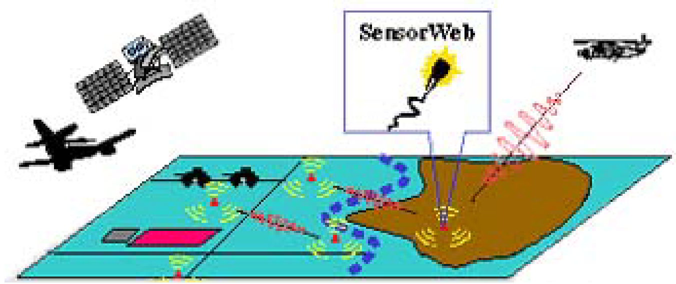
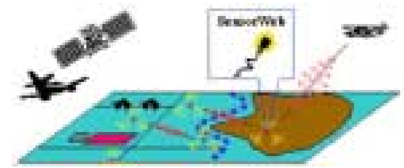


A Hierarchical Framework for Recognition Problems

Maurice Chu and Sanjoy Mitter

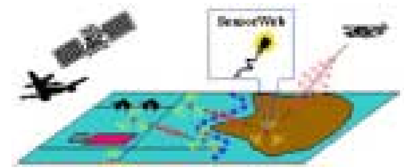
SensorWeb MURI Review Meeting

June 18, 2001



Outline

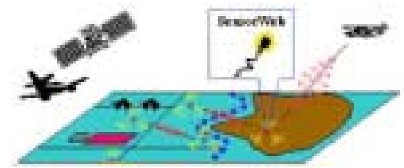
- Motivation
  - Sensor network characteristics
  - Nature of Information
- Purpose
- Hierarchy
  - Definition
  - Intermediate representations
  - Relationship to network
- Work at Xerox PARC and Experimental Setup
- Future Directions



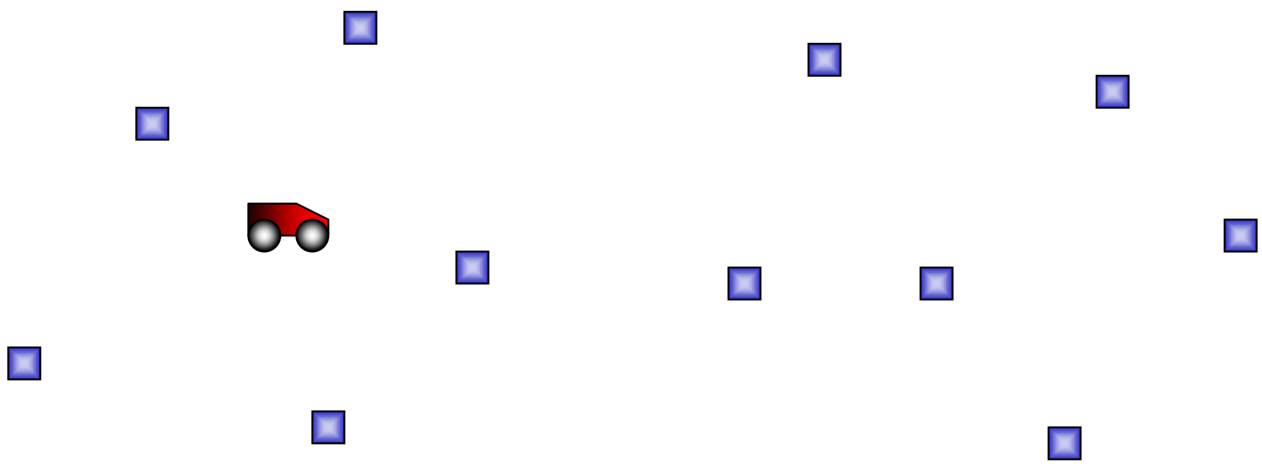
Sensor Network Characteristics

- Ad-hoc network
  - Sensors are placed randomly.
  - Sensing modalities may be heterogeneous.
- Sensor node characteristics
  - Computation power is limited but sufficient for sensing tasks.
  - Communication consumes most of battery power.

Extract as much information as possible with minimal communication!

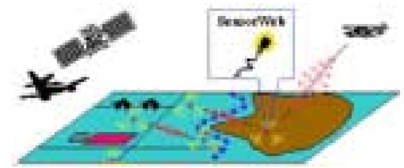


Nature of Information

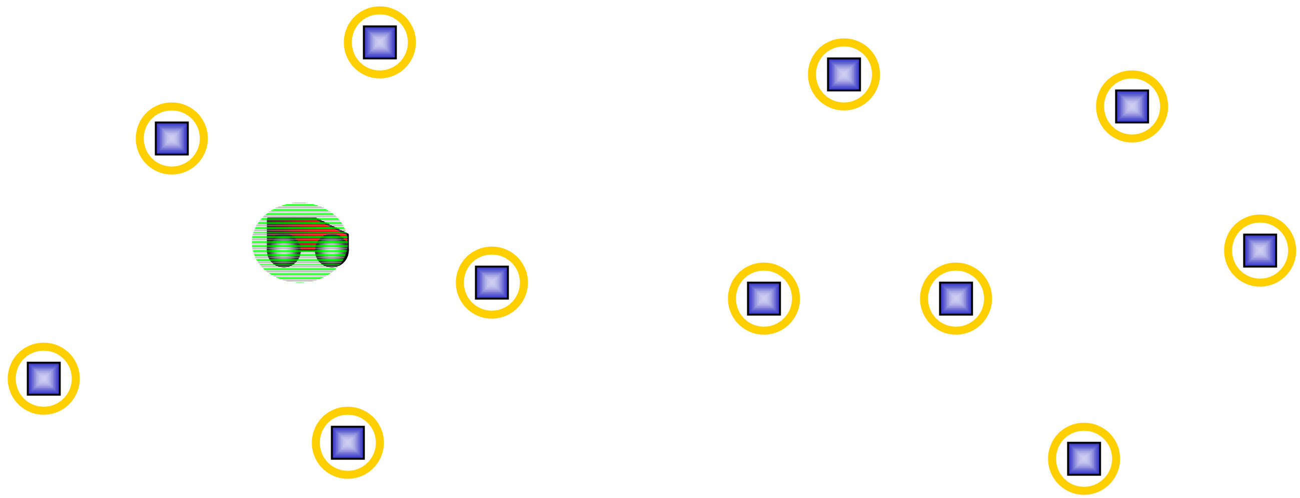


Example: Target Localization with Acoustic Sensors

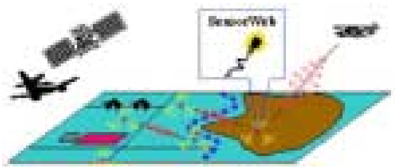
Goal: Compute from raw data (microphone readings) to the high level information (position estimate).



