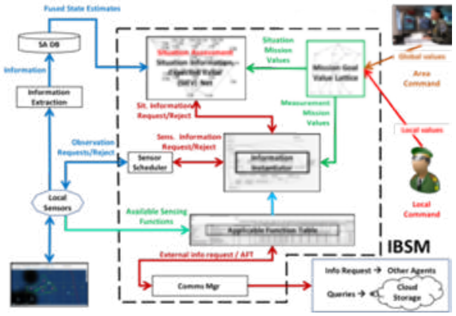


Sensor Management in ISR

Information Based Sensor Management (IBSM)

Kenneth J. Hintz, Ph.D.

George Mason University

Dept. of Electrical and Computer Engineering &

Outline of Presentation

- Motivation for information based sensor management (IBSM)
- Underlying principle is maximizing expected information value rate, *EIVR,* from the real world to the mathematical model of the world
- Situation information *vs* sensor information
- Functional decomposition of sensor manager into orthogonal, realizable components
- Benefits of IBSM
- Recent advances and current research in IBSM

Intelligence, Surveillance, and Reconnaissance (ISR)

"... intelligence is best defined as the ***collection***, analysis, and dissemination of ***information*** on behalf of decision makers engaged in a competitive enterprise and that its performance can be judged according to some relatively simple measures." *

"Decision makers matching wits with an adversary want ***intelligence—good, relevant information*** to help them win. Intelligence can gain these advantages through directed research and analysis, ***agile collection***, and the timely use of guile and theft." **

* J. E. Sims and B. Gerber, *Transforming U. S. Intelligence,* Washington, DC: Georgetown University Press, 2005.

** J. E. Sims and B. Gerber, *Vaults, Mirrors, & Masks: Rediscovering U.S. Counterintelligence*, Washington, DC: Georgetown University Press, 2009

Data, Information, and Knowledge***

- Data, information, and knowledge are often used interchangeably, but have distinctly different technical meanings
  - **Data**: individual observations, measurements, and primitive messages [which] form the lowest level
  - **Information**: organized sets of data
  - **Knowledge**: information once analyzed, understood, and explained
- Data are the result of ***sensor observations*** which are combined into measurements and affect the uncertainty about a process or event
- Information is a ***change in uncertainty*** about a random variable or its underlying probability distribution
- A ***Bayes net is a knowledge repository***
- Information can flow into or out of a BN resulting in a change in the knowledge about a situation (situation assessment, not awareness)

*** E. Waltz, Knowledge Management in the Intelligence Enterprise, Boston: Artech House, 2003.

Sensor Management Problem

- What is the most effective way in which to transfer data from the real world into a model of that world for use by decision makers? *i.e.*, ***obtain valuable, timely, actionable intelligence***
- Optimization criteria for sensor manager
  - Transfer ***information*** not just data
  - ***Mission valued*** information
  - Maximize the ***probability*** of obtaining that information
  - Obtain the information in a ***timely*** manner
- Implementation considerations
  - Computable in real-time or reasonable planning horizon
  - Scalable, *i.e.*, self-similar structure
  - Reduce communications bandwidth
  - Firm theoretical basis for design guidance

Need for a Sensor Resource Manager

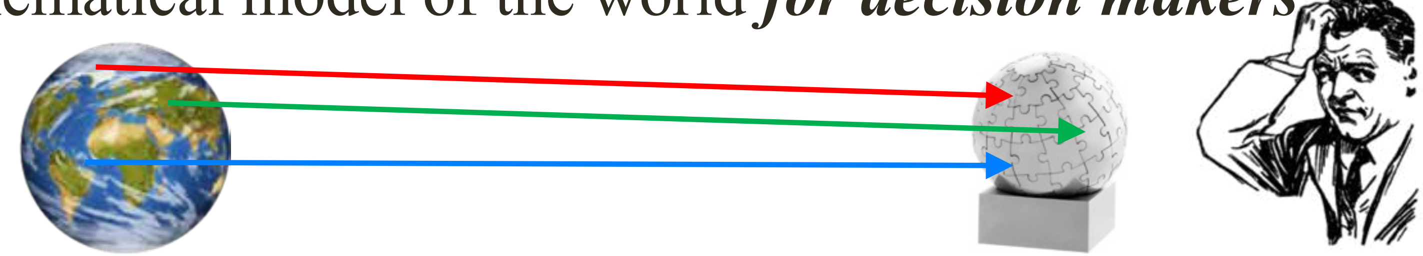
- ***Sensors are constrained*** in measurement, computation, and/or data space
  - Cannot sense from all directions and all sources at the same time
- Different informations have ***different mission values***
  - Cannot satisfy all missions at the same time, but can maximize mission value
- Individual sensors can provide ***different observation functions*** which yield ***different information***
  - Need to tradeoff among accuracy, timeliness, likelihood, and mission value of measurements
- ***No single sensor has global understanding*** of the situation nor the value of its observation
- Need to produce a ***minimum uncertainty, mission goal valued, integrated world model*** from which to make operational decisions

Sensor Management *vs* Sensor Scheduling

- Sensor ***scheduler***
  - Determines the ***best sequencing of measurements*** within the constraints of sensor and platform capabilities once it has been decided which entities to observe
- Sensor ***manager***
  - Determines ***which*** observations to make in order to ***best meet mission objectives*** and ***minimize valued uncertainty*** in our world model
  - Distribute information requests among heterogeneous sensors
  - Use sensors based on the "big picture" which is unknowable by any single sensor

View Sensors as Constrained Communications Channels

- ***Shannon*** considered maximizing the flow of information through a communications channel ***without regard to content*** based on signal-to-noise (SNR) and bandwidth
- IBSM assumes a sensor (communications channel) is performing at its best (in the Shannon sense) and the issue is ***which data to transfer*** from the ***environment*** in order to improve the ***situation assessment*** of the world
- The objective of ***sensor management*** is to maximize the probability of transferring ***mission valued information*** in a ***timely manner*** from the ***real, cyber, or social*** world into the mathematical model of the world ***for decision makers***



Sensor Information

- ***Sensor information*** is a change in uncertainty of a target parameter which results from the ***measurement of a target observable*** of an entity or an environment
  - **Physical**, *e.g.*, kinematic state, existence, identity
  - **Cyber & SCADA**, *e.g.,* DOS, intrusion
  - **Social**, *e.g.*, group membership, size, relationship
- Sensor information enables the choice of the best sensor ***function*** to satisfy an information request
- Sensor information does not infer a target's motivation or intention, *i.e.,* it measures ***what is, not why it is***
  - Sensor information is agnostic about why it is needed
  - Sensor information does not do situation awareness but enables acquiring the best data for situation assessment

Situation Information

- ***Situation information*** is a change in uncertainty of a situation random variable which derives from acquired sensor data fused with context data, *e.g.*,
  - Malware has been detected in our computer system increasing the probability that our computing resources have been compromised
  - An inbound aircraft has been identified as being hostile increasing the probability that we are going to be attacked
  - The population of a local food market has been observed to be lower than the context would suggest indicating the probability of a terrorist attack is increased
- Situation information enables the selection of the ***best next information request*** which will minimize our uncertainty about the situation ***based on our context*** without regard to how to get that information

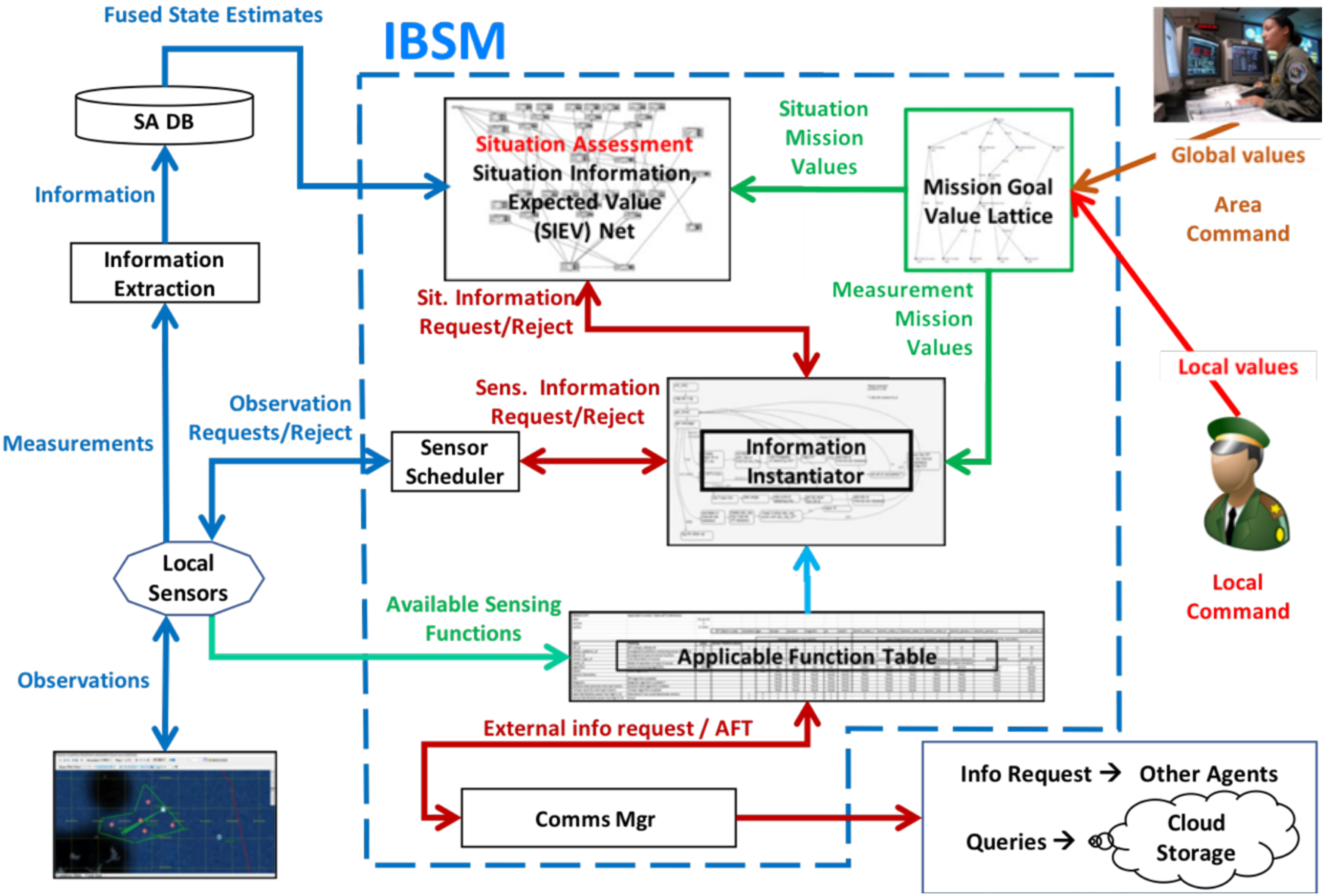
Expected Information Value Rate

The best usage of a sensor is to maximize the probability of obtaining the most valued information in the shortest length of time, *i.e.*, ***EIVR***

