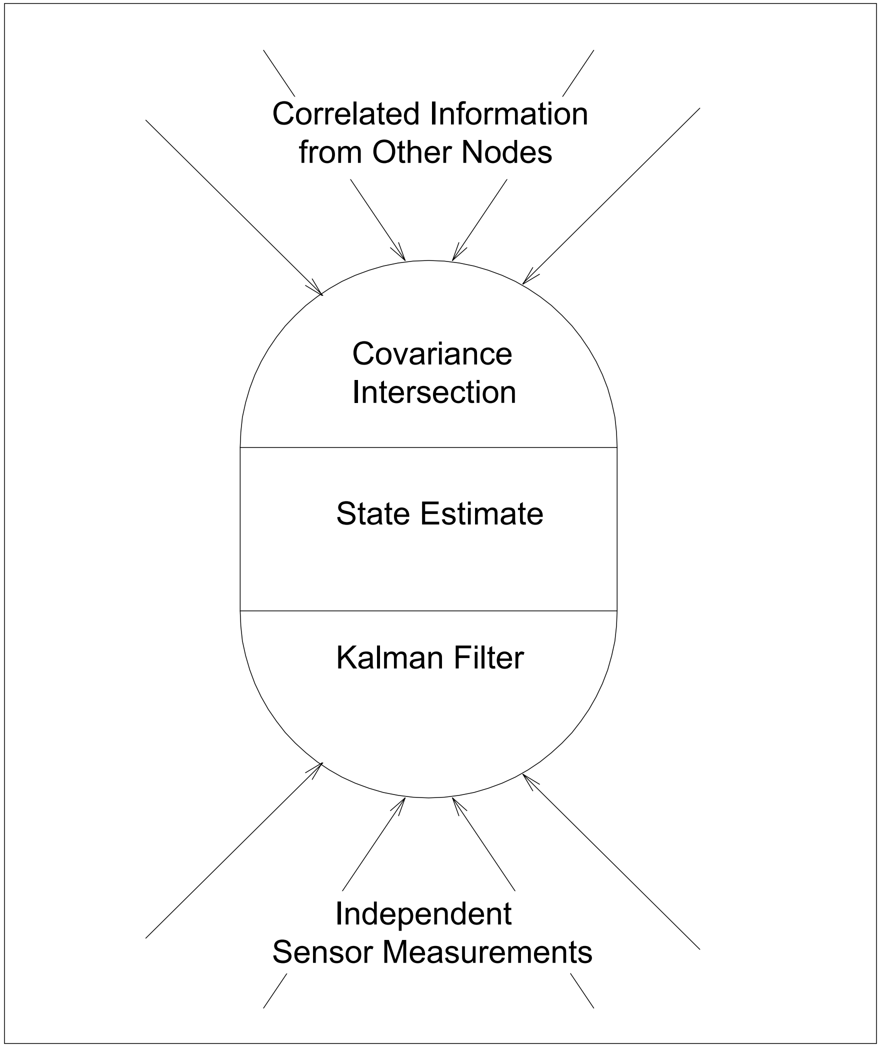


A Canonical Node in a General Data Fusion Network



Covariance Union (CU)

- Assume that in the database deconfliction problem only one mean and covariance estimate, either (**a**, **A**) or (**b**, **B**), is a consistent estimate of the state of an object of interest. The other estimate, (**a**, **A**) or (**b**, **B**),must be discarded.
- Because it is not generally possible to know which estimate is spurious, the only way to rigorously combine the estimates is to form a unioned estimate, (**u**, **U**), that is guaranteed to be consistent with respect to *both* of the two estimates.
- In other words, the estimate (**u**, **U**) must be consistent if the estimate (**a**, **A**) is correct and (**b**, **B**) is spurious, and it must be consistent if (**b**, **B**) is correct and (**a**, **A**) is spurious. This estimate will be referred to as the Covariance Union (CU) of the two estimates.

Covariance Union (CU) Equations

- Given two mean and covariance estimates, **(a, A)** and **(b, B)**, only one of which is known to be consistent, the Covariance Union (CU) estimate **(u, U)** is defined as the mean vector **u** with the smallest possible covariance matrix **U** satisfying the inequalities:

$$\mathbf{U} \geq \mathbf{A} + (\mathbf{u}-\mathbf{a})(\mathbf{u}-\mathbf{a})^T$$
$$\mathbf{U} \geq \mathbf{B} + (\mathbf{u}-\mathbf{b})(\mathbf{u}-\mathbf{b})^T$$

- These inequalities are based on the observation that if the estimate **(a, A)** is consistent, then the translation of the vector **a** to **u** will require its covariance to be enlarged by the addition of a matrix at least as large as the outer product of **(u-a)** in order to be consistent. The same reasoning applies if the estimate **(b, B)** is consistent.

DDF Summary

- A Decentralized Data Fusion (DDF) framework, as a key enabler for HI, has been proposed.

- The DDF paradigm is based upon the concepts of covariance intersection (CI) and covariance union (CU).

- CI always produces a consistant fused estimate with no assumptions regarding correlation required.

- CU provides the first provably rigorous and optimal solution to the database deconfliction problem.

- In the context of the DDF framework for HI, work still remains to develop efficient and robust implementations and applications of CI and CU.