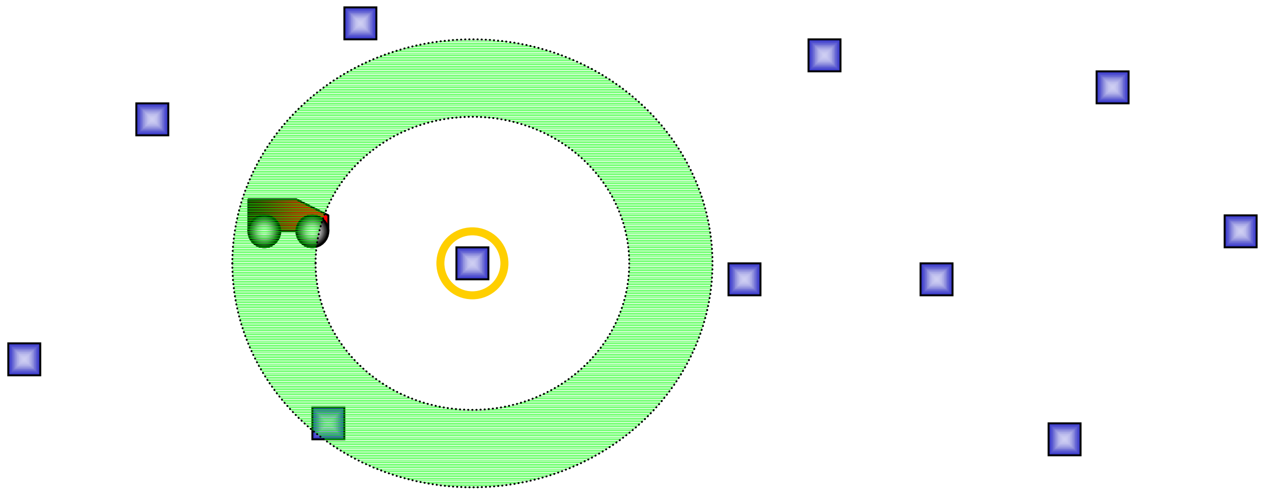
Nature of Information



1) Information is sufficient.

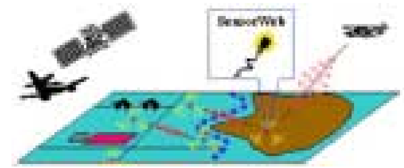


Nature of Information

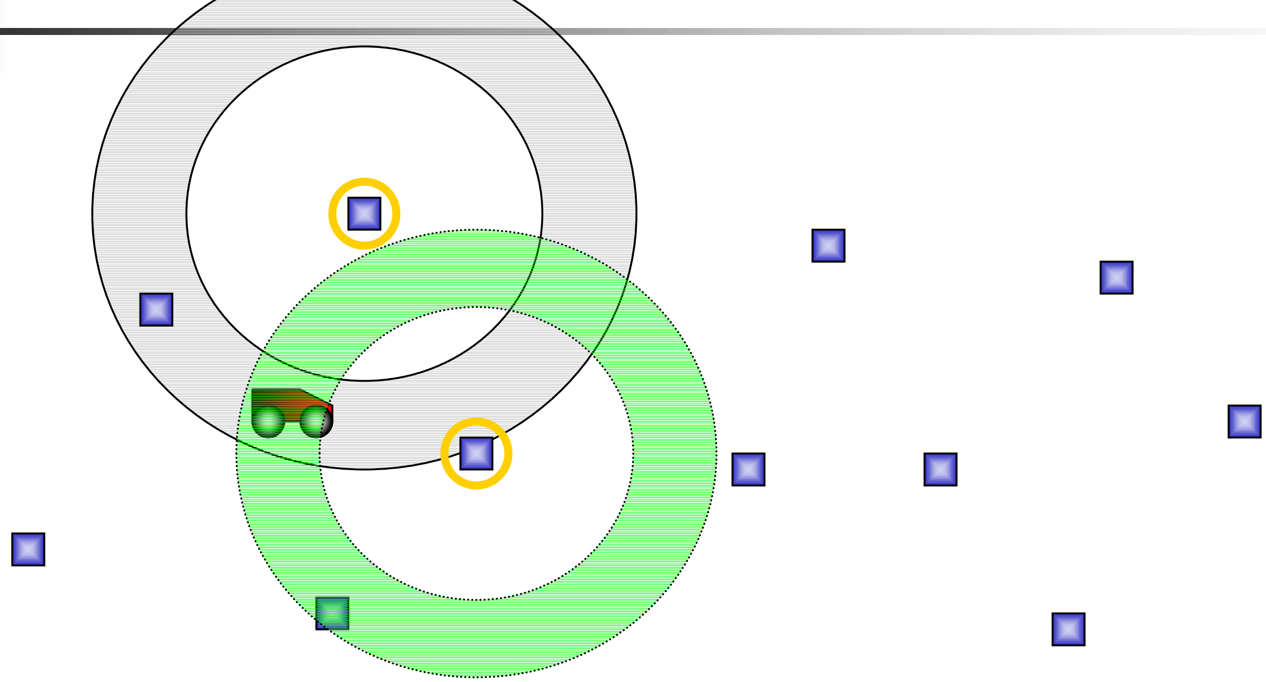


1) Information is sufficient.

2) Information is distributed.



Nature of Information



1) Information is sufficient.

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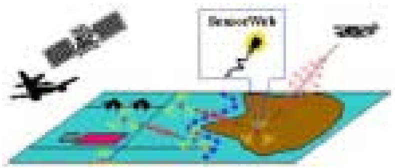
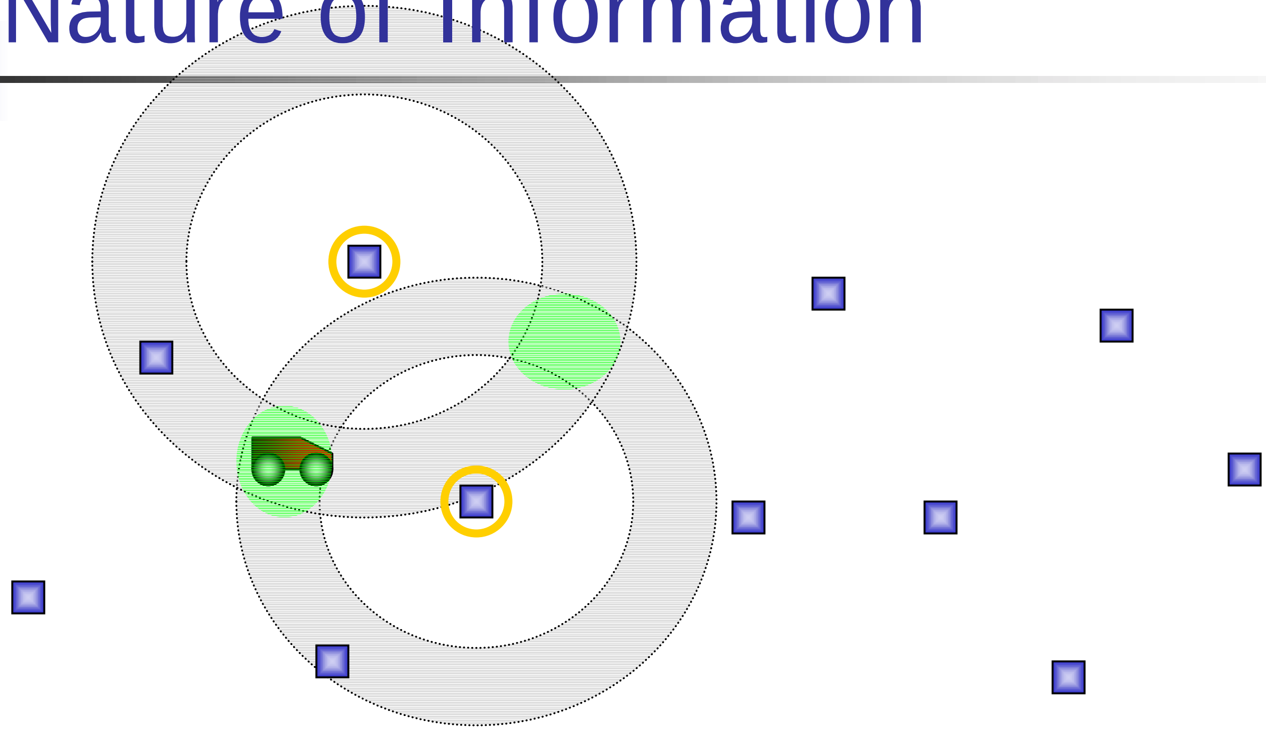
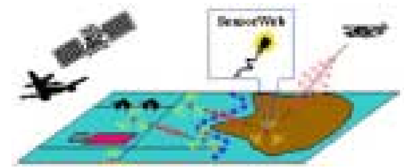
Nature of Information