- ***Expected*** (probability): Probability of obtaining the information which depends on sensor type, range, SNR, clutter, *etc*.
- ***Information***: The amount of situation or sensor information which can be obtained is predictable, *e.g.*, norm of the error covariance matrix in a Kalman filter state estimator, Bayes net
- ***Value***: Mission value of both situation information and sensor information can be computed, *e.g.,* utilizing a mission goal lattice
- ***Rate***: the inverse of the time it will take to obtain the information, *e.g.*, revisit time, dwell time, change orbit time

$$EIVR = max\left[\sum_{\text{all targets}} E\left\{ \frac{d\left(IV\right)}{dt} \right\} \right]$$

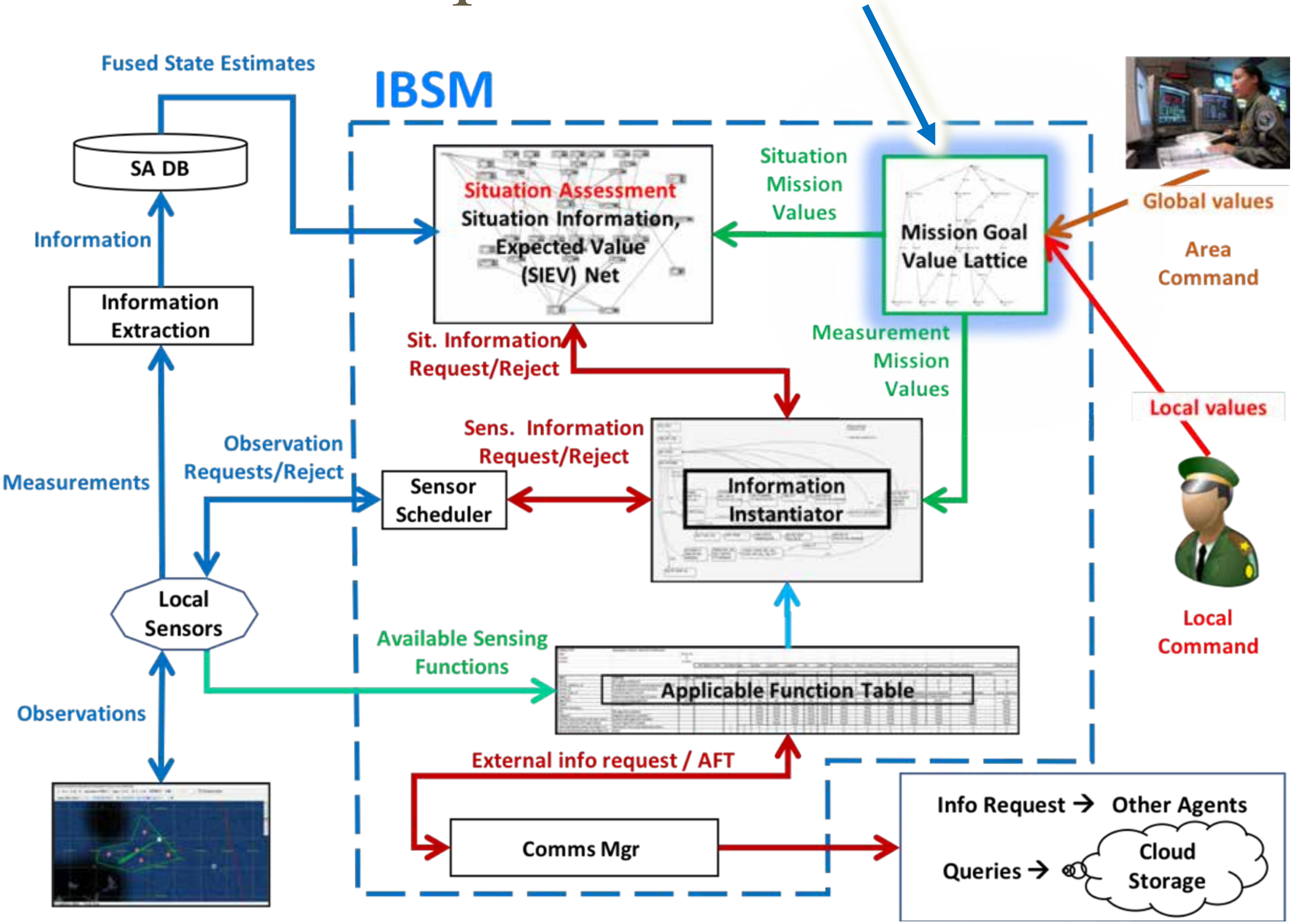
IBSM Components



Six Components

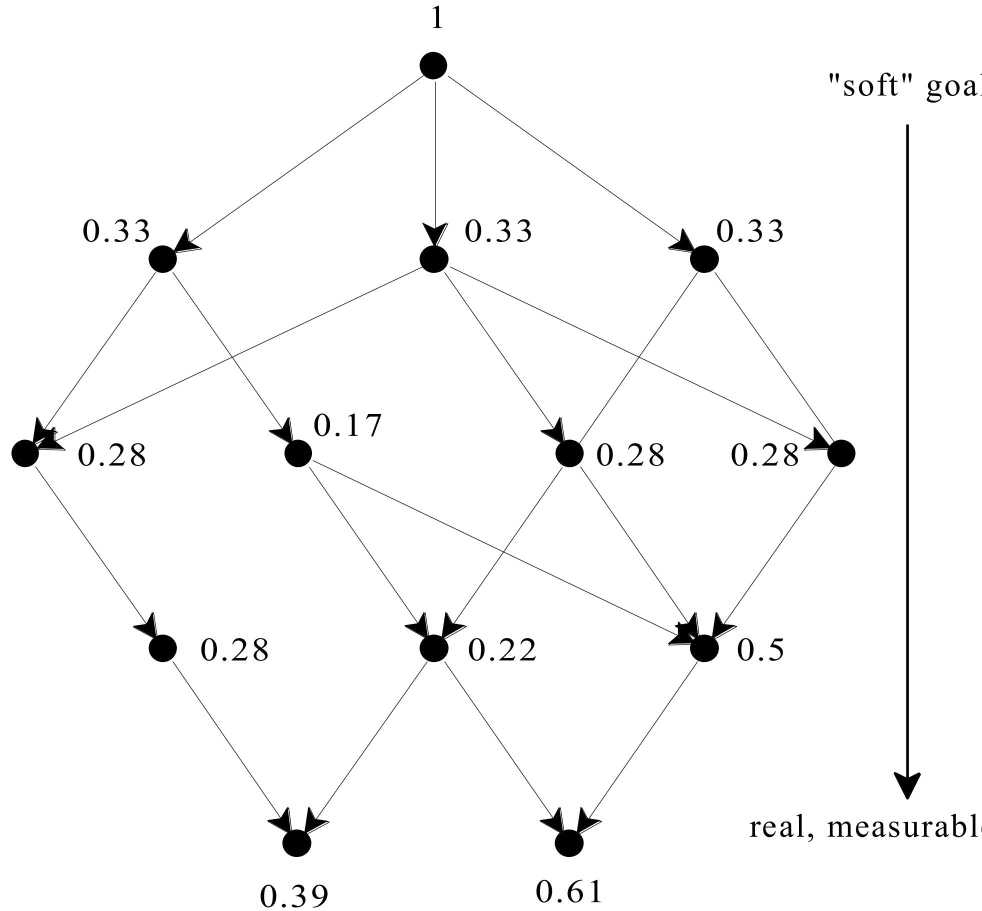
- ***Goal lattice (GL)*** assigns mission values to ***situation information*** needs as well as to alternative sensing functions to satisfy those needs
- **Situation information expected value network *(SIEV-net)*** incorporates contextual information into the situation information needs evaluation through conditional probabilities
- ***Information Instantiator (II)*** utilizes ***sensor information*** to map situation information needs to sensor functions
- ***Applicable Function Table (AFT)*** maintains a dynamic list of available sensor functions for use by information instantiator
- ***Sensor Scheduler (OGUPSA)*** maps ***sensor functions*** to ***sensor observations*** utilizing an on-line, greedy, urgency drive, pre-emptive scheduling algorithm
- ***Communications Manager (CM)*** transmits and receives non-local information requests

IBSM Component: *Goal Lattice*



Goal Lattice Methodology

- Lattice
  - Set
  - Ordering relation
- Goal Lattice
  - Assign relative goal values
  - Apportion to below
  - Accrue from above

