Thematic Mapping with Remote Sensing Satellite Networks

John Richards

College of Engineering and Computer Science
The Australian National University

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John Richards
CECS ANU

outline

- satellite networks
- implications for analytical methods
- candidate analytical techniques
- knowledge fusion
- some important implications

Thematic Mapping for Satellite Networks

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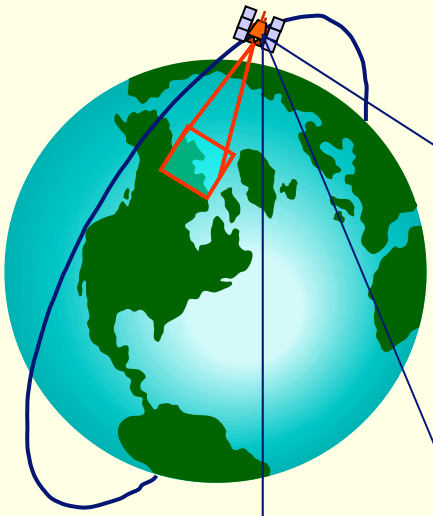


categorical and topographic

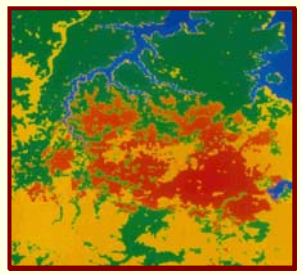
from other agencies

radar
multiple wavebands & polarisations

hyperspectral
100's of wavebands

multispectral
a few wavebands

"classification"



thematic map

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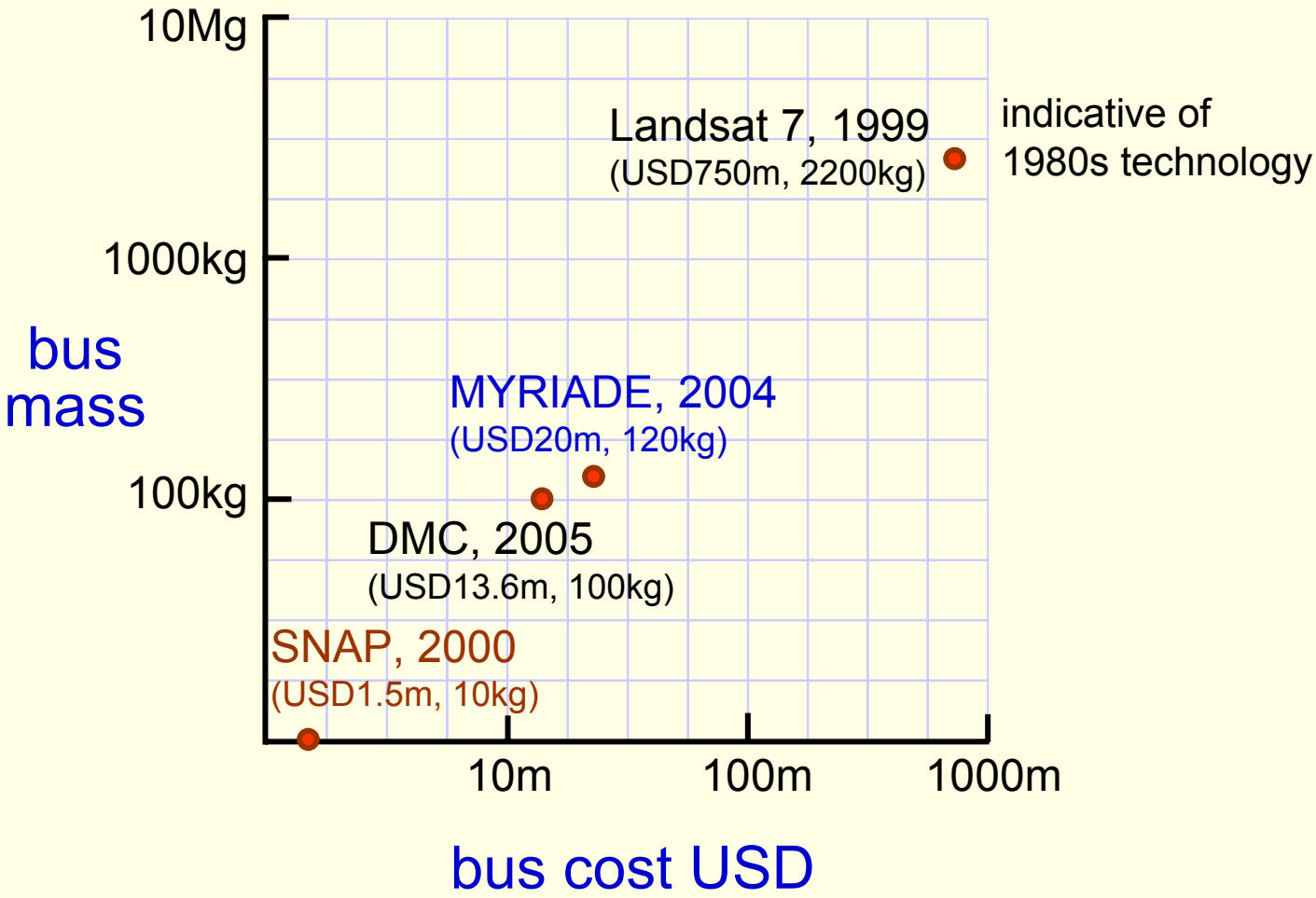
trends to satellite networks …

