From sensing to making sense to decision support

Éloi Bossé, Ph.D.

Adjunct Professor at
Université Laval (Québec)
University of Calgary (Calgary)
University McMaster (Hamilton)

CANADA

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Outline

- Sensing and monitoring
  - distributed sensor networks
- Making sense: data-information fusion
  - Sensor fusion
  - High-level information fusion
  - Frameworks & models
- Decision support: reaching human brain
  - Cognitive systems engineering
  - Visualisation
  - Decide on action

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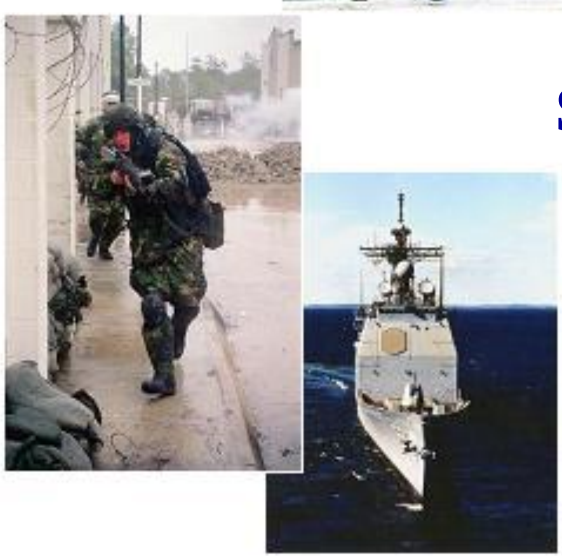
The New Defence and Security Context