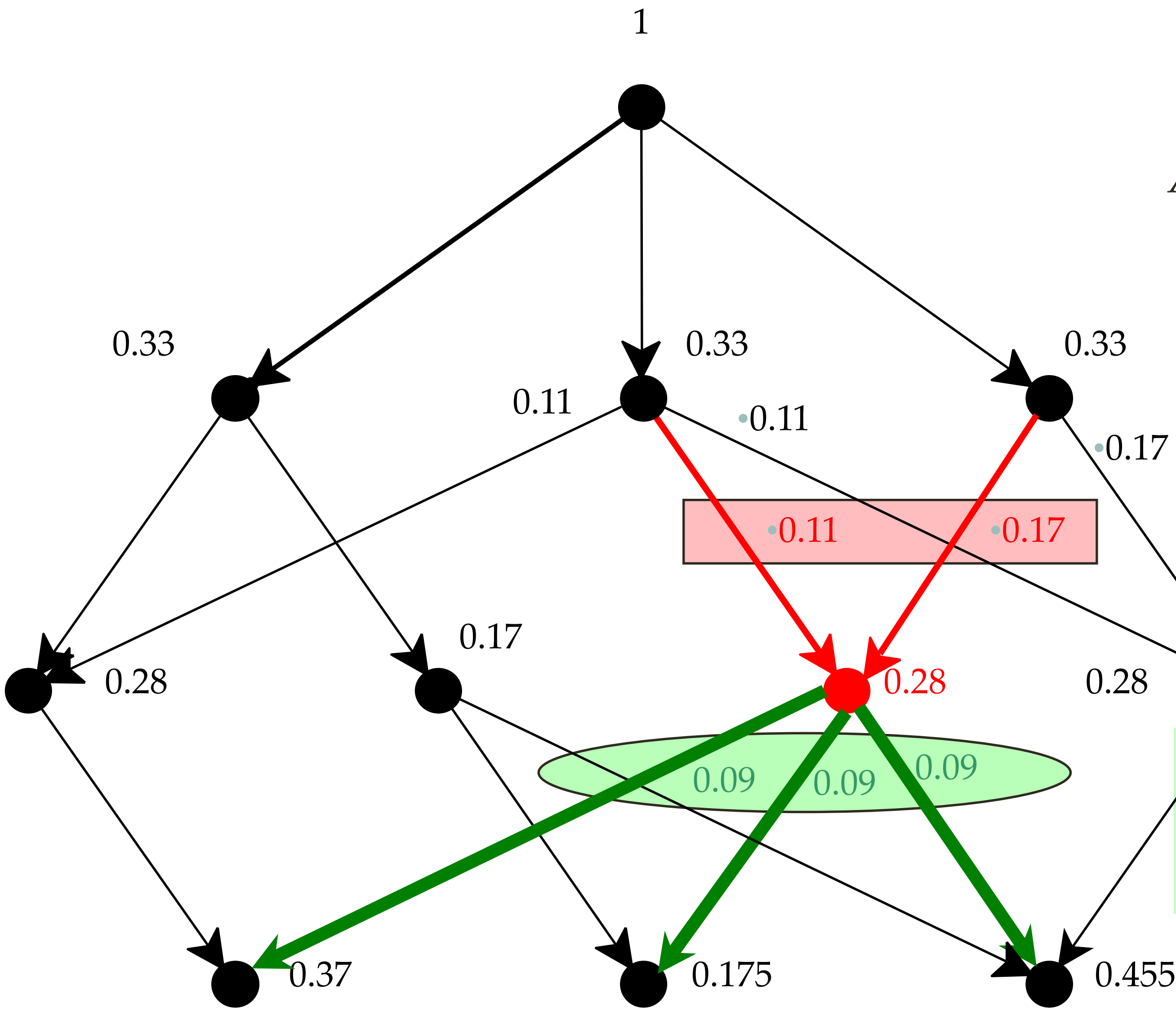


a) Uniformly apportioned values

Goal Lattice Apportions Mission Value Among Sensor Actions

- The mission goals are treated as a set, and an ordering relation is applied to that set leading to a partially ordered set (POSET)
- Ordering relation for our purposes
  - "Is necessary for the accomplishment of"
- Adjoined to the lattice at each goal is a value
  - Goal Value ***accrues from the (higher) goals*** in which it is included, and,
  - Goal Value is ***apportioned among the (lower) goals*** which it includes
- Goals on ***top*** of GL are ***soft, difficult to define mission goals***
- Goals on ***bottom*** of GL are ***real, measurable, mission-valued sensor actions***

Goal Lattice Numerical Example



e.g., EQUAL APPORTIONMENT

ACCRUAL from higher
(including goals)

APPORTIONMENT among lower
(included goals)

Mission-Based GL Example

Topmost goal values used by ***SIEV-Net***

Protect Self

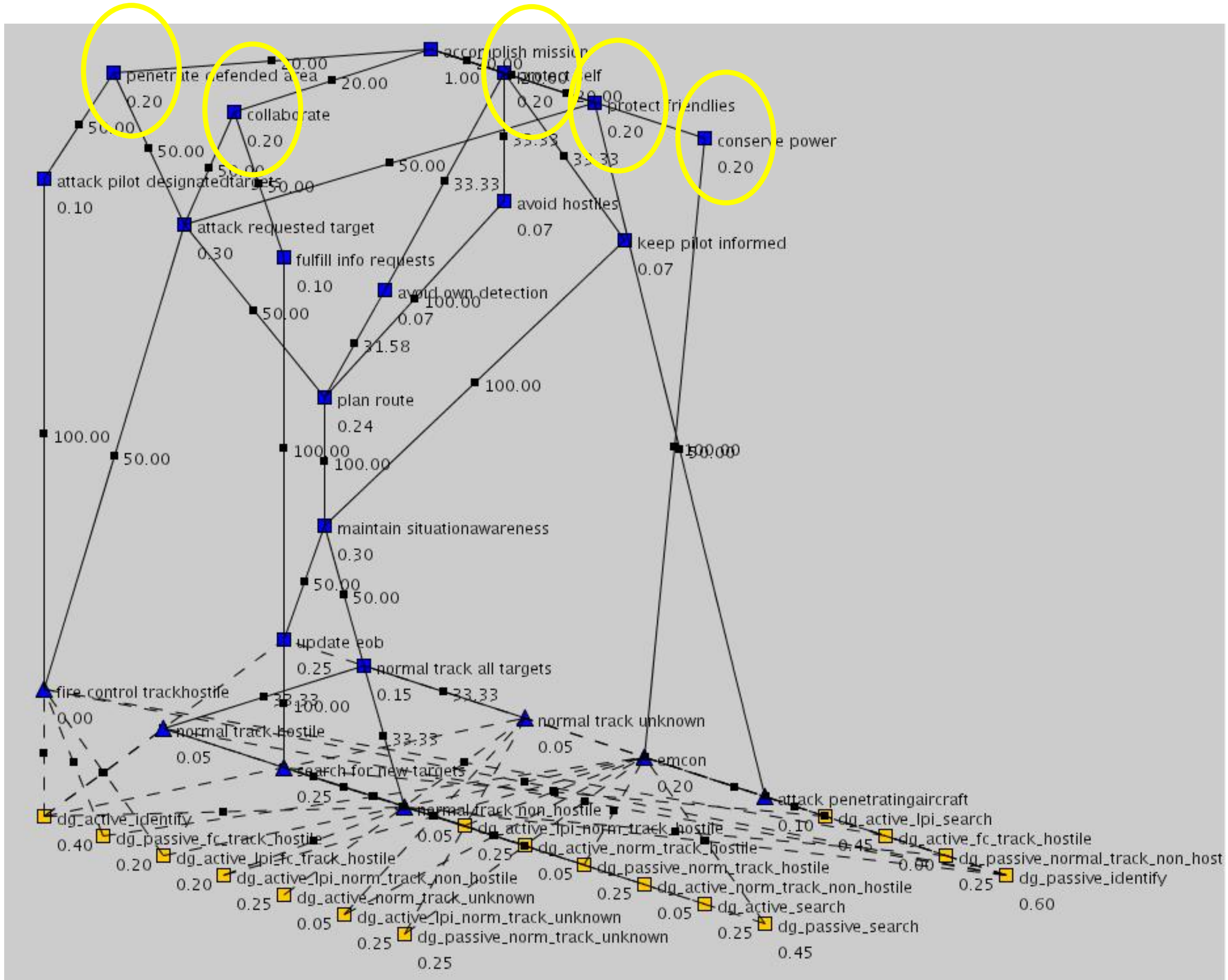
Protect Friendlies

Conserve Power

Penetrate Defended Area

Collaborate

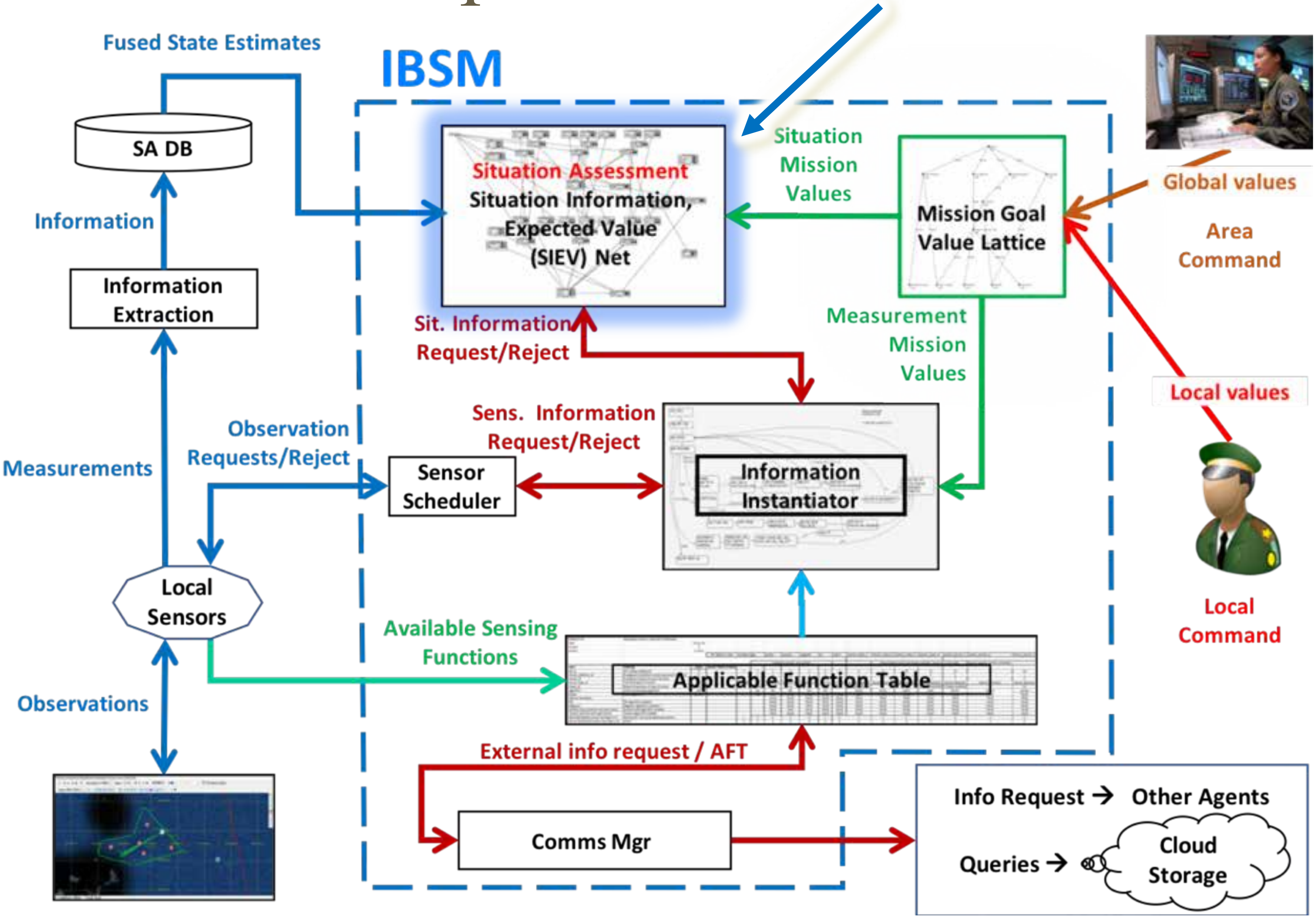
Bottommost goal values used by ***Information Instantiator***