Comparison of large and micro-, nano-satellites



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To date expensive, special purpose satellite platforms have mostly been used in remote sensing.

We are now witnessing falling hardware costs for satellite buses along with simpler instrumentation.

Inexpensive micro- and nanosatellites able to support modest (imaging) payloads are now viable and have been proposed for other purposes (eg NASA ANTS).

Remote sensing in the future is likely to depend on sets, or **formations**, of small satellites working cooperatively, either **autonomously** or under control from ground stations.

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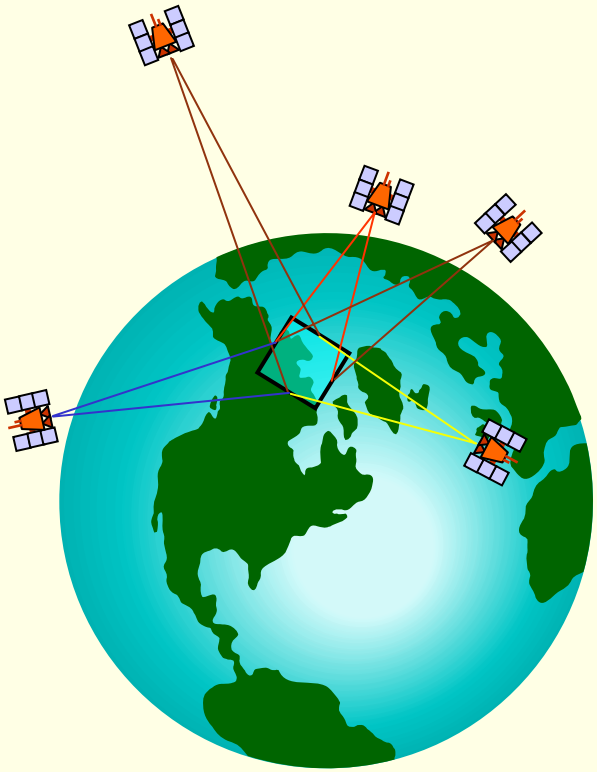
The future will be characterised by satellite sensor networks



Clusters of small platforms that form an imaging sensor network.

Imaging modalities can be different (radar, hyperspectral, other mapping).

With advances in sensors, computing and communications, along with reductions in weight and costs of the platforms, it is conceivable that quite large clusters could be orbited.

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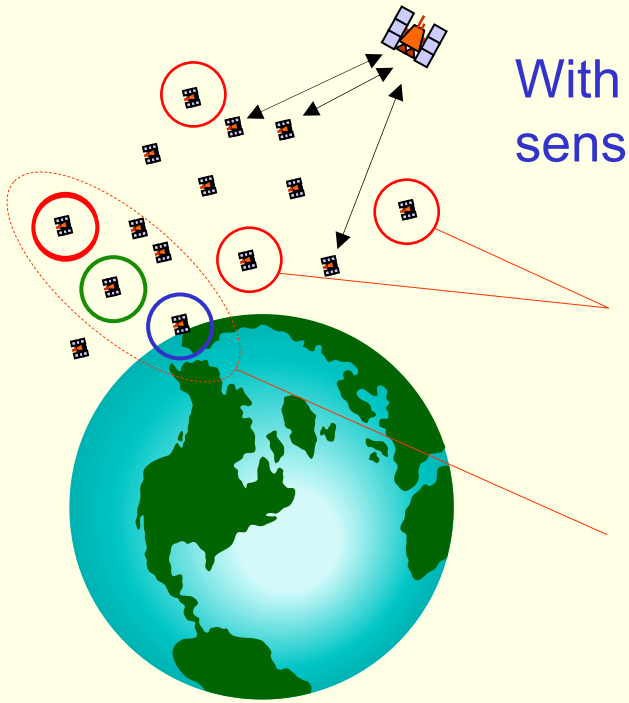

