The PRISM Intelligent System

Sudha Sivashanmugam

ssivasha@ittc.ku.edu

July 01, 2004

PRISM

- Polar Radar for Ice Sheet Measurements
- Developing a set of *mobile, autonomous, intelligent* radar sensors for the measurement and study of the mass balance of the Greenland and Antarctic ice sheets.
- Involves research in
  - Radars and Remote Sensing
  - Mobile Robotics
  - Intelligent Systems
  - Communication Systems

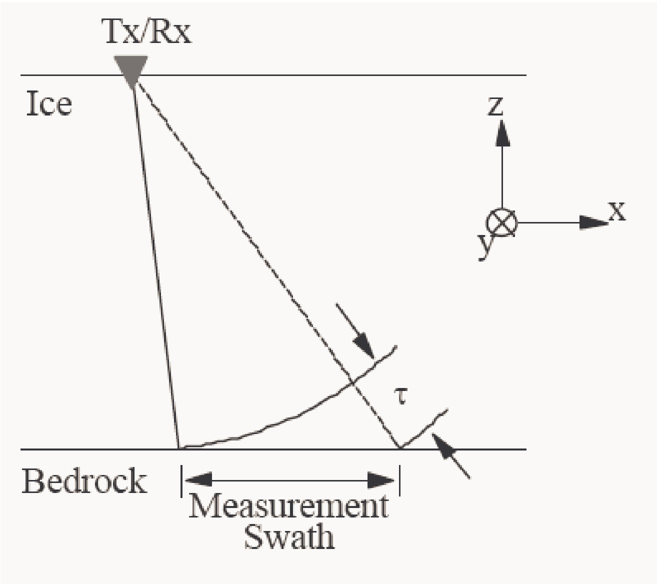
PRISM Radar Sensors

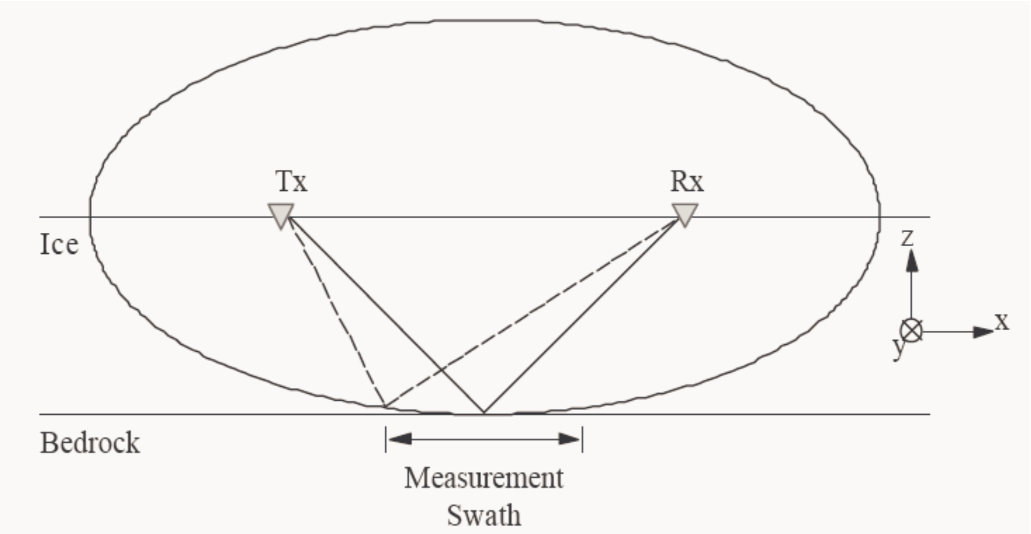
- Synthetic Aperture Radar (SAR)
  - Generates 2-D reflectivity maps of the bed for determining basal conditions including the presence and distribution of basal water
- Wideband Dual-mode Radar
  - Radar Depth Sounder
    - Measures ice thickness and maps deep internal layers
  - Accumulation Radar
    - Maps near surface internal layers

SAR

- Two operation modes
  - Monostatic Vs. Bistatic (M/B)
- Three operation frequencies
  - 60, 150 and 350 MHz