Goal Lattice Creation

- Web client is used by mission planner to ***create and modify goal lattice structure and values***
  - Enter and edit goals
  - Specify relations among goals
  - Goal Lattice Engine (GLE) is a background process which
    - Insures lattice integrity
    - Automatically creates missing goals (pseudo-goals) if required to form a lattice
    - Computes goal values
- ***Dynamic goals are instantiated/uninstantiated in real-time***
    - Diversity of sensors
    - Multiplicity of sensor modes
    - Inclusion of EMCON and power management in static GL
    - Intermittent availability of on-board and off-board sensors
    - Graceful degradation

IBSM Component: *SIEV-net*



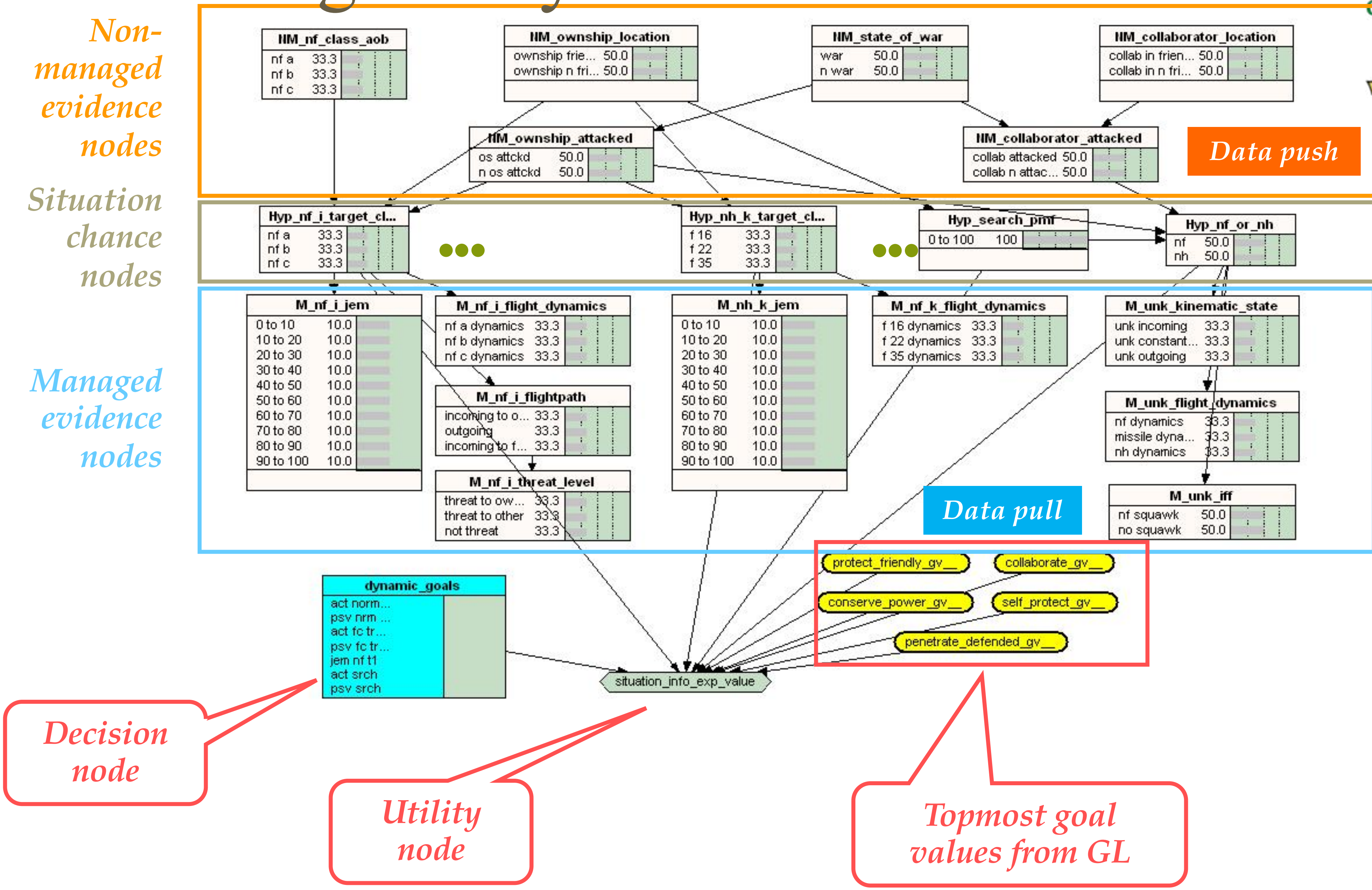
Situation Information

- The purpose of a sensor system is to gather ***mission-valued information*** in order to infer the intent or future state of cooperative, neutral, and uncooperative processes
- ***Situation assessment*** is crucial to the IBSM paradigm since it allows us to decide ***what information we need*** while ***not (yet) deciding how to obtain that information***
- An extension of ***Bayes net*** can be used for situation assessment
  - ***Information gain*** of a Bayes Net is computable
  - The effect of obtaining different types of information on global situation assessment ***can be computed a priori***
- …therefore, a computation on a Bayes net formulation can be ***used to decide what information would maximally reduce our uncertainty*** about a situation and hence, allows us to determine what information to acquire ***without concern for how to obtain that information***

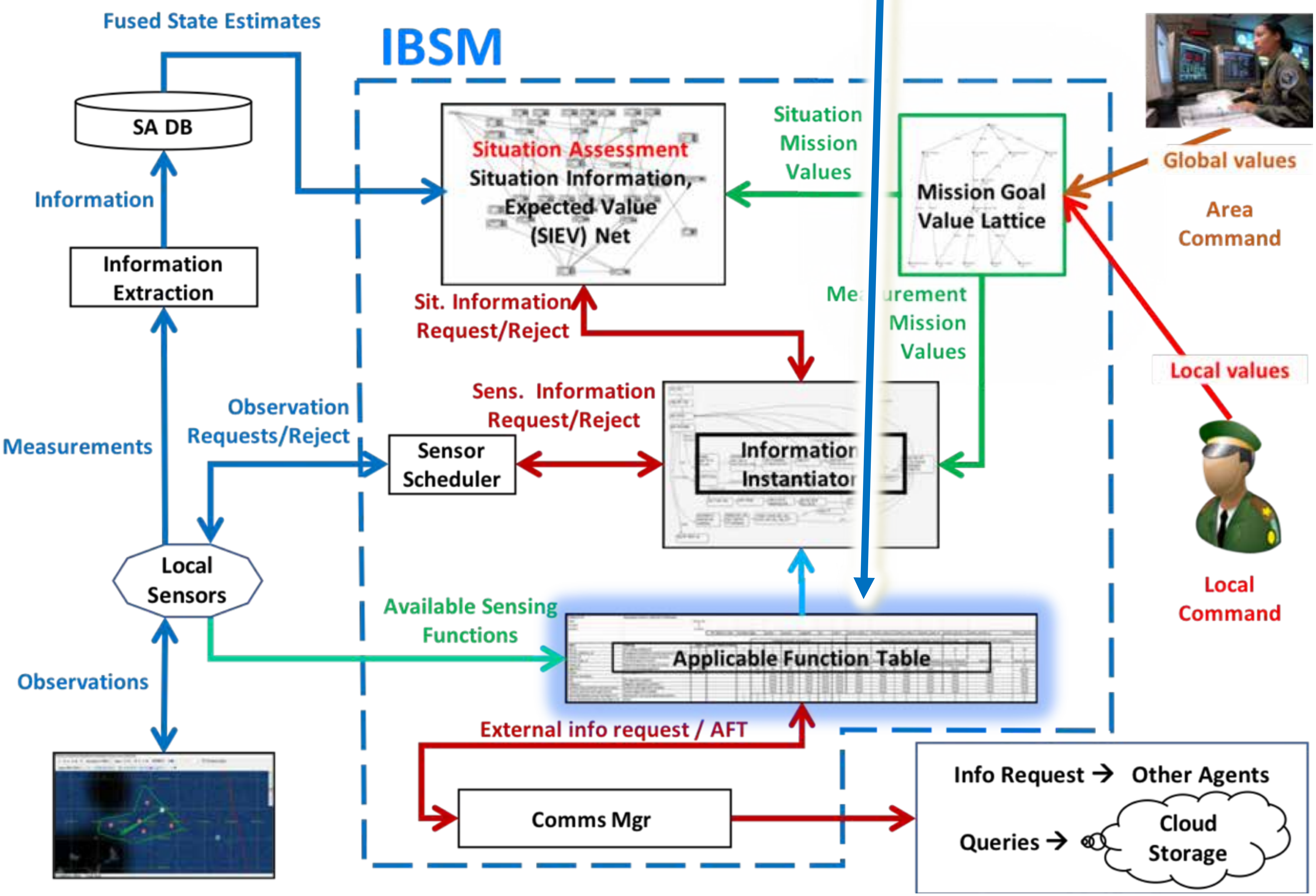
Context is Introduced into IBSM via Unmanaged and Situation Nodes