With such a large number of inter-communicating sensors (or agents), we can envisage:

some members of the cluster having (simple) sensors targeted on specific applications (eg vegetation detector)

aggregation of members to provide wider (eg hyperspectral) coverage if required

the cluster self-healing in the event of an individual agent failure

the cluster perhaps collaborating with more sophisticated satellites

protocols are being developed …

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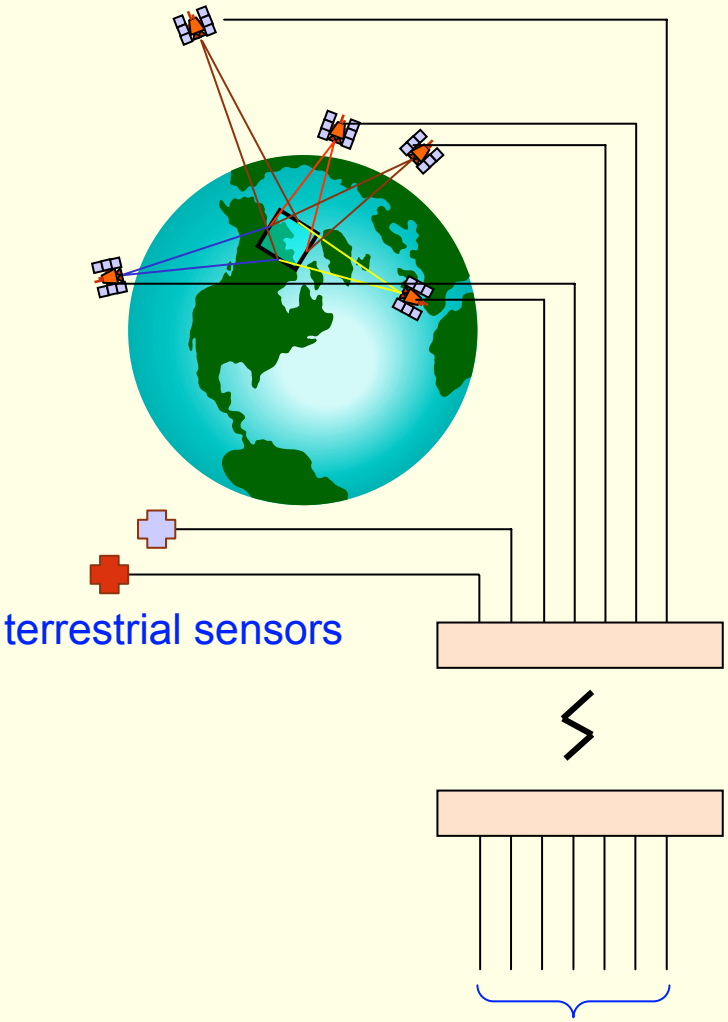

sensor networks have three layers:

the sensor layer

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the communications layer

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the information layer

S. Liand, A. Croitoru & C. Tao, Computers and Geosciences, vol 31, 2005, p221-231

What is important in specifying the information layer?

large number of simple sensors recording a large data volume

need to communicate among a group for control and for imaging

sensor types may be quite different

individual platforms should perhaps make autonomous decisions

joint decisions should to be possible

landscape knowledge gathered by a set of sensor types might be quite different from the knowledge able to be acquired by any platform acting on its own

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What are the implications for thematic mapping?

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The problem of earth surface mapping from satellite sensor networks is essentially is a fusion problem.