Complex Conflict Spectrum

Asymmetric Threats

Globalization of Science and Technology



Common Defence and Security Agenda

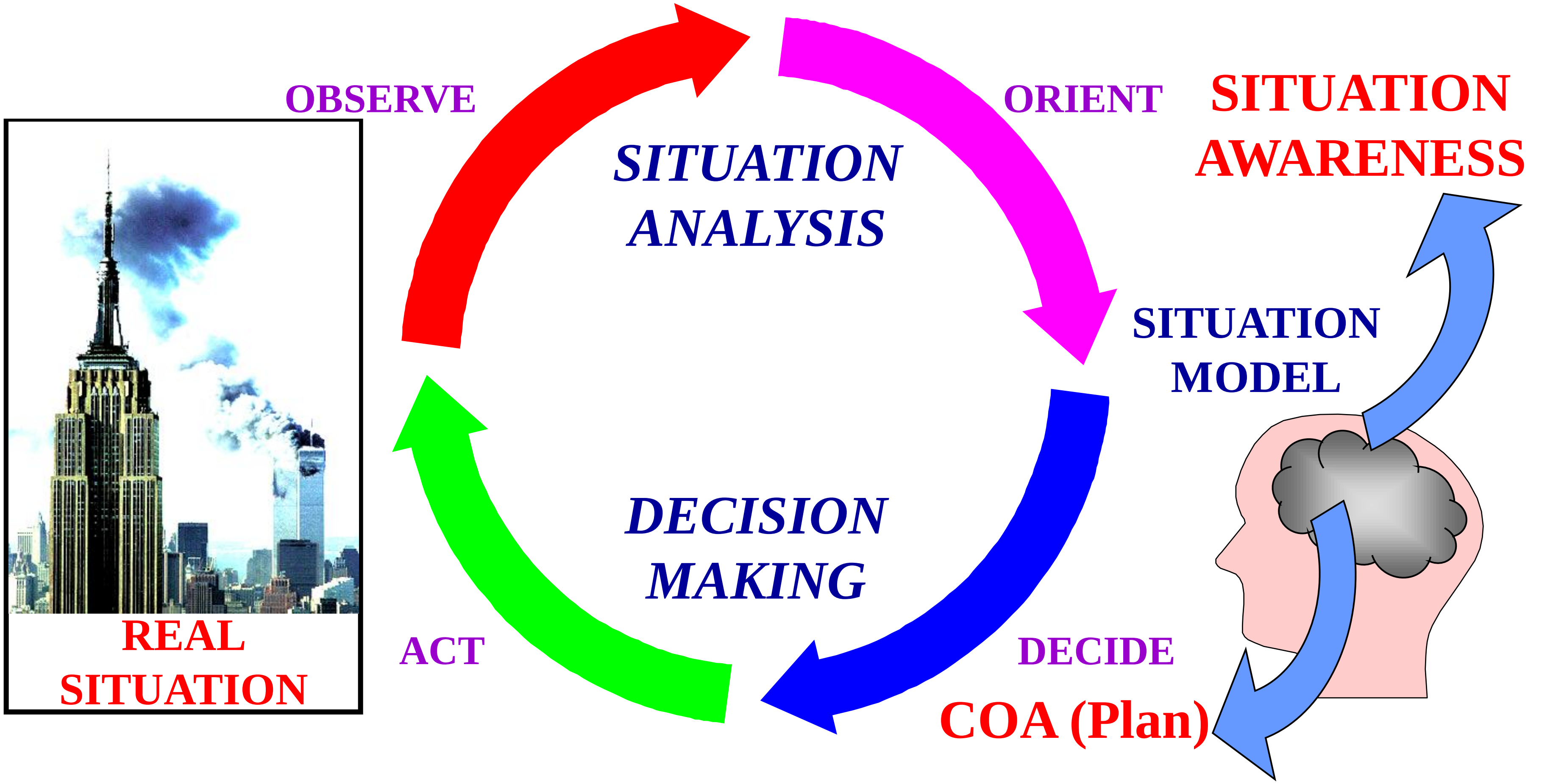
The Future Security Environment

- *The challenges of the 21st century include a variety of humanitarian disasters (earthquakes, floods, tsunamis), failed states, instability, global terrorism, intractable conflicts, pandemics, economic crises, and poverty among others.*
  - *These problems are not one dimensional, but rather involve the consideration of effects in multiple, inter-related dimensions. These dimensions include* ***social, political, and economic effects****.*
- *These challenges are beyond the ability of any single actor or even a small set of very capable actors (*e.g. CFs*).*
- *Responses to these challenges, if they are to have a chance of success, must involve a large,* ***heterogeneous collection of entities working together****.*
- *The 21st century mission challenges described above are referred to as* ***Complex Endeavours***

Sensing to Understanding to Decision Support

Situations

OODA loop as a decision-making process



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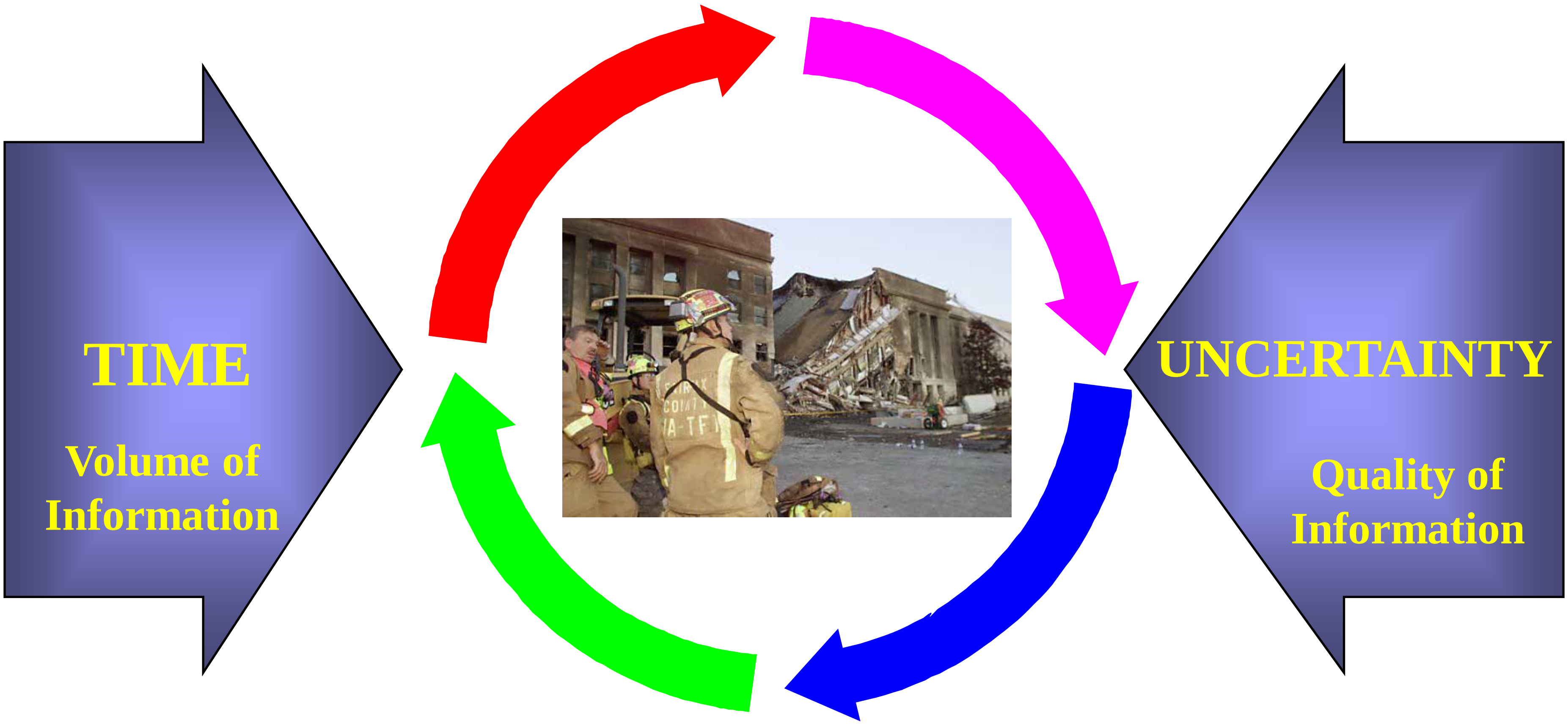
OODA loop as a decision-making process