- SIEV-net contains
  - ***Unmanaged evidence nodes*** which are non-local information sources which provide context
  - ***Situation chance nodes*** which are the conditional probability related to events (situations) in our environment based on context
  - ***Managed evidence nodes*** are context sensitive local sensing functions which are under control of the sensor manager with which it is able to acquire situation information
- SIEV-net is a ***temporal, object orient Bayes Net*** (OOBN)
  - Newly detected targets are instantiated as new situation chance nodes, thereby changing the context through their inter-related conditional probabilities
- SIEV-net is ***contextual***
  - ***Unmanaged evidence nodes provide global context*** info as conditioning probabilities
  - Newly instantiated ***situation chance nodes provide local context***

Example SIEV-Net Instantiated Utilizing Norsys Netica



IBSM Component: *App. Function T.*



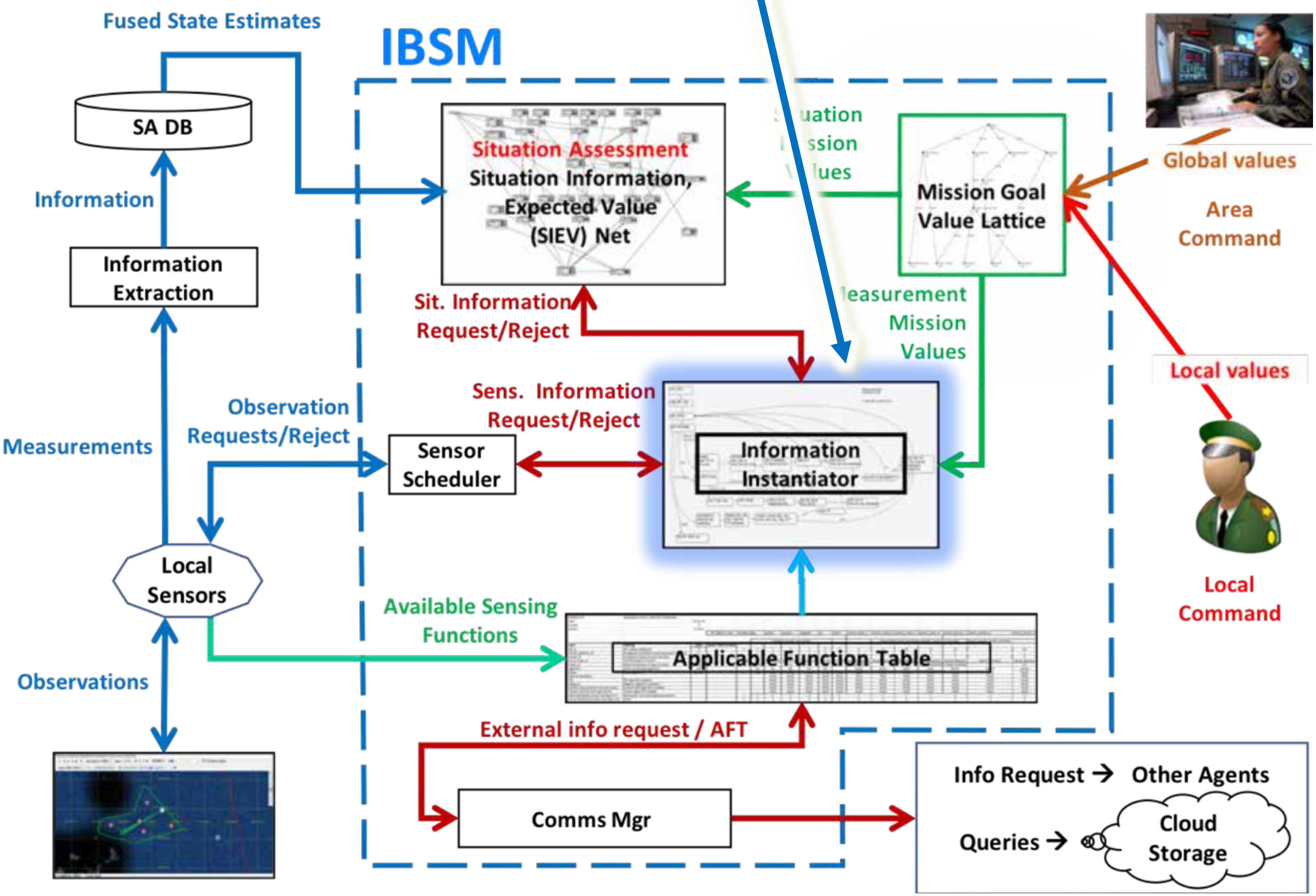
Applicable (Sensor) Function Table

- When sensors become available to IBSM, they announce themselves and populate the AFT with functions they can perform and their associated parameters
  - A "bus", *e.g.,* a UAV, can fly with different sensors on different missions ***without a change in sensor manager***
  - Some sensors (other sensor platforms) become available during a mission based on communications from other sensing platforms
- The ***AFT is dynamic*** and allows for graceful degradation of sensor system as well as ***real-time addition of external sensors*** via communications channel

Sensor Functions *vs* Sensor Observations

- The ***information instantiator*** needs to decide which ***sensor function*** produces the maximum ***sensor EIVR*** without regard to which actual sensor performs that function or how it does it
- ***Sensor scheduling*** of actual observations is done separately
- Sensors have capabilities which are defined by their ***operating modes or functions***
  - A sensor may be capable of performing more than one function
  - More than one sensor may be capable of performing the same function
- Each sensor function is a separate entry in AFT
  - More than one sensor may map to a single AFT entry
- Local or remote sensors ***add/remove capabilities*** from AFT as they become available, unavailable, degraded, or enhanced