Standard image fusion approaches in remote sensing:

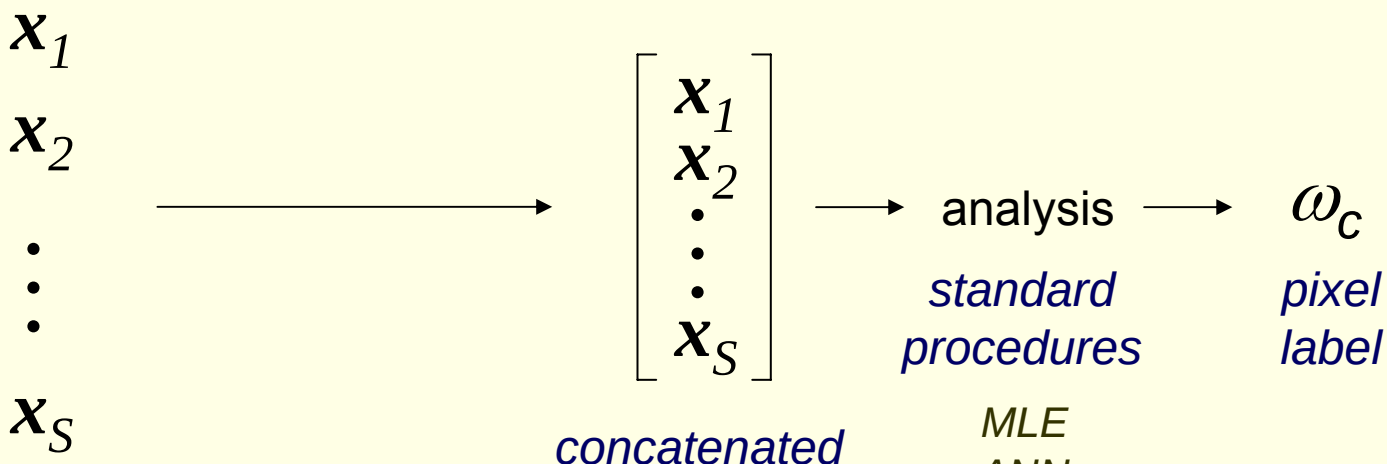
data fusion

feature fusion

decision fusion

knowledge fusion *(generalised decision fusion)*

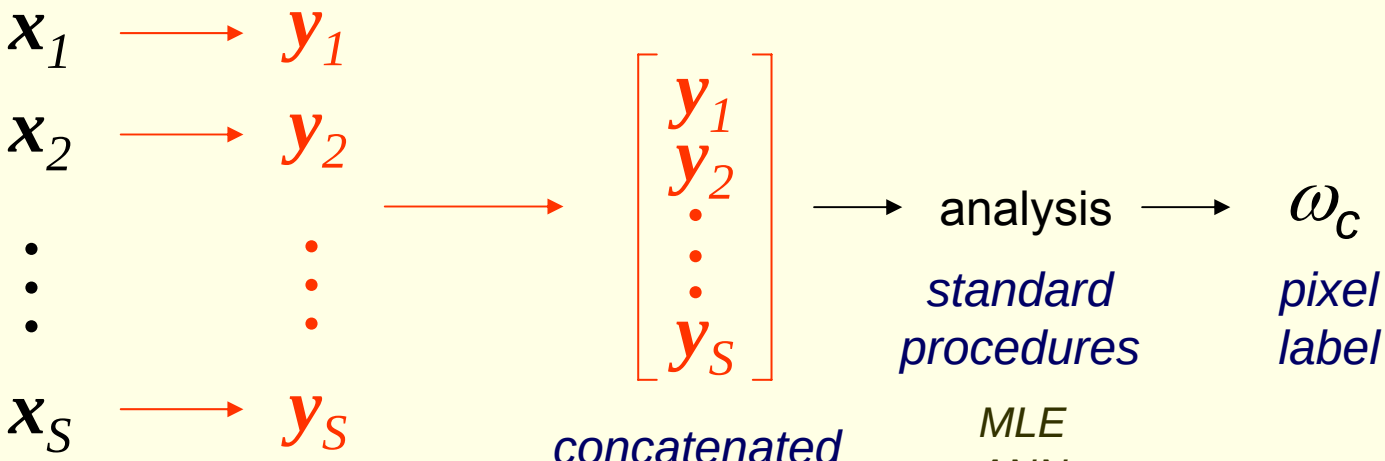