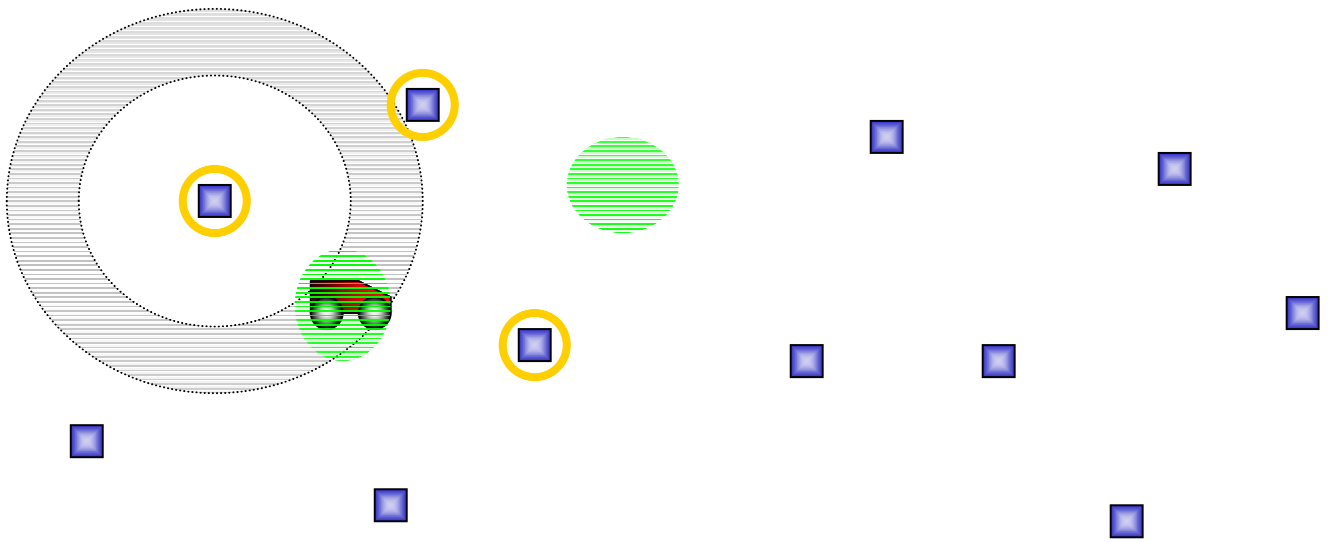


1) Information is sufficient.

2) Information is distributed.



Nature of Information



1) Information is sufficient.

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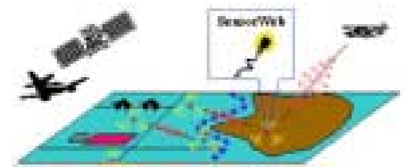
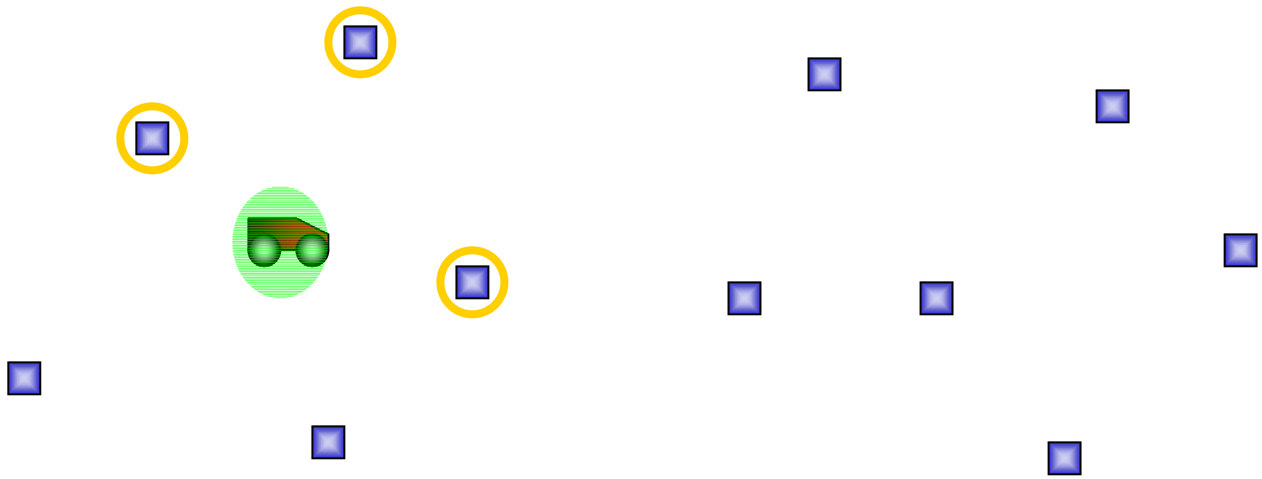
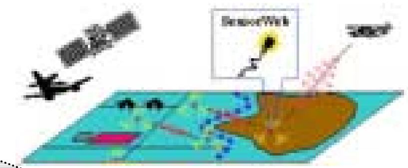