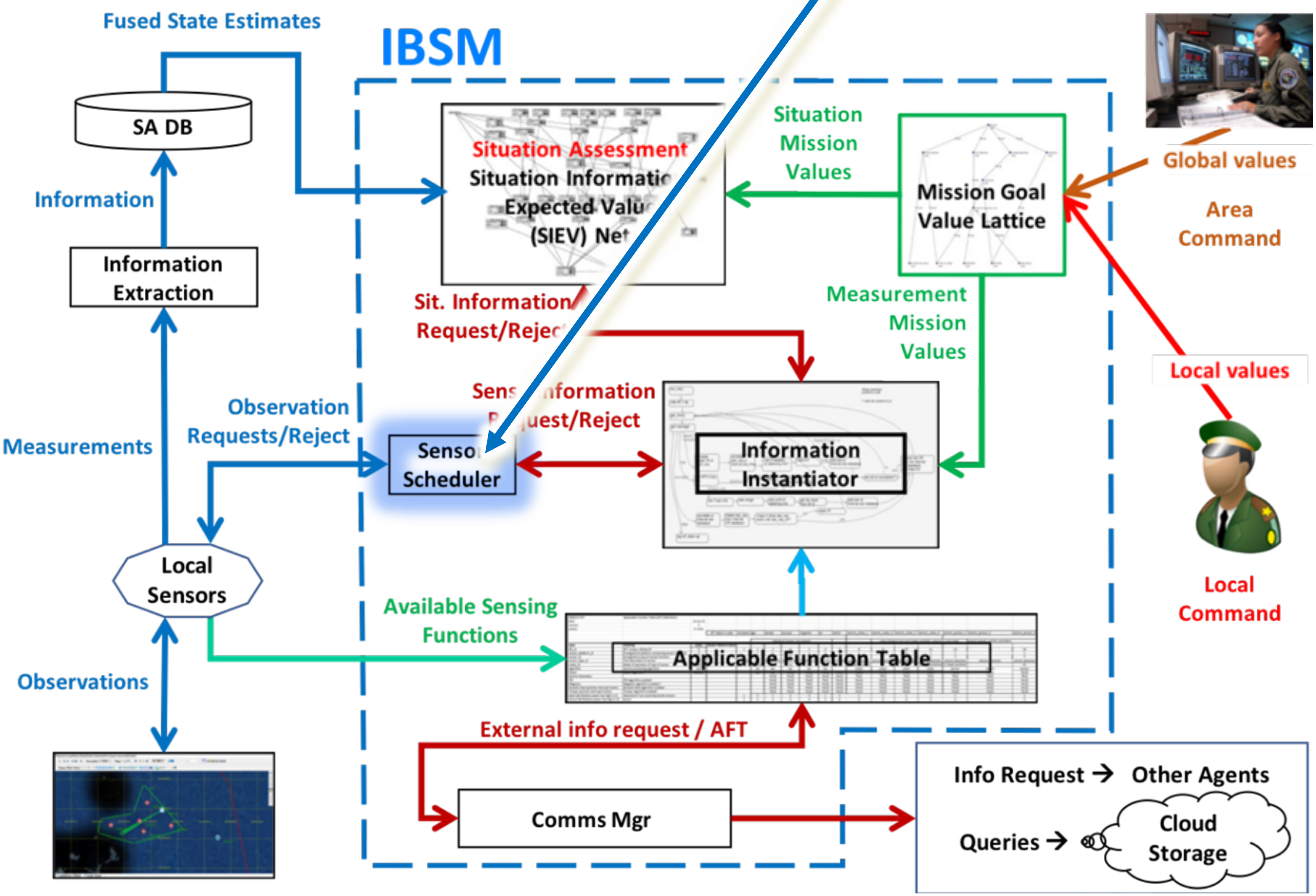
IBSM Component: *Info Instantiator*



Information Instantiator

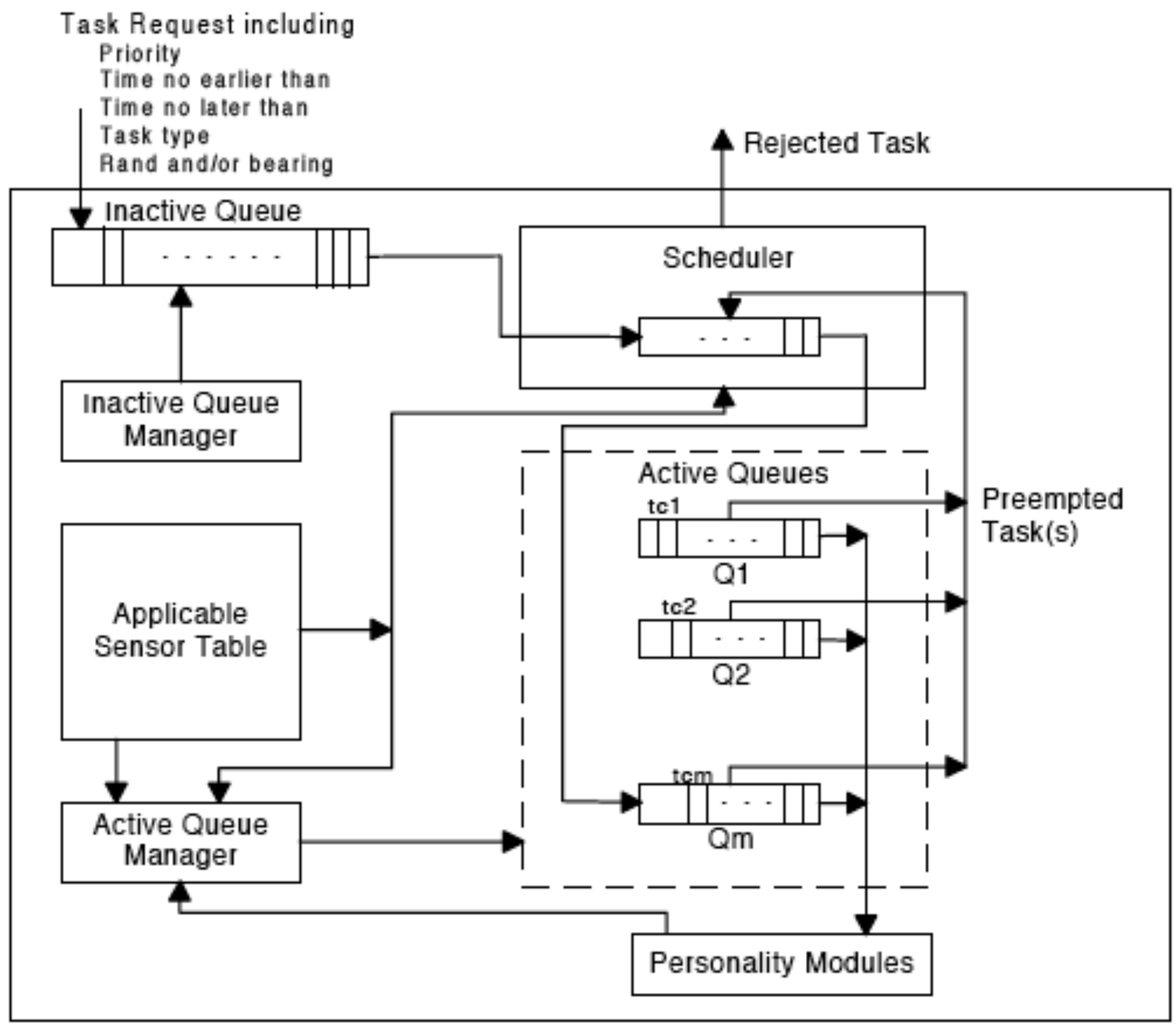
- ***Converts information request*** (sensor is not specified) from SIEV-net into an ***observation request*** (sensor still not specified)
- ***Downselects*** from the Applicable Function Table (AFT) to a set of ***admissible functions*** (AF)
- ***Computes sensor EIVR*** of each admissible function
- ***Chooses observation requests*** (OR) with greatest Expected Information Value Rate (***EIVR***)
- Passes ***observation requests*** to the on-line, greedy, urgency driven, preemptive sensor scheduling algorithm (OGUPSA)

IBSM Component: *Sensor Sched.*

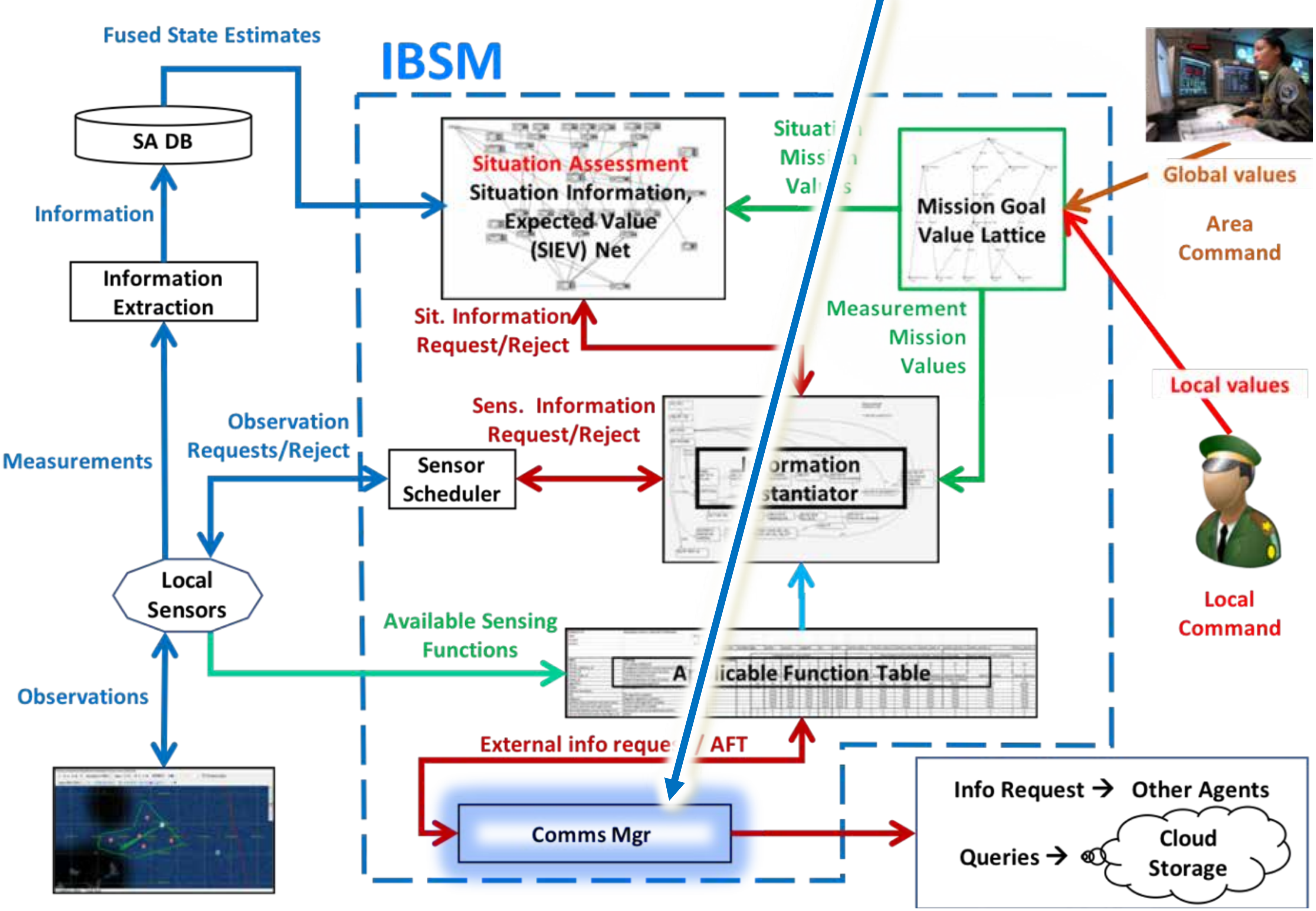


OGUPSA

- **O**n-line
- **G**reedy
- **U**rgency Driven
- **P**re-emptive
- **S**cheduling **A**lgorithm