data fusion



measurement vectors for a pixel from S different sensors

feature fusion

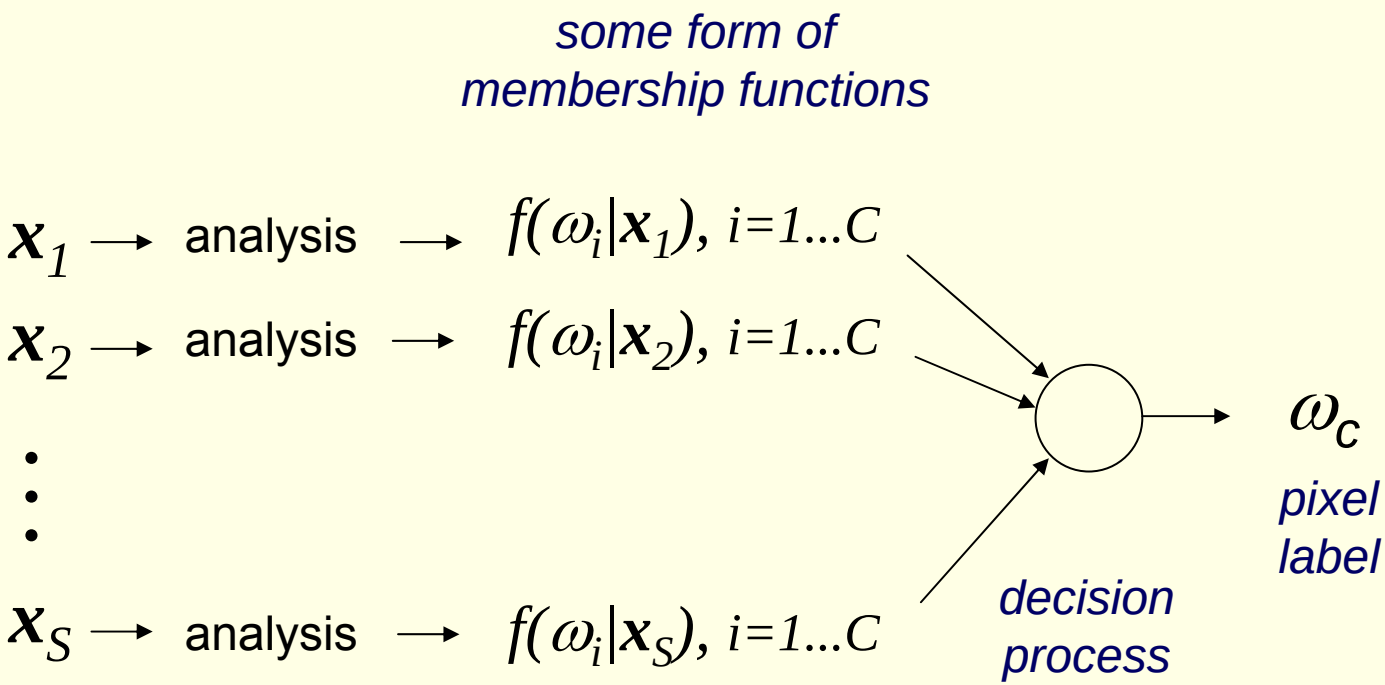
reduce the dimensionality of each vector through feature selection or transformation