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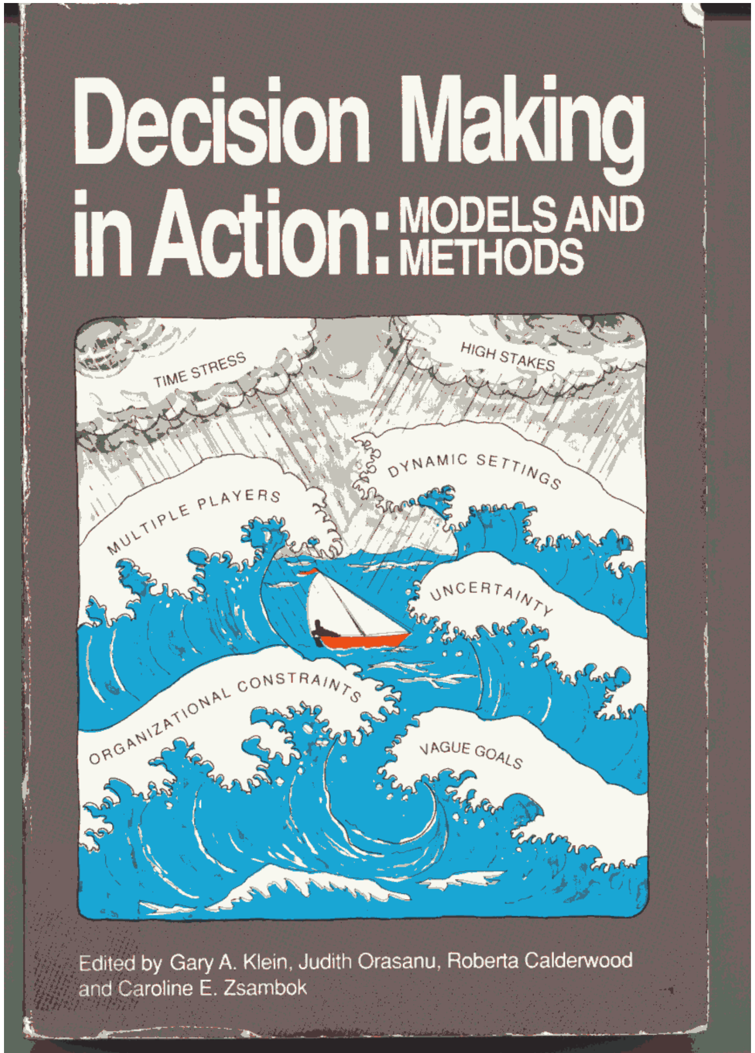
Decision-making models

- Two (2) general classes:
  - Rational models range from normative to more descriptive models (expected utility theory, prospect theory, regret theory, ..etc);
  - Naturalistic models ‘individual’s resorting to his or her experience to reach a decision’
    - e.g. recognition-primed decision model

Decision Making Models



There are two basic categories of decision making models (Lipshitz, 1993): *process models* and *typological models*.

- The former describes the order of processes in which decisions are made whereas
- the latter classifies decision processes into types and describes the situation these processes are used in.