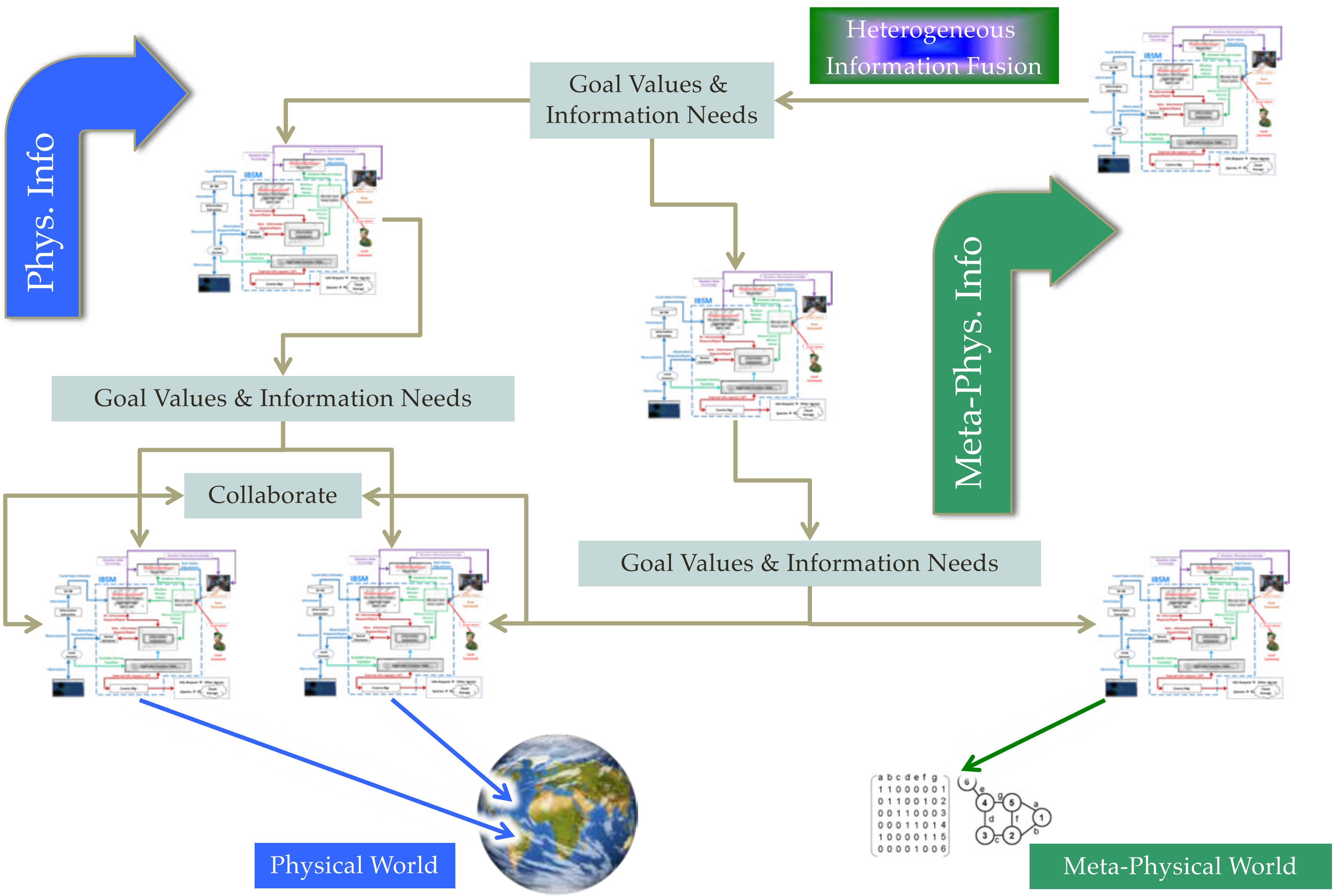
IBSM Component: *Comms. Mgr.*



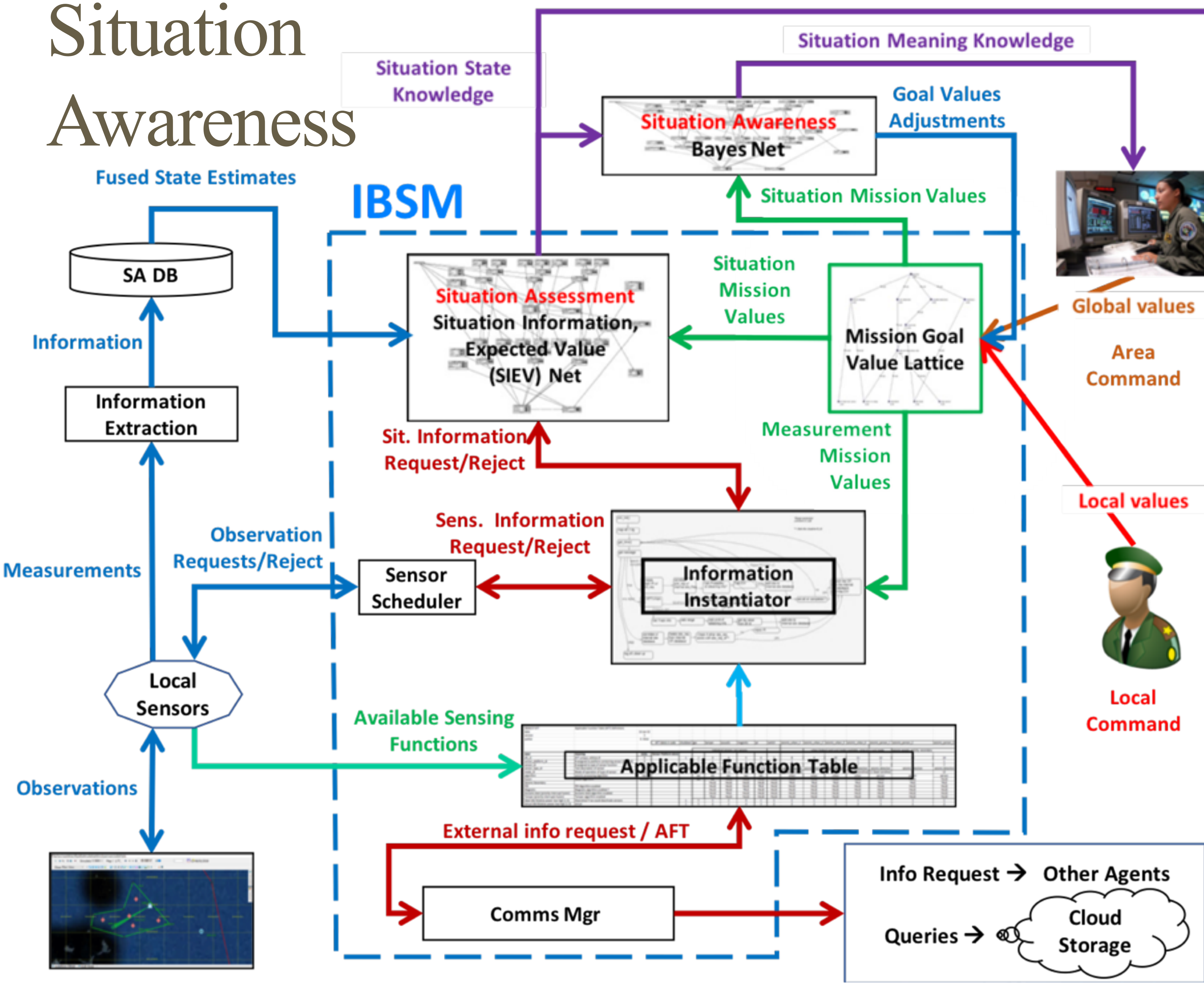
Communications Manager

- Allows for sending/receiving ***information requests*** to/from collaborating and friendly platforms, and cloud services
- Allows for sending/receiving ***AFT entries*** to/from collaborating and friendly platforms
- Allows for ***receiving shared goals*** from higher authority
- Allows for ***transmitting actual operating goal values*** of shared goals to higher authority
- Allows acquiring data to update unmanaged evidence nodes

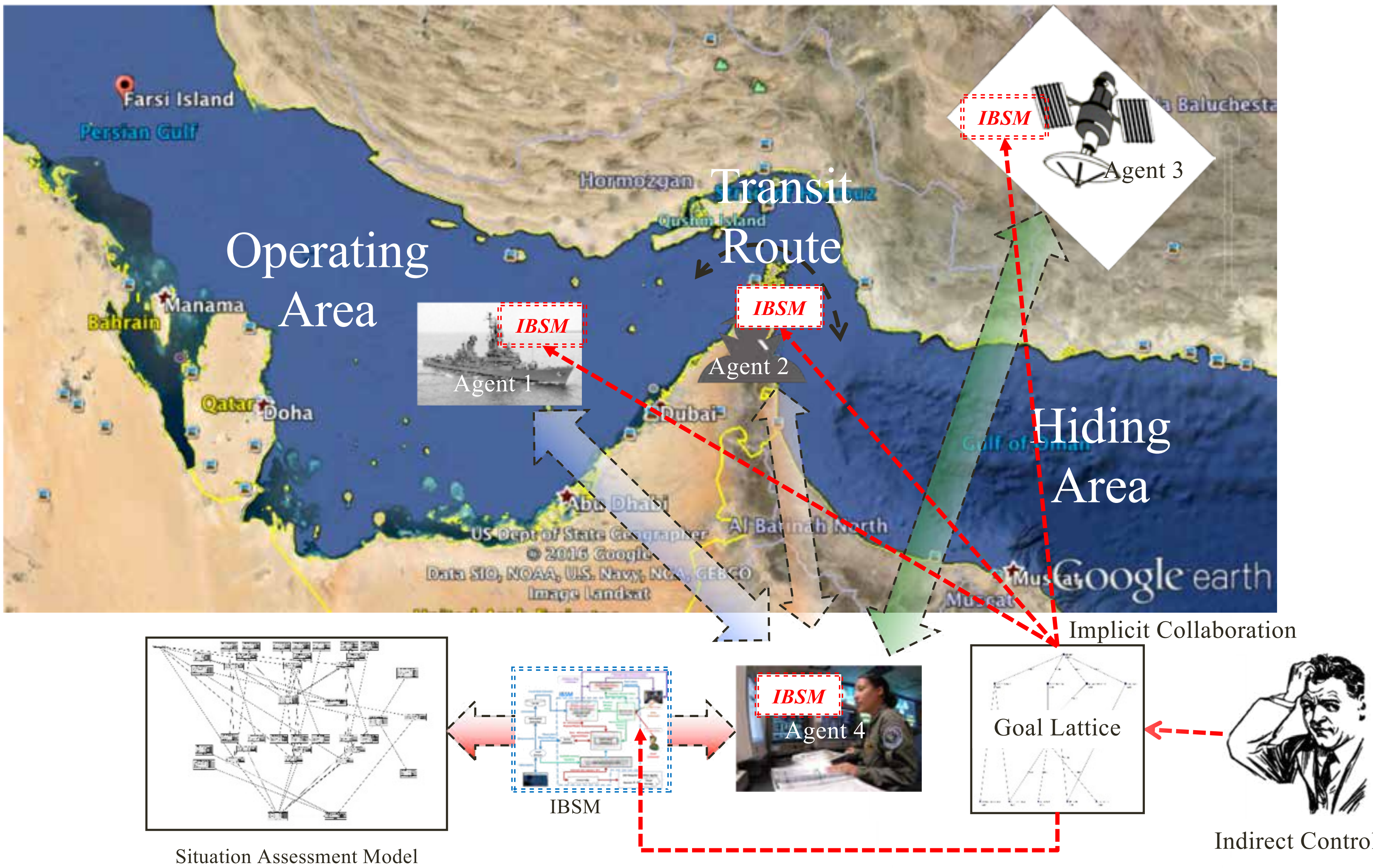
Networked IBSM, Hard/Soft Fusion



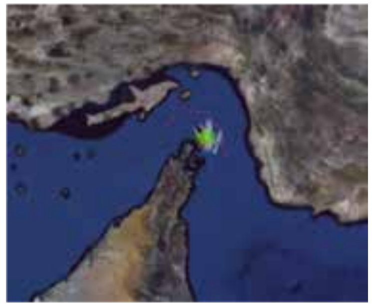
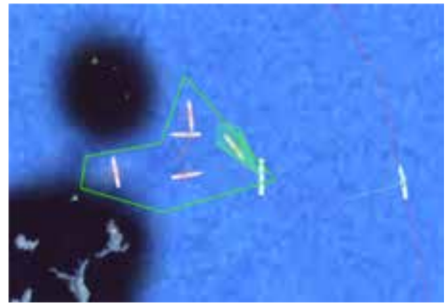
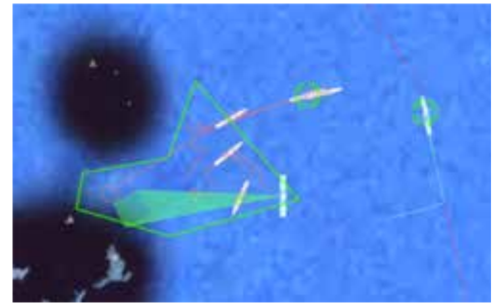
Situation Awareness