measurement vectors for a pixel from S different sensors

$\dim y_i < \dim x_i$

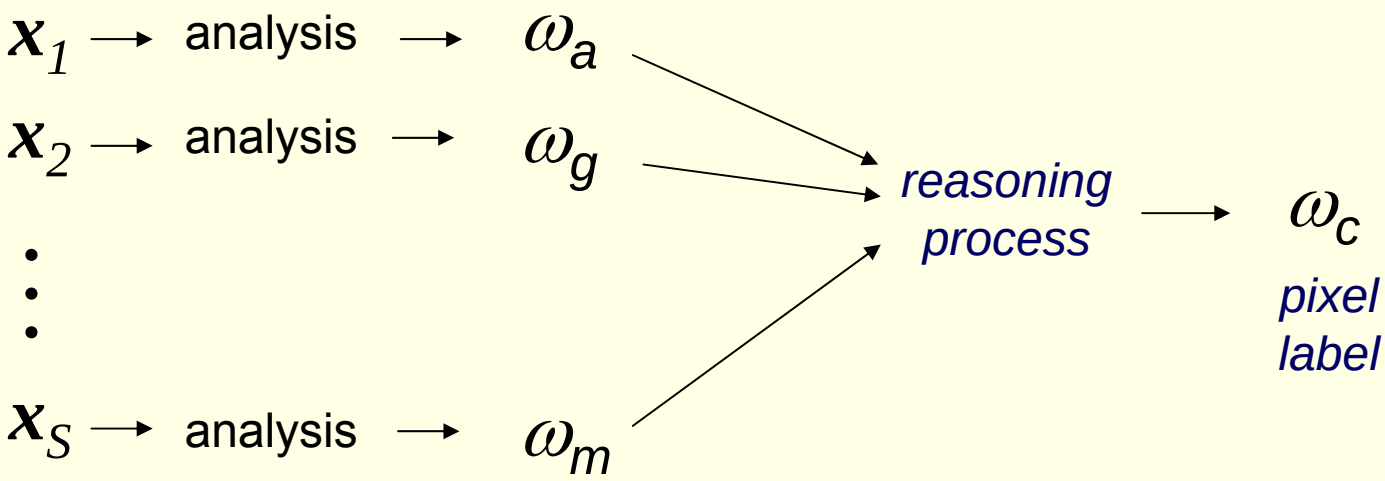
decision fusion



measurement vectors for a pixel from S different sensors

$f(\omega_i|\boldsymbol{x}_S)$ *are often posterior probabilities*

knowledge fusion



measurement vectors for a pixel from S different sensors

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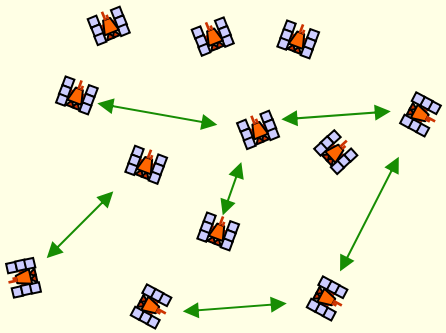
In considering candidate fusion techniques there are also some network-specific considerations that should be taken into account…



How should inter-agent communication occur?

Apart from control data, remote sensing information could be transferred among agents either:

- in the form of recorded data (signals)
- possibly as labels after each platform performs an analysis based on its recorded data alone

Communications of labels requires much smaller bandwidths and amounts to *knowledge transfer* among agents.

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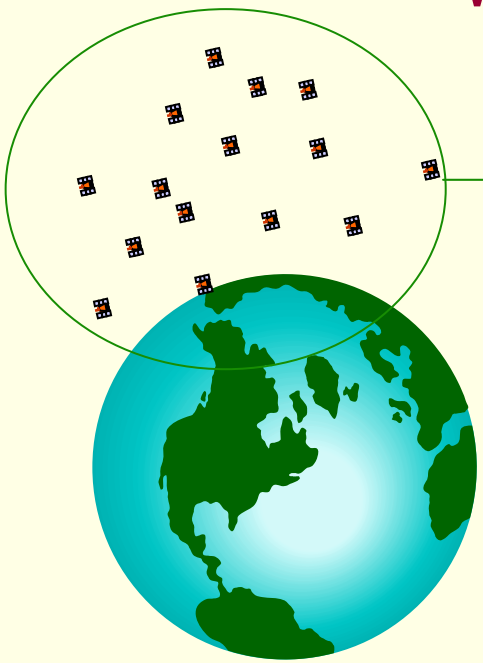
What does this mean for interpretation?



By adopting a knowledge fusion protocol the data recorded by each sensor can be mapped to a common vocabulary - *ground cover type labels* - that can be fused as required to provide joint inferences for what is being observed on the ground.

National Land Cover Definitions:

http://landcover.usgs.gov/classes.php

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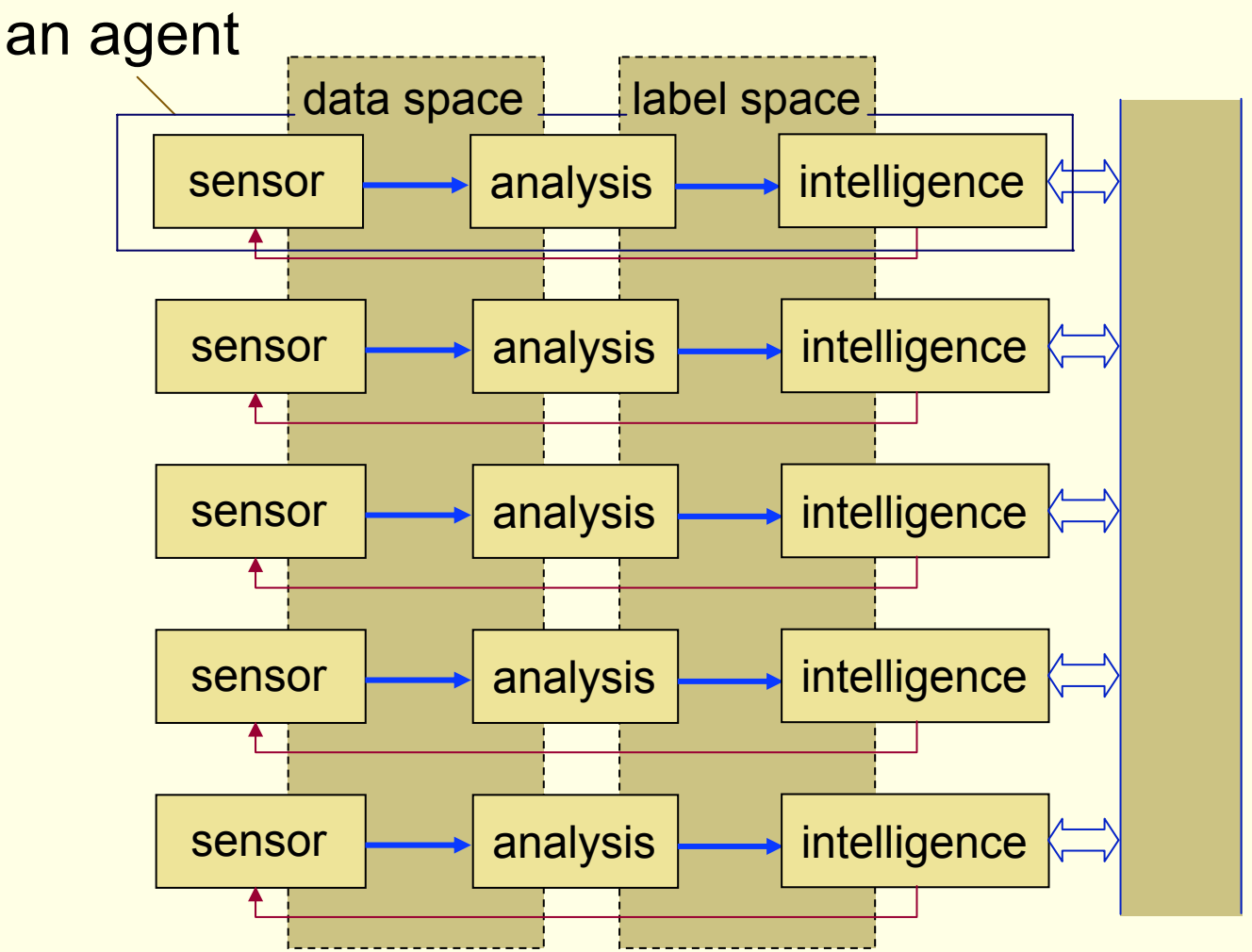

inter-agent (local) communication and down-link to ground station

a possible information layer topology

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How restrictive is it to do processing on-board based only on the data recorded by that agent, thus denying the opportunity to do analysis of the (fused) data recorded by a multiplicity of sensors?

We can address that question by looking at the means by which individual remote sensing image data sources can be analysed?

There are arguably optimal techniques for mapping from individual data sources, that are not easily transferrable …

Particular data types have preferred methods for analysis

multispectral	machine learning methods
hyperspectral	library searching, approximate statistical methods or biophysical modelling
radar	backscatter modelling, radar statistical methods, target decomposition

The techniques are not sensibly transferable between data types if good results are expected. Machine learning methods are not necessarily optimal for analysing fused data.

The label sub-spaces are also different

multispectral	vegetation, soil, water, clouds
hyperspectral	geochemistry, mineralogy, pigmentation
radar	geometry and dielectric constant

The classes relevant to one data type may not be reachable from a different data type. Indeed they are often complementary

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So what fusion techniques can be used with agents that perform their own analyses based on analytical methods best matched to their data types?

data fusion	*require high volume data transfer*
feature fusion	*landscape classes have to be common*
decision fusion	*low bandwidth options*
knowledge fusion	*landscape classes can be different from data classes*

Candidate methods

decision fusion

knowledge fusion

- Consensus theory
- Dempster-Shafer Theory of Evidence
- Expert systems and other AI approaches
- Bayesian nets

effectively they reason in terms of labels

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to go from data to labels (ie for basic thematic mapping):

if (infrared/red) is high **then** probably vegetation

if radar tone is dark **then** smooth cover type

to process labels, in which case compound rules are used:

if vegetation **and** smooth **then** probably grassland

A. Srinivasan & J.A. Richards, *International Journal of Geographic Information Systems,*1993.

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Two significant operational considerations

Spatial registration

to make joint inferences possible

Need to reason with uncertainty

individual platform decisions may be uncertain

Two significant operational considerations

Spatial registration

coarse level using models and ephemeris data?

precise level for accurate user products?