Nature of Information

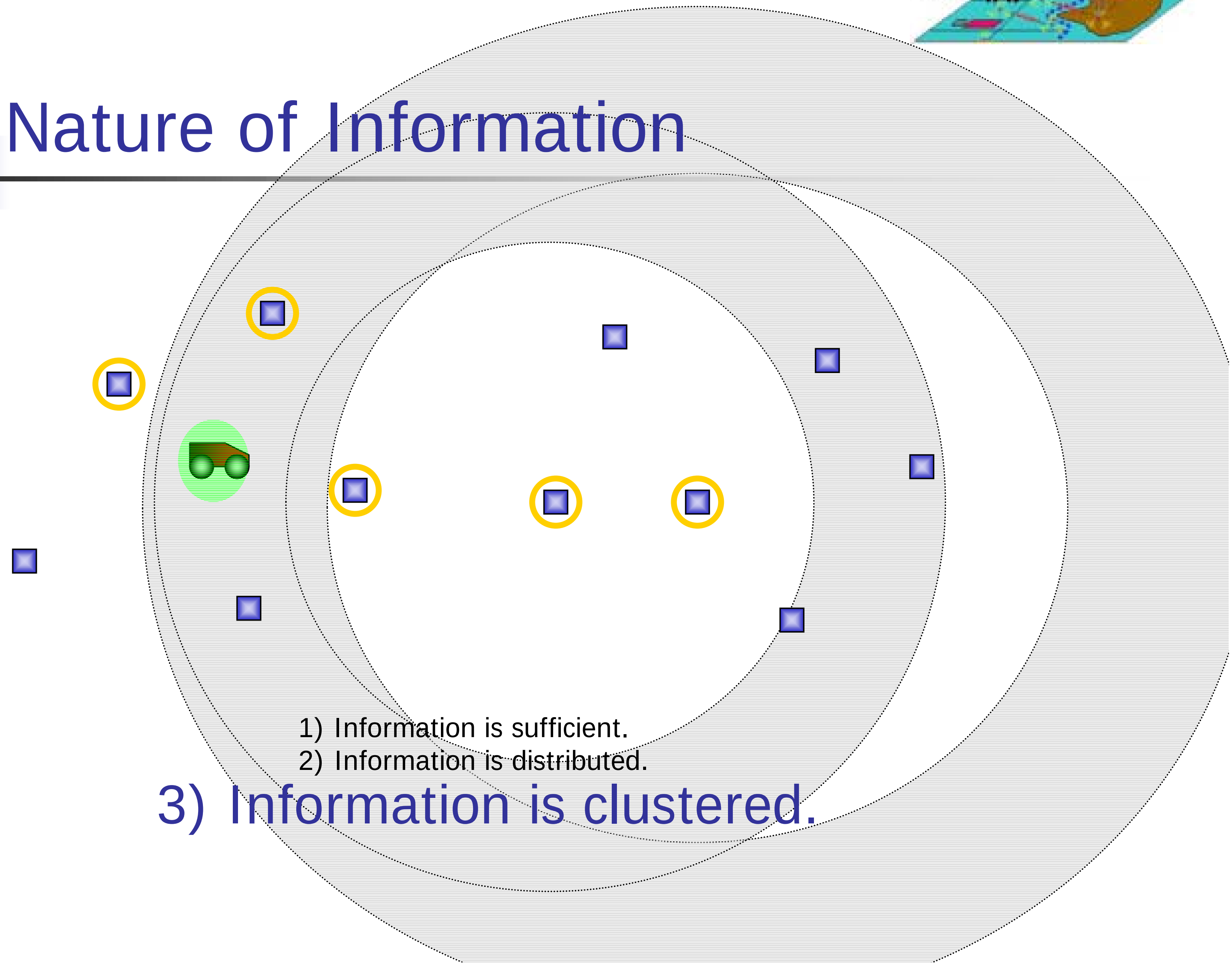


1) Information is sufficient.

2) Information is distributed.

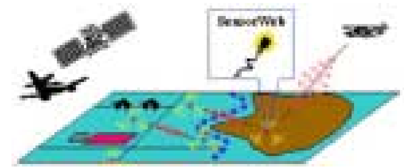


Nature of Information



1) Information is sufficient.
2) Information is distributed.

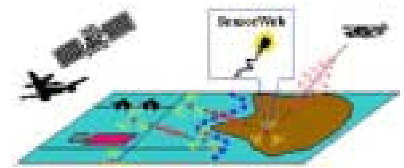
3) Information is clustered.



Purpose

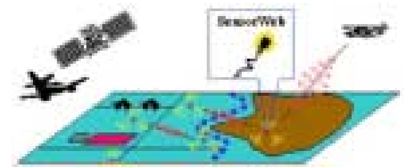
Provide a framework which maintains the relationship between raw data and parameter estimates from which various metrics (probability of detection, false alarm rate, communication power consumption) can be computed. (RCA-5)

- *Must be able to show the tradeoff between choosing what sensor information to use and communication power needed.*
- *For robustness to sensor failures, must allow for some redundancy.*



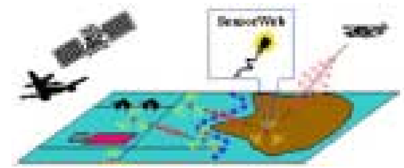
Characteristics of the Hierarchy

- A hierarchy defines a class of algorithms which can be shown to be dependent on what intermediate representations are defined. (RCA-4)
  - Intermediate representations determine amount of resources needed to compute the sensor task.
  - Network constraints determine what intermediate representations are possible.



Hierarchy (Preliminaries)

- Ω set of all possible outcomes (e.g. set of all possible joint sensor readings)
- Γ set of tokens (e.g. sensor identifiers)
- Z range space of all functions of the hierarchy which includes a special element ξ representing no output.



Definition of Hierarchy

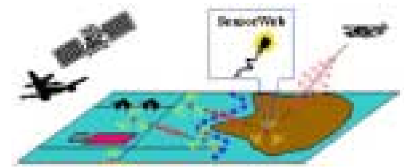
Hierarchy on Γ

$$H = (G_0, \ldots, G_N)$$

- G_0 is a collection of functions $\{f_\gamma\}_{\gamma \in \Gamma}$, $f_\gamma : \Omega \to Z$
- Each G_n is a collection of functions taking values in Z such that each $g \in G_n$ depends on the output of m functions

$$h_1, \ldots, h_m \in G_0^{n-1}$$

called the *decomposition* of g ,
and at least one h_i is an element of G_{n-1}
called the *spawning representation*.

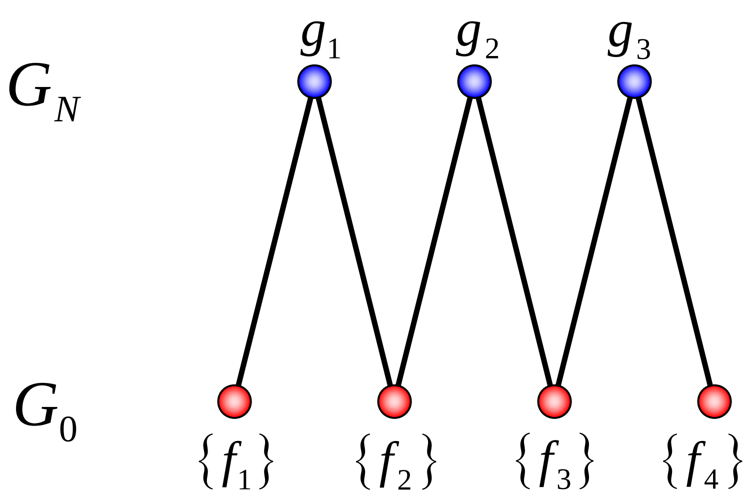


Graphical Representation of Hierarchy

Example

$$Z = \{\xi, 0, 1\} \qquad G_N = \{g_1, g_2, g_3\}$$

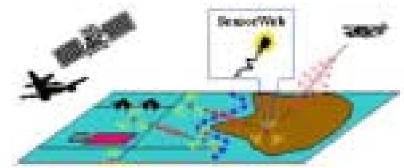
$$\Gamma = \{1, 2, 3, 4\} \qquad g_i = f_i \wedge f_{i+1}$$