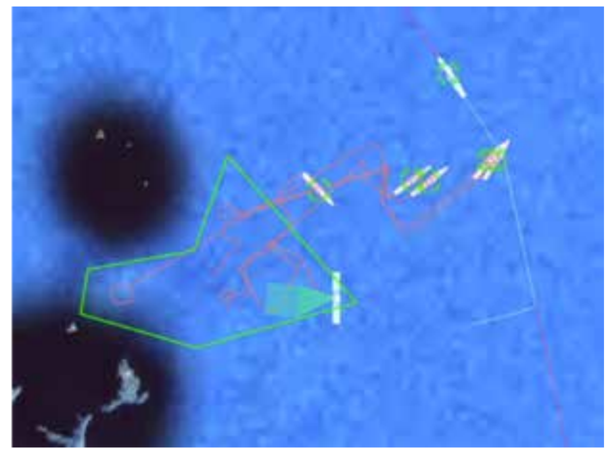
Reification of the Notional Spatial Model

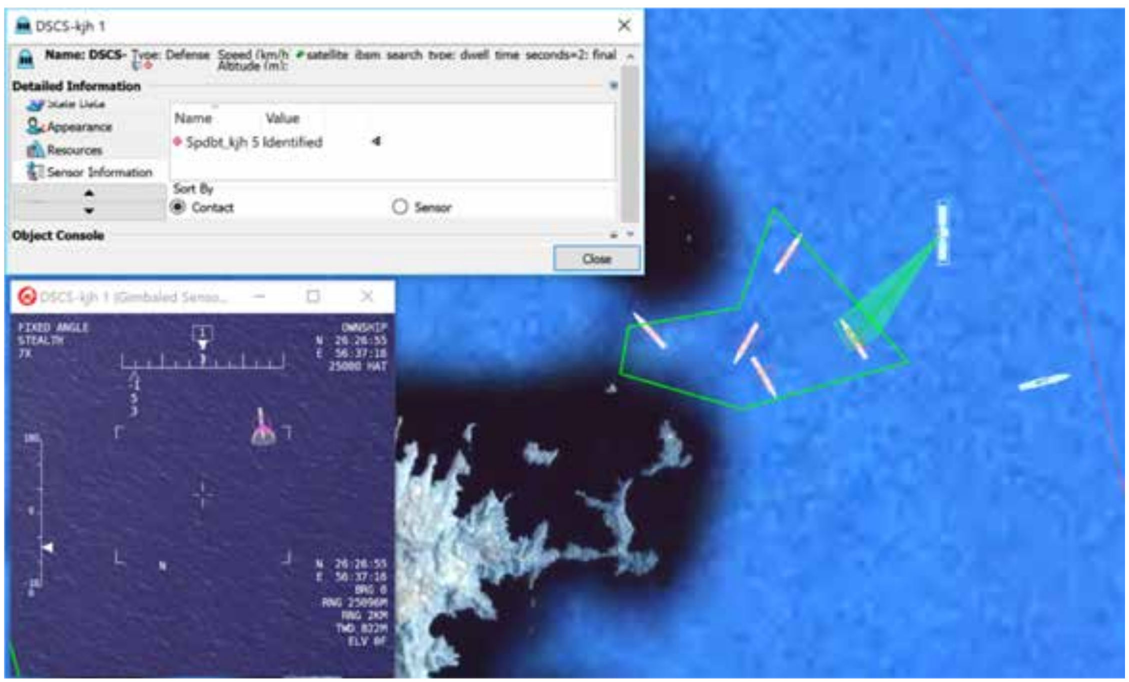


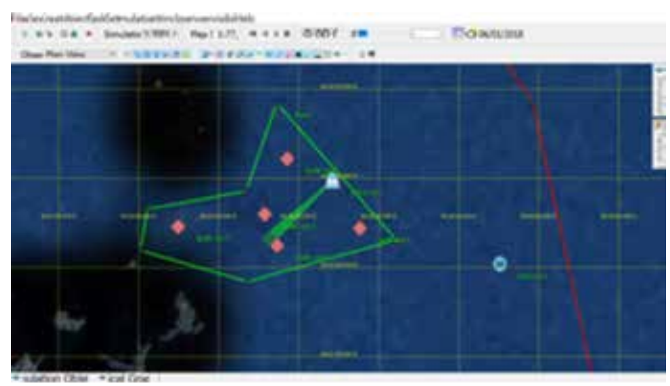
St. of Hormuz Scenario, Overhead Surveillance, simulated in MAK, VR Forces

Speedboats random movement in area converting to attacking transiting DDG







IBSM Is a ***Satisficing Solution*** To Multiplatform Heterogeneous Real-Time Sensor & Mission Management

- ***Real-time, scalable, collaborative system*** from individual platform sensor management to management of battlespace reconnaissance assets
- Based on ***maximizing expected information value rate (EIVR)*** to ***minimize uncertainty*** in the ***world model*** while ***maximizing mission value***
- Provides the ***highest valued, lowest uncertainty, context sensitive, situation assessment*** from which to make command decisions
- ***Closed loop, indirect, and context sensitive*** control through the use of interacting, mission oriented goal lattice

GEORGE MASON UNIVERSITY

C4I & CYBER CENTER

NPS

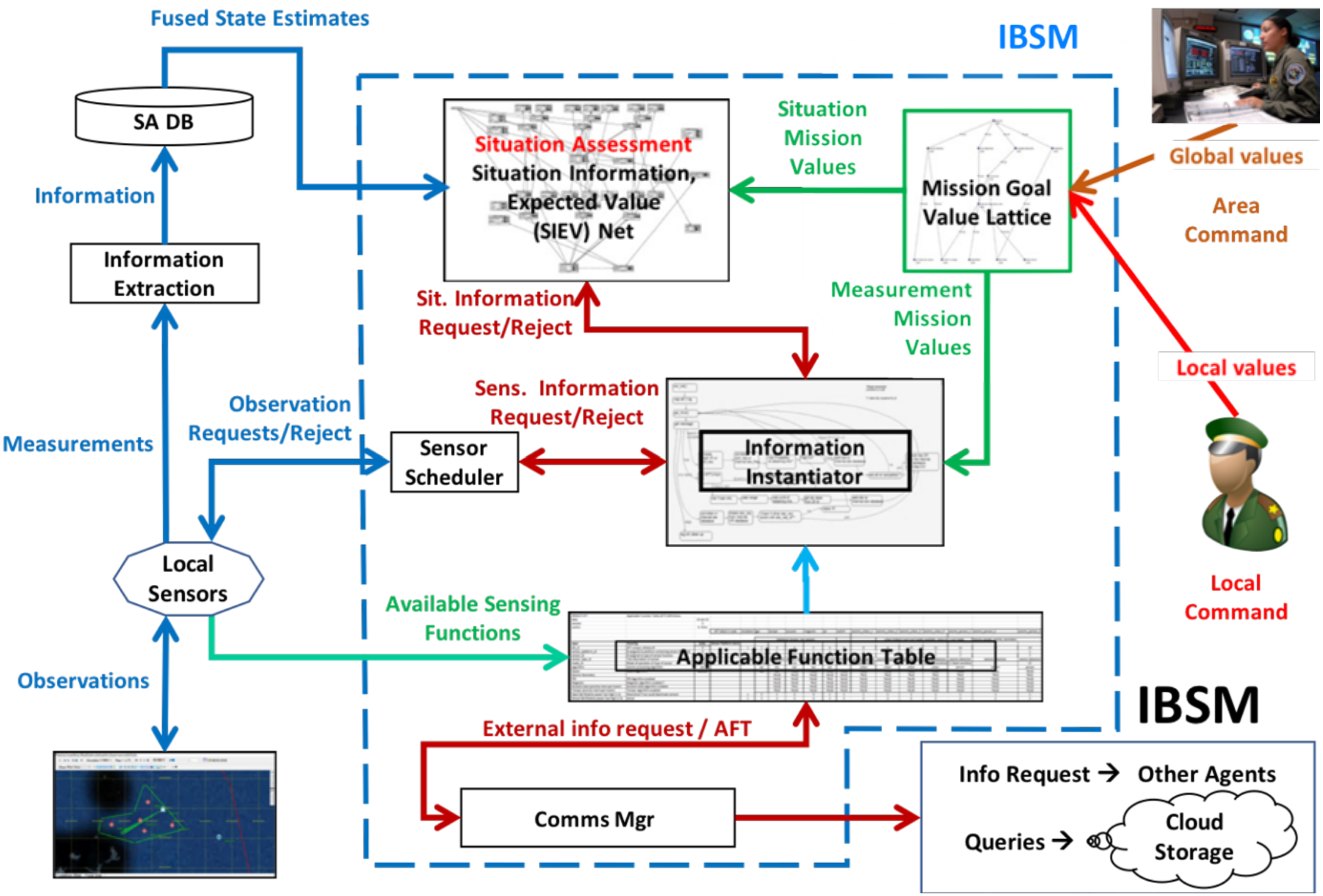
IBSM Is a ***Satisficing Solution*** To Multiplatform Heterogeneous Real-Time Sensor & Mission Management

- ***Dynamically reconfigurable*** through use of ***applicable*** (sensor) ***function table***
- ***Information instantiator*** allows for ***one sensor management model*** to be the framework for multiple platforms and hierarchical levels of resource management
- Sensors can be added or removed in real-time without redesigning the system which provides for ***graceful degradation and robust behavior in dynamic, stressing environments***
- Autonomous systems behave with ***subservient autonomy***

Research Topics

- ***Recent*** Advances in IBSM
  - ***Implicit Collaboration*** of Intelligent Agents through Shared Goals
  - Cross-Domain ***(hard/soft) Pseudo-Sensors***
  - Cross-Domain Pseudo-Sensor Information Measure
  - ***Information Measure*** of cross-domain, temporal Bayes Net
- ***Current*** NPS grant & Contract
  - Developing SIEV-nets from non-Bayesian Resources

Questions?



Fused State Estimates
IBSM
SA DB
Information
Information Extraction
Measurements
Observation Requests/Reject
Local Sensors
Observations
Situation Assessment
Situation Information, Expected Value (SIEV) Net
Situation Mission Values
Mission Goal Value Lattice
Global values
Area Command
Local values
Local Command
Sit. Information Request/Reject
Measurement Mission Values
Sens. Information Request/Reject
Sensor Scheduler
Information Instantiator
Available Sensing Functions
Applicable Function Table
External info request / AFT
Comms Mgr
IBSM
Info Request → Other Agents
Queries →
Cloud Storage