Need to reason with uncertainty

individual platform decisions may be uncertain

three, qualified, rank ordered labels may be needed

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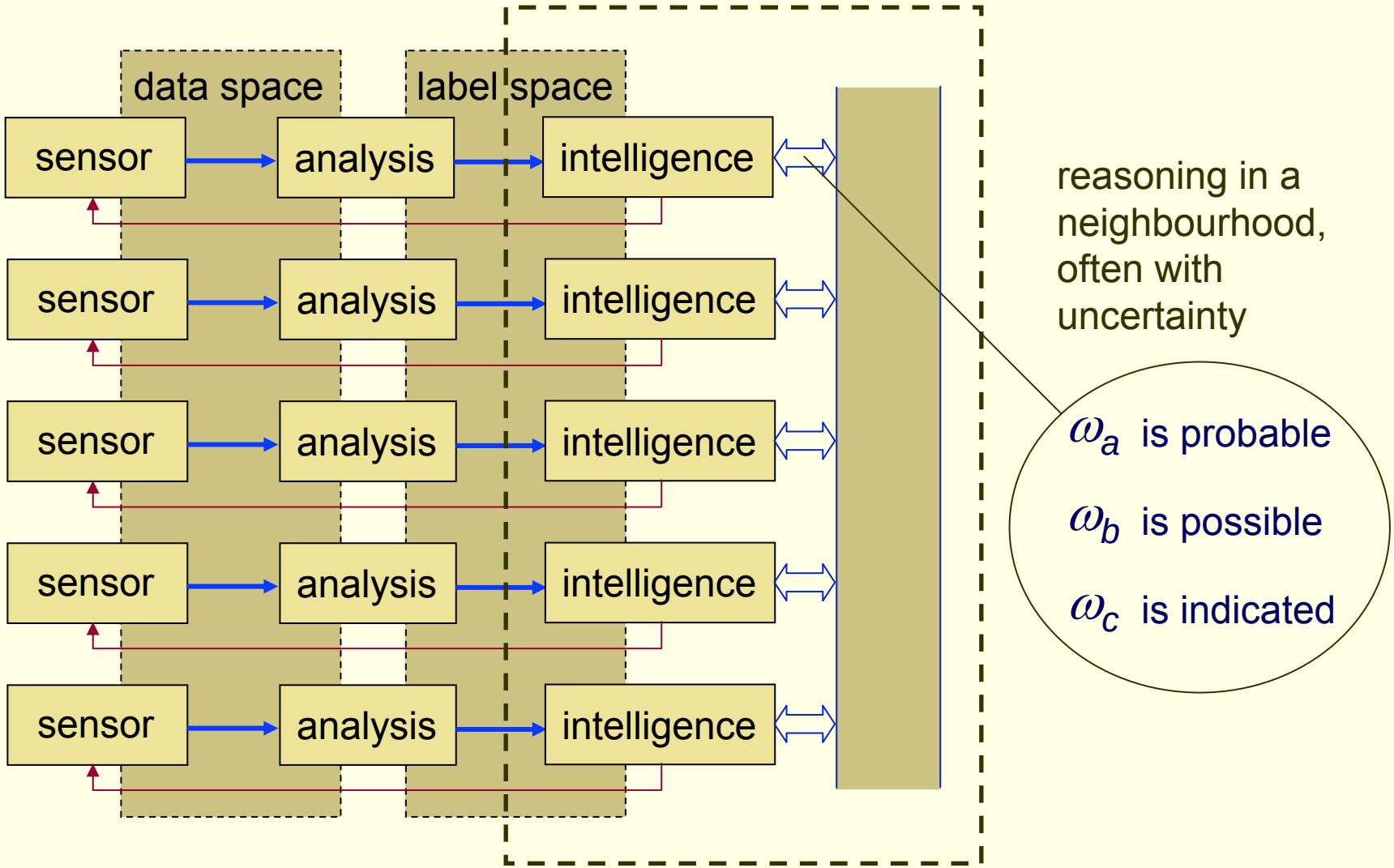

Concluding Remarks

Large numbers of (micro-) sensors in formations are likely to contribute to or define remote sensing data gathering in the future.

New forms of distributed image analysis will be needed, possibly based on knowledge fusion, to allow local and global decision making and mapping.

Reasoning in a neighbourhood with uncertainty is necessary.

Need to solve the registration problem.

The short term may involve simple minded swarms plus fewer sophisticated satellites.

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