Monostatic Vs. Bistatic SAR



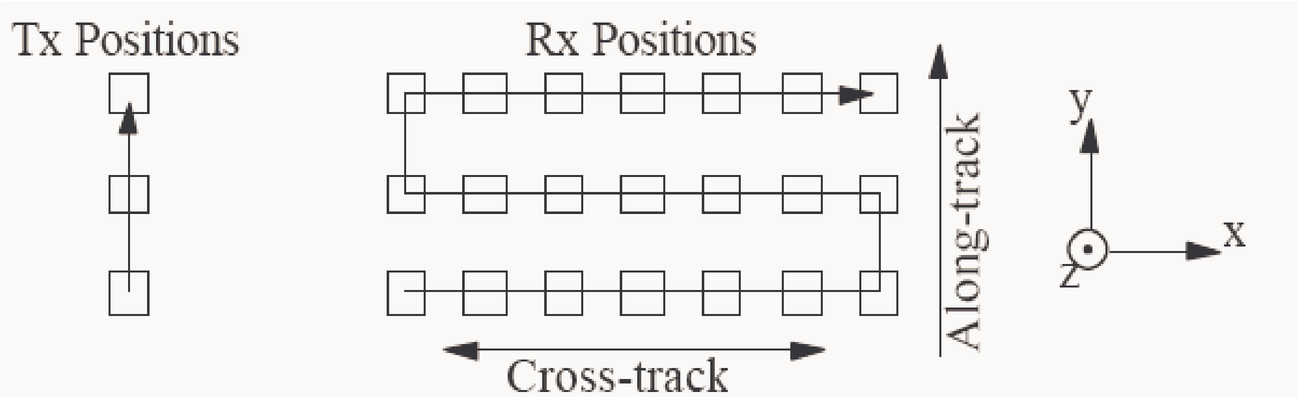


PRISM Rovers

- Manned vehicle
  - Hosts the SAR transmitter, the monostatic SAR receiver and one dual-mode radar
- Autonomous robotic vehicle (“rover”)
  - Hosts the bistatic SAR receiver and another dual-mode radar
  - Equipped with the necessary power supply, sensory systems (e.g. laser range finder, bump sensor, etc), control and computing devices and outreach equipment (e.g. cameras)

Rover Movement

- Rover moves in nearly straight line paths (along the manned vehicle) during monostatic SAR measurements
- Rover makes cross-track and along-track transects during bistatic SAR measurements



“Onboard” Intelligent System (IS)

- Must allow autonomous and semi-autonomous control of the rover (from the manned vehicle)
- Must dynamically select the “optimum” sensor configuration for imaging the bed.
  - SAR operation mode (monostatic vs. bistatic)
  - SAR operation frequency (a combination of 60, 150 and 350 MHz)
  - Distance of the vehicles from the center of the measurement swath
  - Cross-track/Along-track spacing in bistatic SAR mode
  - Resolution of the SAR image
  - Speed and Scan path of rover

Additional Responsibilities

- Act as an intelligent interface between the radar image-analysis systems and rover to direct and coordinate rover activities
- Must assure overall system integrity – planning and resource scheduling, hazard avoidance, health monitoring and fault tolerance
- Must determine patterns of rover movements relative to the movements of the manned vehicle
- Must maintain precise coordination in the operation of the two radar units on the two vehicles
- Must combine any commands issued by remote human operators with local intelligence

Decision Making

- Complex and real-time
- Analyze and fuse any recently collected sensor data with a priori information (e.g. from satellites like RADARSAT and other imaging data)
- Reason under uncertainty
- Consider multiple criteria
  - Science – What are the potential scientific benefits?
  - Power – Do I have enough fuel?
  - Computing resources – Can I process radar images as fast as I am getting them?
  - Wear and tear – Is this going to kill me?
  - Quality of Judgment – How confident am I in my current picture of the world?