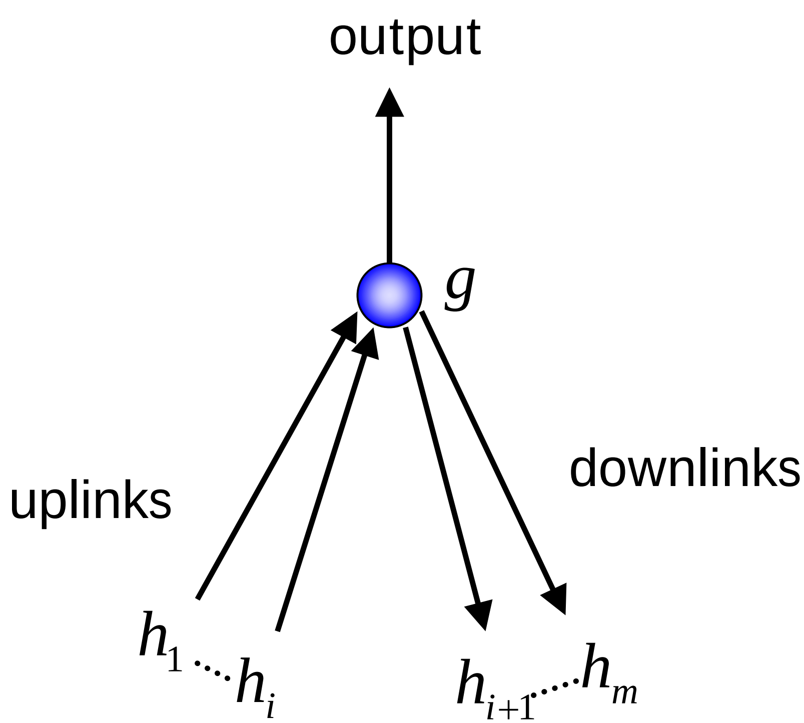
parameter estimates

Goal: Set all upper level representations to 1 if they are evident in the input.

raw data

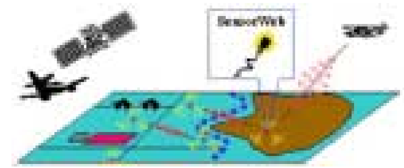


The Computational Unit



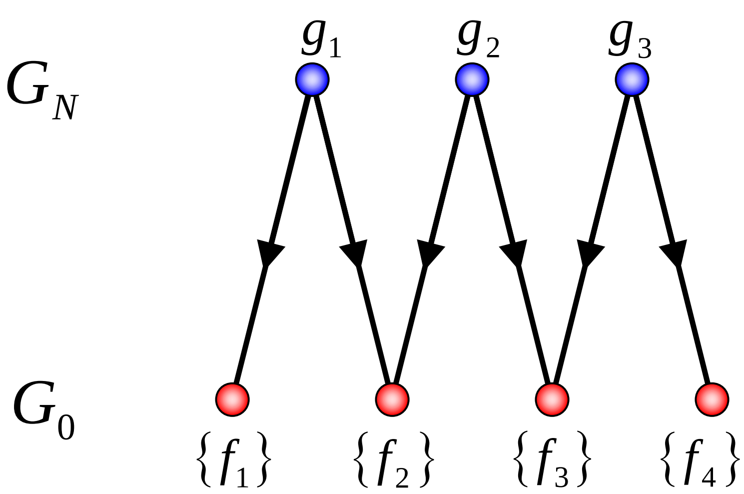
Algorithm:

1. If all uplinks not equal to ξ then activate node.
2. If the values of $h_1, \ldots, h_i$ permit $g \neq \xi$, then check downlinks.
3. Output value of g.



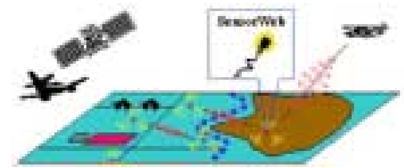
Top-down Algorithm

Model-based approach where a template is compared against the input.



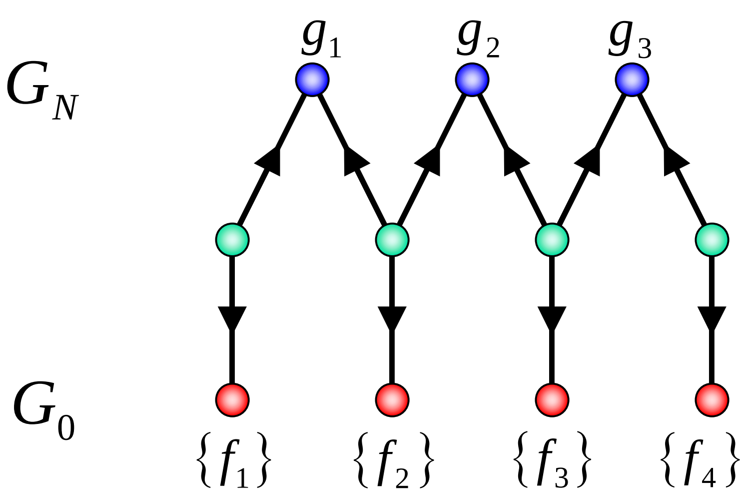
Number of downlinks invoked:

Top-down 6



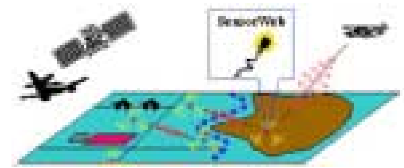
Bottom-up Algorithm

Compute generic features and build up to higher levels of representation.



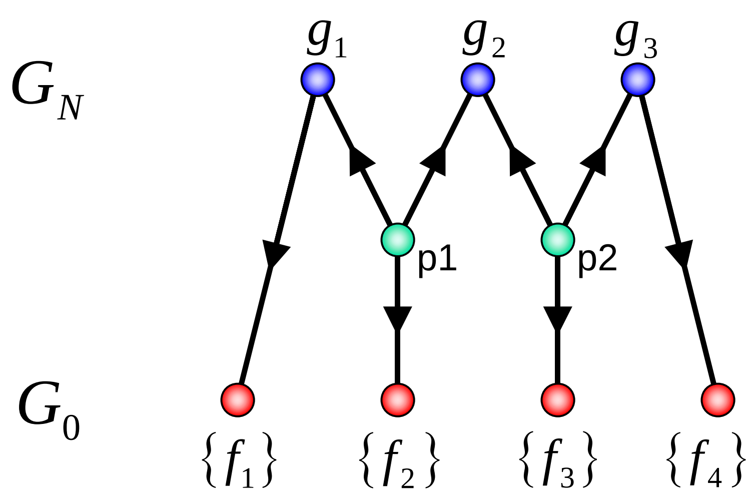
Number of downlinks invoked:

Top-down	6
Bottom-up	4



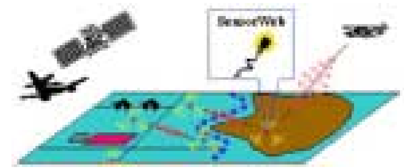
Hybrid Algorithm

Combination of top-down and bottom-up processes.



Number of downlinks invoked:

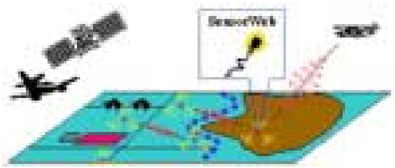
Top-down	6
Bottom-up	4
Hybrid	2+p1+p2



Intermediate Representations

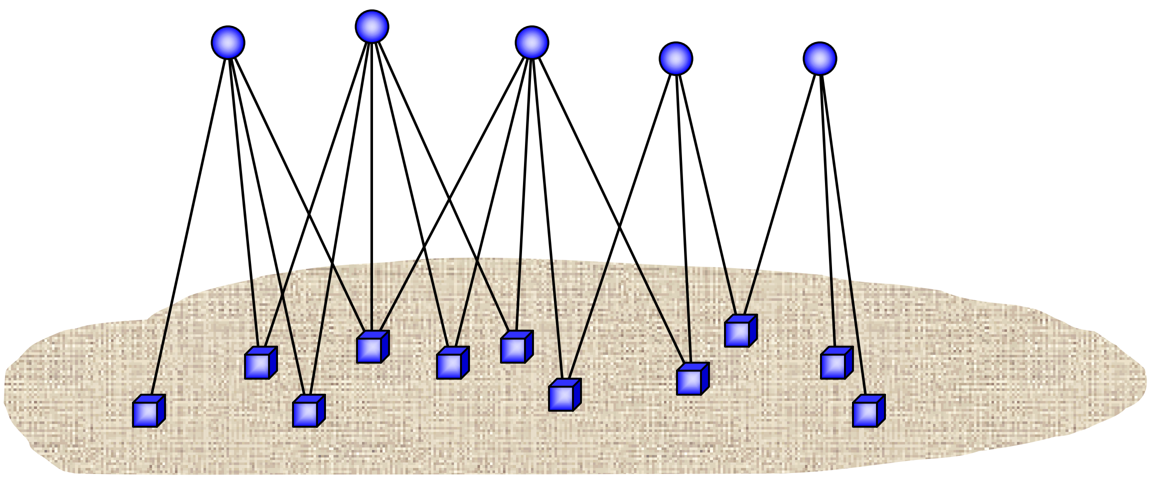
- Hybrid algorithm is computationally better and computes the same solution as the top-down and bottom-up algorithms.
- Choice of intermediate representations is key to minimizing costs of the problem while guaranteeing a solution is computed.

How do we select intermediate representations?

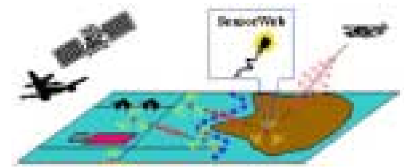


Relation to Sensor Network

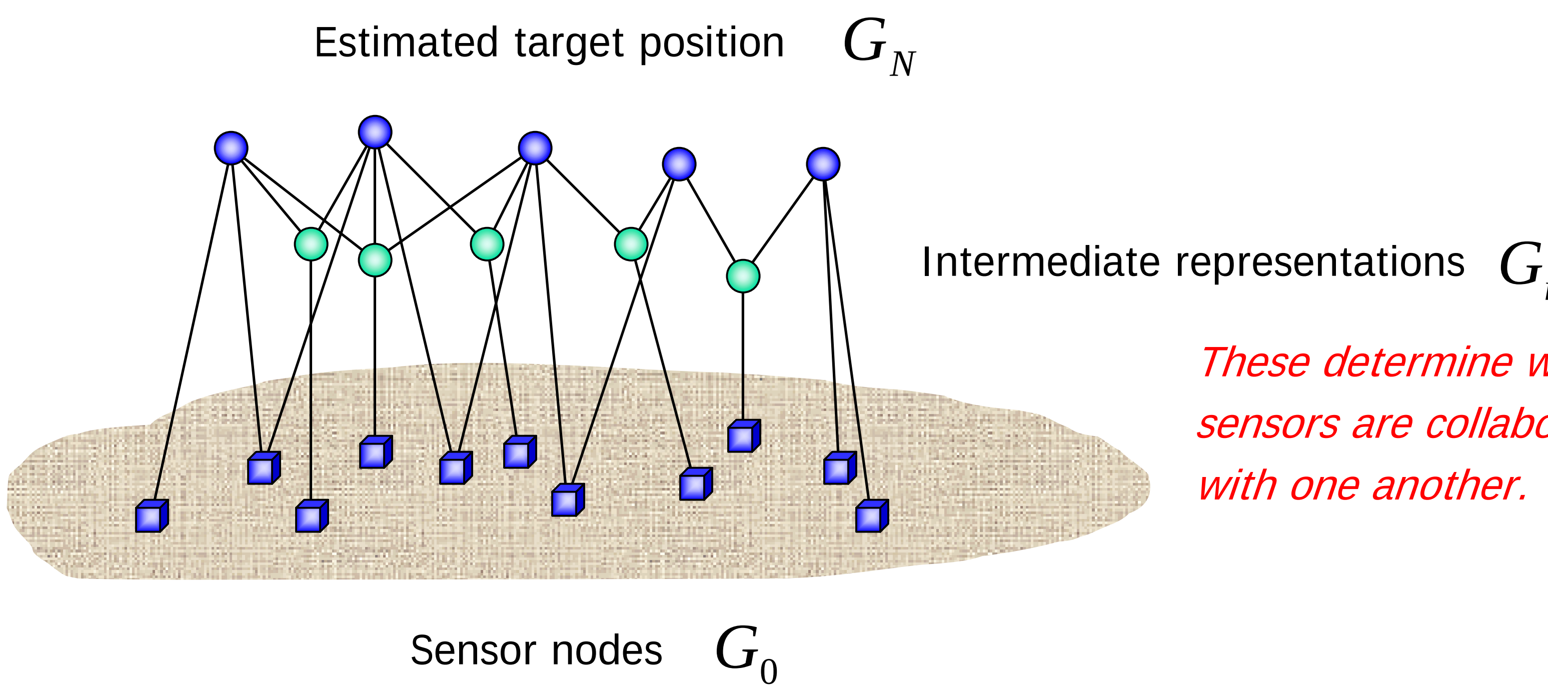
Estimated target position G_N



Sensor nodes G_0

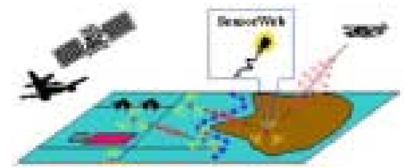


Relation to Sensor Network



These determine which sensors are collaborating with one another.