Some Keywords

- Agents
- Multiagent System
- MatchMaking
- Inference Engine

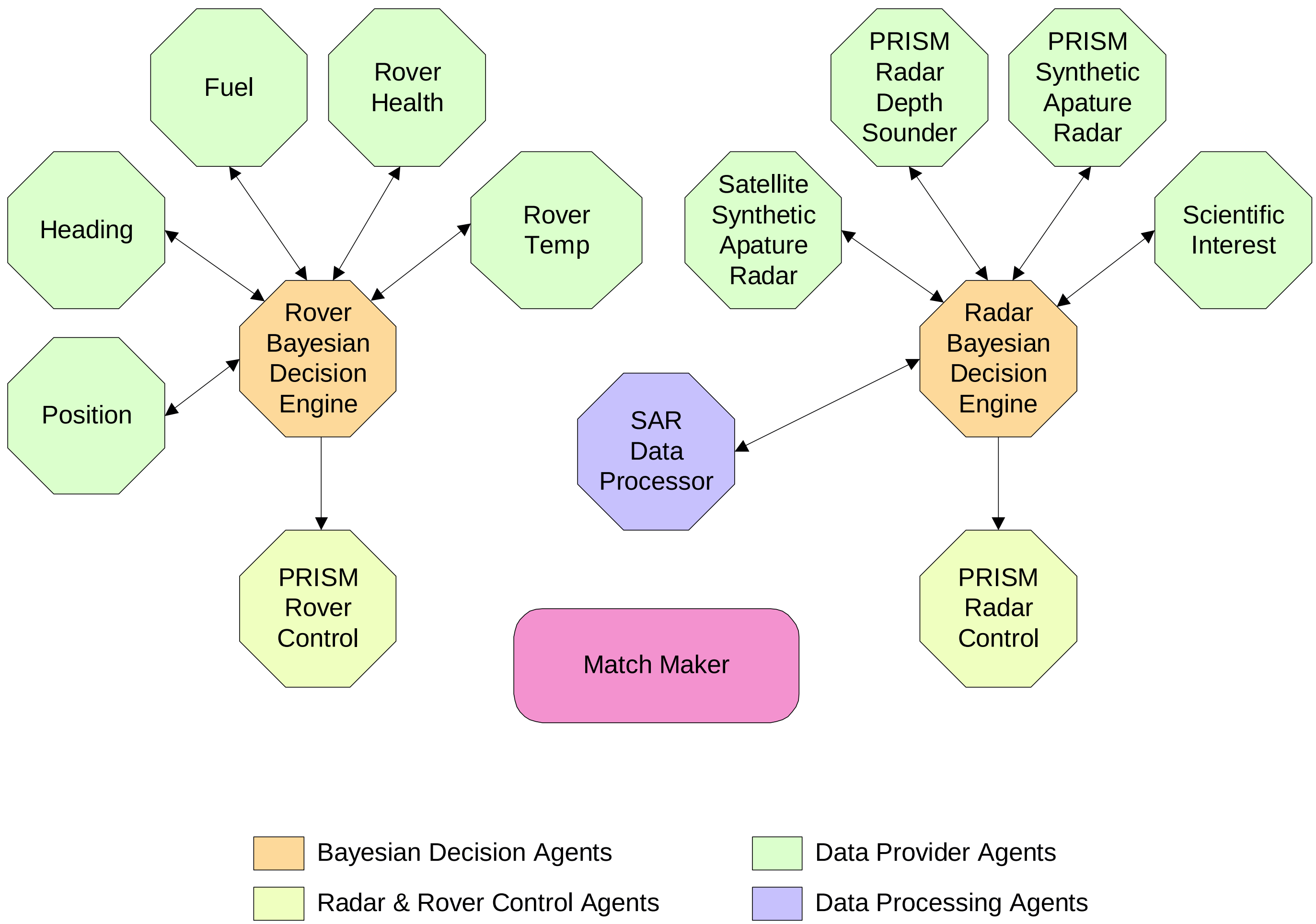
Components of the IS

- Distributed computing framework of agents
  - Multiagent System (MAS)
    - Intelligent collaborative agents
      - Collect, analyze and disseminate real-time data from multiple sources (radar, rover, satellites, etc.)
      - Make radar/rover control decisions
    - MatchMaking service
  - Bayesian Decision Engine (BDE)
    - Probabilistic inference engine
    - Makes decisions based on the axioms of classical probability theory
    - Fuses data from multiple sources based on several criteria
    - Reasons under uncertainty

Multiagent System

- Data provider agents – wrap data sources
- (Bayesian) decision agents – query other agents and formulate decisions that control the rover and radars
- Control agents – set radar parameters and activate rover actuators
- Data processing agents – perform services for other agents
- MatchMaker – a service that allows for dynamic provisioning of information and services within the collaboration