Main Question: How do we determine intermediate representations?



Work at Xerox PARC

Main Idea: Dynamically choose which sensor to incorporate into belief by using a measure of information utility.

Work funded by DARPA: SensIT program (Sri Kumar, PM)

- Information-Driven Sensor Querying (IDSQ)

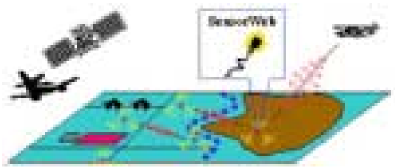
Joint work with F. Zhao, H. Haussecker

$A \subset \{1, \ldots, N\}$	subset of sensor indices incorporated into belief state
$B\left(\{z_i\}_{i \in A}\right)$	belief state with sensors in A incorporated
$\psi(\cdot)$	information measure

Choose next sensor by

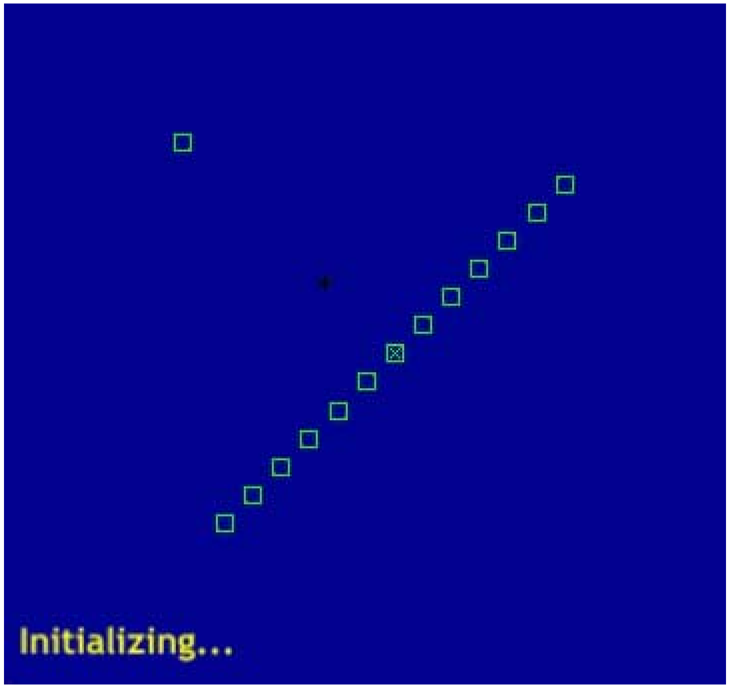
$$\hat{j} = \arg \max_{j \notin A} \; E_{z_j} \left[\psi\left(B\left(\{z_i\}_{i \in A} \cup \{z_j\} \right) \right) \right]$$