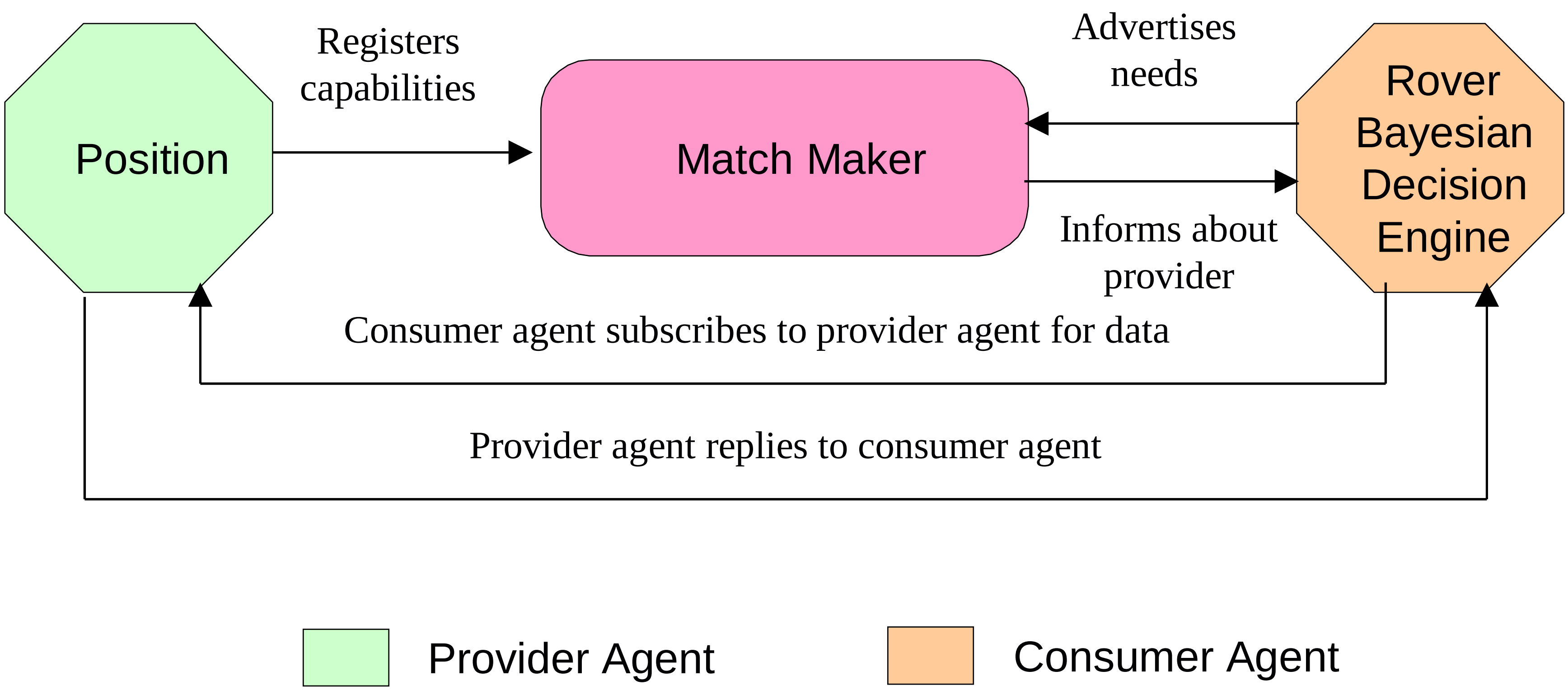
Multiagent System



MatchMaking

- Allows source agents to advertise capabilities and data consumer agents to advertise needs
- Consumers register for data with sources using *time-* or *event-driven subscriptions*
- Dynamic matching of agents capabilities with agent needs allows for flexibility and redundancy in agent collaboration

MatchMaking (contd..,)



Implementation Details

- Agents implemented as remote Java objects
- Agents communicate across Java VMs using RMI
- The system implements common action performatives (inform, request, etc.)
- The system provides for finer-grained control of subscriptions than other Java-based architectures (JADE)
- Agent messaging conforms to FIPA standards (ACL, Communicative Acts, RDF)

Example Messages

Time Driven Subscription:

```
<fipa:Action rdf:ID="temperature_subp_0">
   <fipa:actor>TemperatureAgent</rdf:actor>
      <fipa:act>subscribePeriodic</rdf:act>   <fipa:argument>
   <rdf:seq>
         <rdf:li>temperatureCelcius</rdf:li>
         <rdf:li>2000</rdf:li>
         <rdf:li>20000</rdf:li>
   </rdf:seq>
</fipa:argument> </fipa:Action>
```