Xerox Palo Alto Research Center
parc

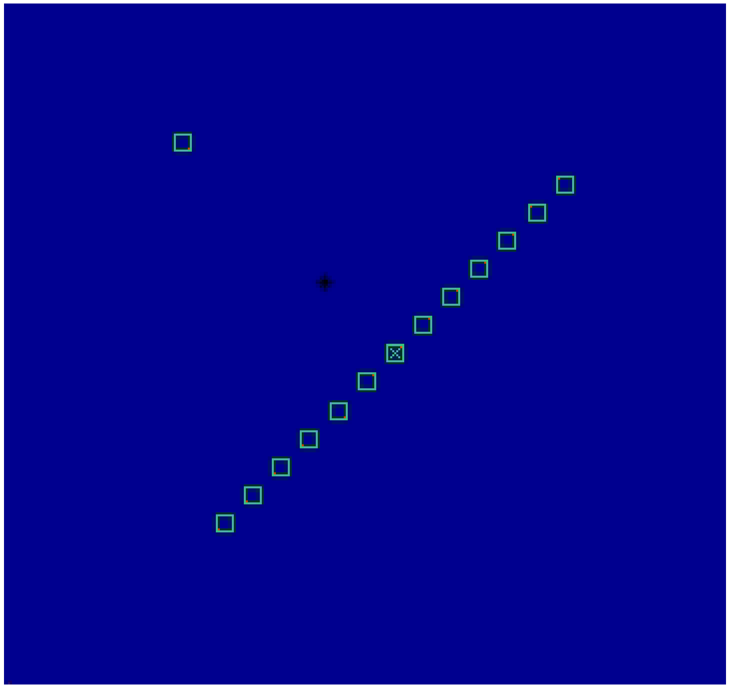


IDSQ Simulation

IDSQ

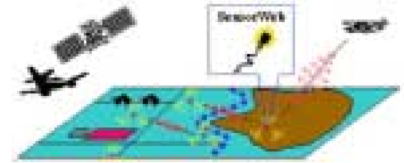


Nearest neighbor

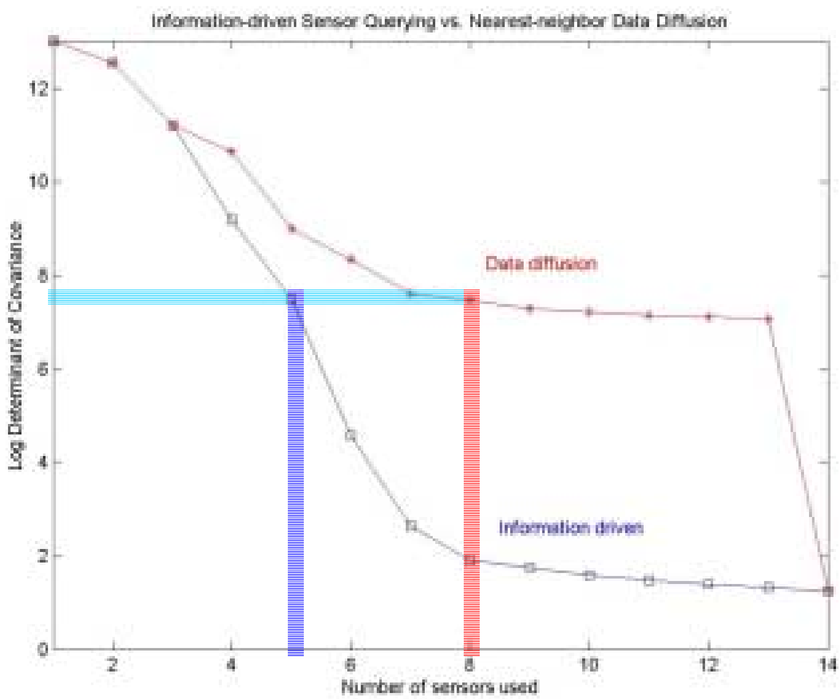


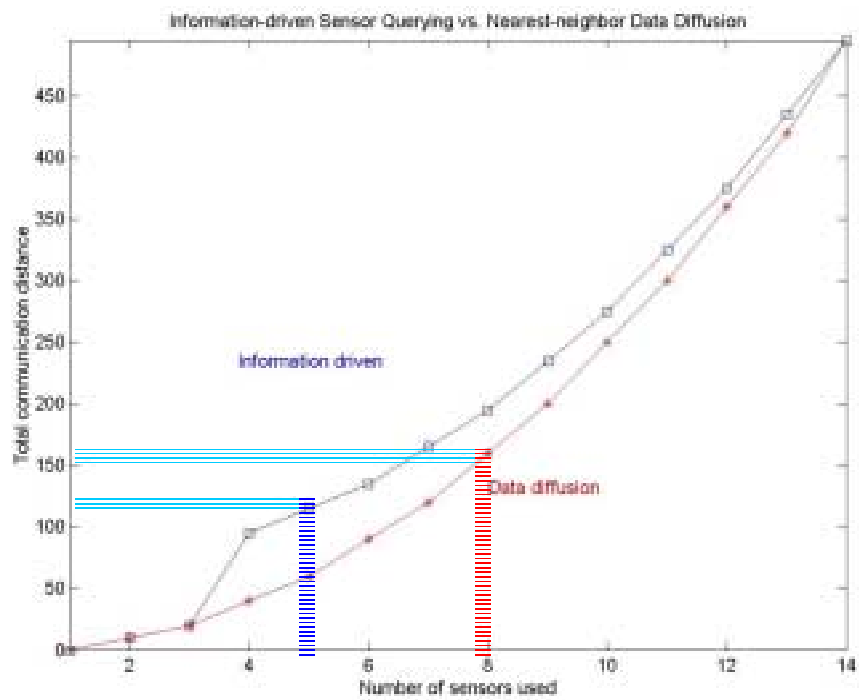
Information criterion: Mahalanobis distance to estimate

$$\hat{j} = \arg\max_{j \notin A} \left(x_j - \hat{\mu}\right)^T \hat{\Sigma}^{-1} \left(x_j - \hat{\mu}\right)$$



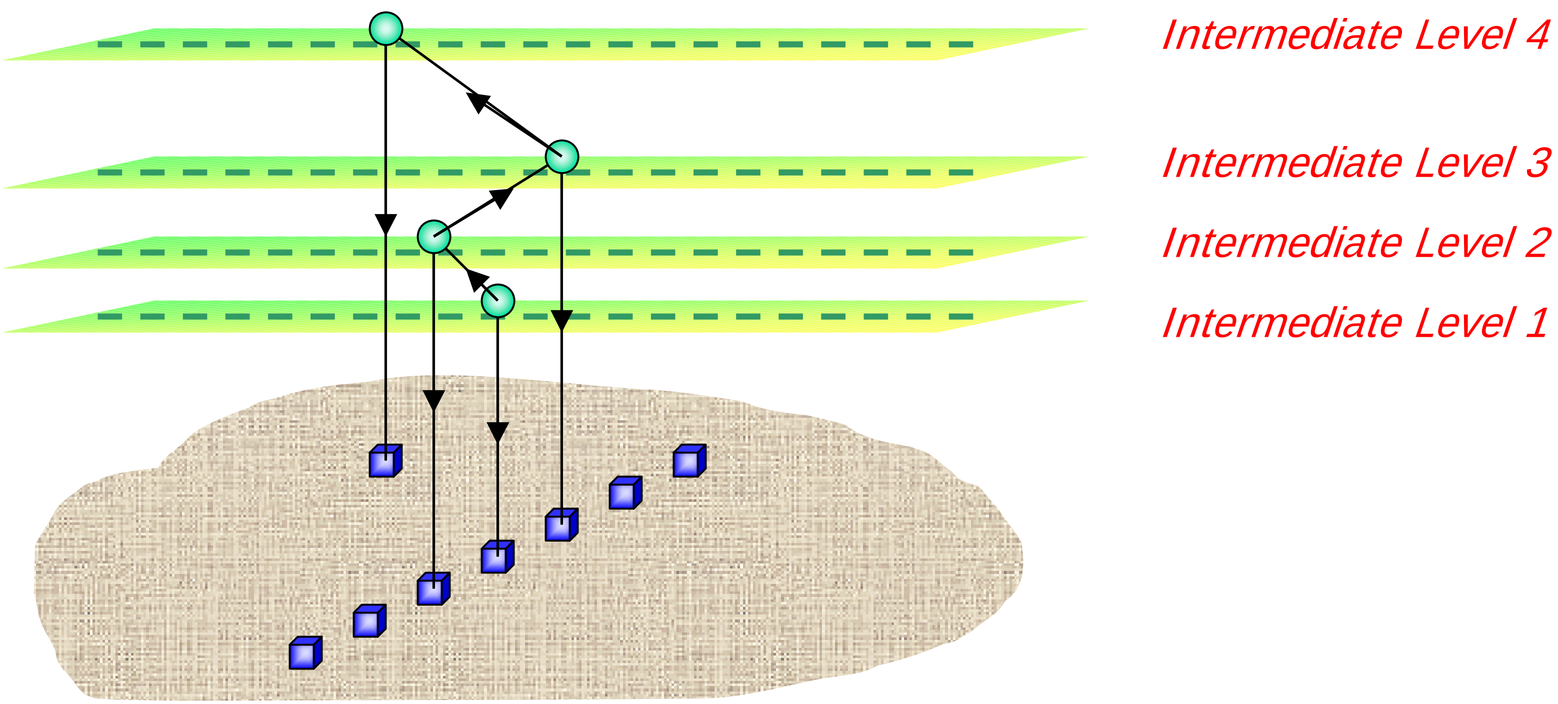
IDSQ vs. Nearest-neighbor diffusion

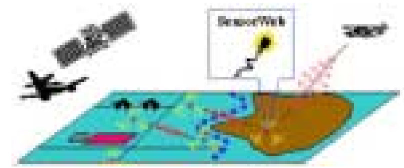




Xerox Palo Alto Research Center parc

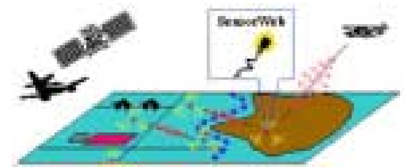
Hierarchical View of IDSQ





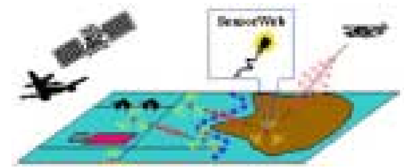
Why a Hierarchy?

- Since IDSQ can build the hierarchy, what's the point of even having a hierarchy?
  - Pre-computation vs. on-line computation
  - Leads to adaptively learning what to pre-compute. (i.e. on the fly optimization of processes)
- How is the hierarchy different than a decision tree?
  - Explicitly shows which agent is querying for information and which agents are providing information.
  - Distributed computation can be modelled because nodes are computational units which activate under certain conditions.



Experimental Setup at Xerox PARC

- Xerox PARC Wideband data from 29 Palms SITEX00 Experiment.
- Distributed sensor nets
  - Berkeley motes (8 bit Atmel processor) *currently at PARC*
  - Sensoria nodes (full Redhat Linux)
- Anechoic Chamber



Future Directions

- Connection between graph properties of the hierarchy and various criterions for choosing sensors.
- Partial instantiation of the hierarchy for optimizing algorithms on-line.
- Distributed nature of the hierarchy.