Example Messages (contd..,)

Event Driven Subscription:

```
<fipa:Action rdf:ID="temperature_sube_0">
   fipa:actor>TemperatureAgent</rdf:actor>
   <fipa:act>subscribeEvent</rdf:act>
   <fipa:argument>
      <rdf:seq>
      <rdf:li>edu.ku.ittc.prism.intel.agent.rules.Comparator</rdf:li>
      <rdf:li>greaterThan</rdf:li>
      <rdf:li>temperatureCelcius</rdf:li>
      <rdf:li>35.0</rdf:li>
      </rdf:seq>
   </fipa:argument>
</fipa:Action>
```

Example Messages (contd..,)

Data response:

```
<rdf:Description about="temperature_suba_0">
    <fipa:done>true</fipa:done>
    <fipa:result>19.984596</fipa:result>
</rdf:Description>
```

Bayesian Decision Engine

- Models dependencies between decision inputs and outputs as a Bayesian network (BN)
- Codes probabilistic rules of decision making into conditional probabilities

Bayesian Network

- An expert system paradigm
- Used to model a domain containing uncertainty in some manner
- Directed acyclic graph of a set of variables (nodes) and directed edges
- Edges between nodes reflect dependency (cause-effect) relations within the domain
- The strength of an effect is modeled as a probability. Hence to each variable A with parents B1, …, Bn, there is attached the conditional probability table P(A | B1, …, Bn). If A has no parents, then the table reduces to unconditional probabilities P(A).

Bayesian Network (contd..,)

- Used to make probabilistic inferences based on the notion of evidence propagation.
- The mathematical basis is the Bayes theorem:

  $P(A \mid B) = P(B \mid A). P(A) / P(B)$

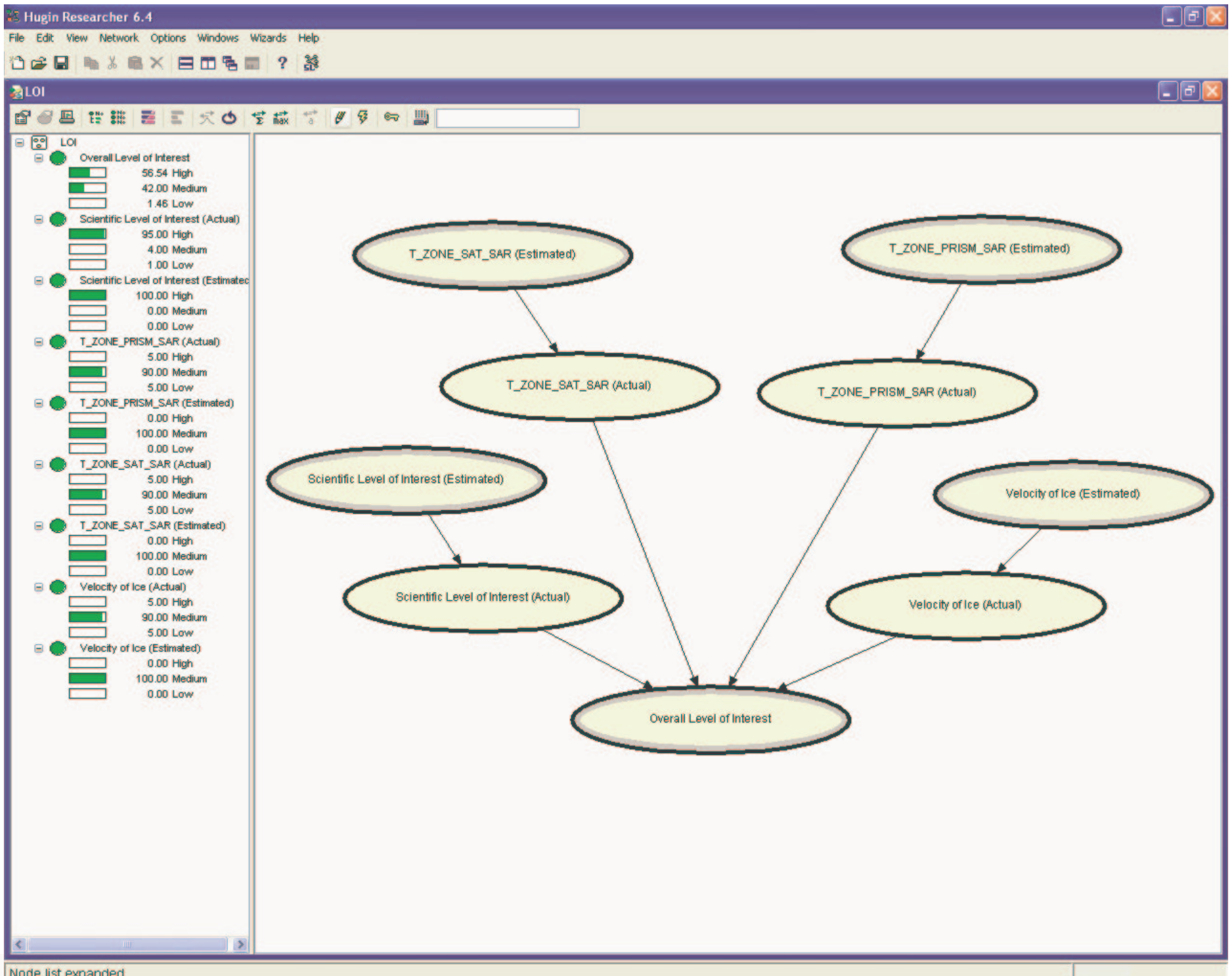
The PRISM BN

- Nodes
  - Parent nodes – decision inputs
  - Leaf nodes – decision outputs
  - Other nodes – intermediate decision parameters
- Links
  - Identify causal-effect relationships between nodes
  - Quantified by the use of conditional probability tables .
  - Conditional probability tables
    - specify prior joint distribution of nodes
    - Serve as means of coding explanation criteria
    - Enable setting preferences over inputs
    - Assign confidence values while combining them

The PRISM BN (contd..,)

- Built upon Hugin
- Bayesian decision agents receive and propagate input evidence in the Bayesian network as follows:
  - Analyze and transform source data into “decision states”
  - Identify the corresponding input node in the network
  - Populate the node’s conditional probability table by setting a value of ‘1’ to the decision state observed and a value of ‘0’ to others.
  - Calls Hugin functions for evidence propagation
  - Uses the computed posterior probability distributions of output nodes to come up with a rank (or risk) value that enables the choice of the best possible decision alternative

Example



Hugin Researcher 6.4
File Edit View Network Options Windows Wizards Help
LOI
Overall Level of Interest
56.54 High
42.00 Medium
1.46 Low
Scientific Level of Interest (Actual)
95.00 High
4.00 Medium
1.00 Low
Scientific Level of Interest (Estimatec
100.00 High
0.00 Medium
0.00 Low
T_ZONE_PRISM_SAR (Actual)
5.00 High
90.00 Medium
5.00 Low
T_ZONE_PRISM_SAR (Estimated)
0.00 High
100.00 Medium
0.00 Low
T_ZONE_SAT_SAR (Actual)
5.00 High
90.00 Medium
5.00 Low
T_ZONE_SAT_SAR (Estimated)
0.00 High
100.00 Medium
0.00 Low
Velocity of Ice (Actual)
5.00 High
90.00 Medium
5.00 Low
Velocity of Ice (Estimated)
0.00 High
100.00 Medium
0.00 Low
T_ZONE_SAT_SAR (Estimated)
T_ZONE_PRISM_SAR (Estimated)
T_ZONE_SAT_SAR (Actual)
T_ZONE_PRISM_SAR (Actual)
Scientific Level of Interest (Estimated)
Velocity of Ice (Estimated)
Scientific Level of Interest (Actual)
Velocity of Ice (Actual)
Overall Level of Interest
Node list expanded

Results & Conclusion

- MatchMaker implemented and tested
- Probability network implemented in Hugin and tested
- All available sources have been wrapped
- Agents and wrapped sources communicate using RMI
- We are using simulated radar data for the time being
- Goals of Greenland experiment: test in real operational environment; determine potential data transmission bottlenecks
- Future plans: Wrap all sources, develop radar data analysis algorithms, connect agent actuators to rovers and radars, start developing reflection for rover and radar to deal with the use of consumable resources (fuel, cpu, frequency channels for communication, etc.)