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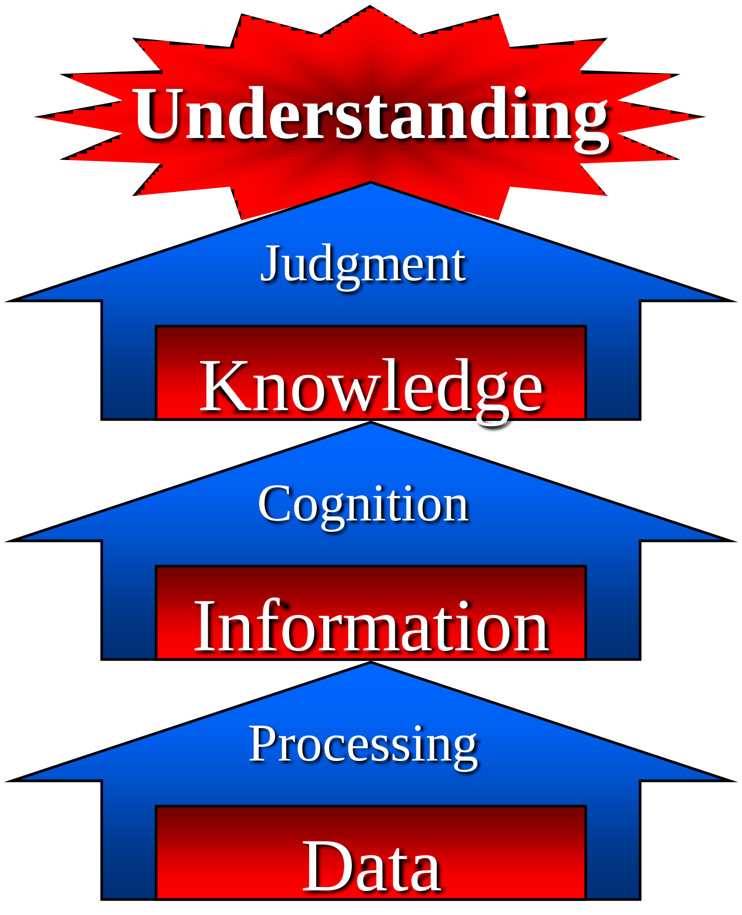
The Cognitive Hierarchy



"Key to DECISIONS is INFORMATION"

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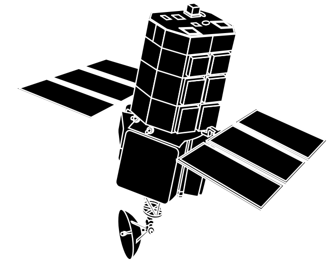
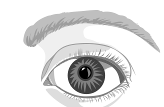
1. Sensing and monitoring:

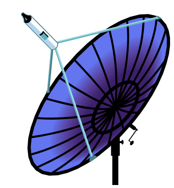


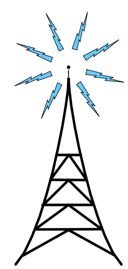
Solar Maximum Mission Satellite

Heterogeneous sources



(Hard & Soft)





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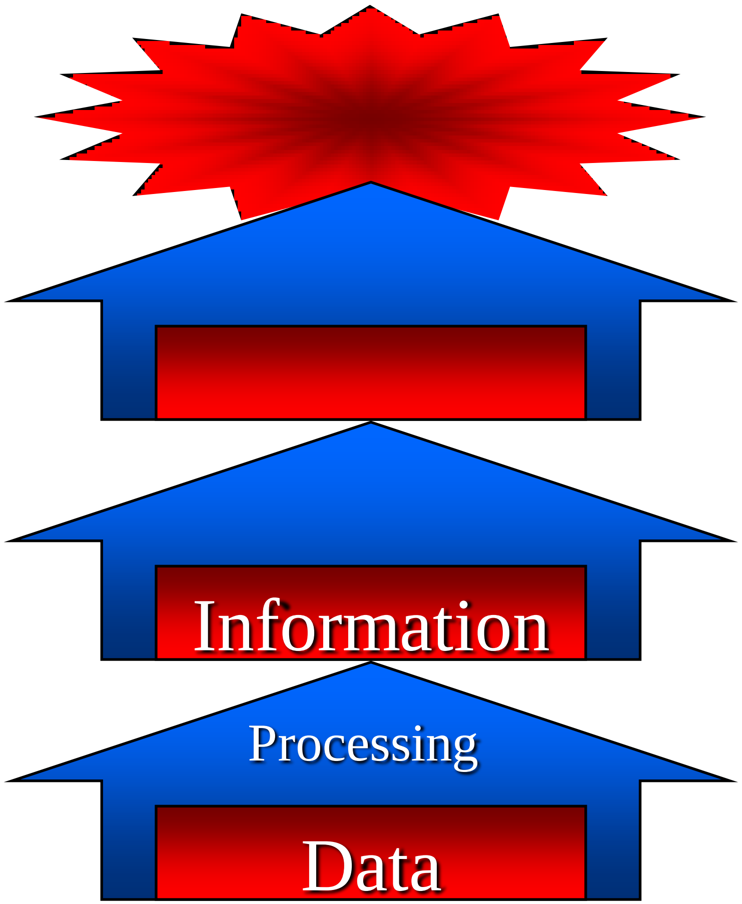
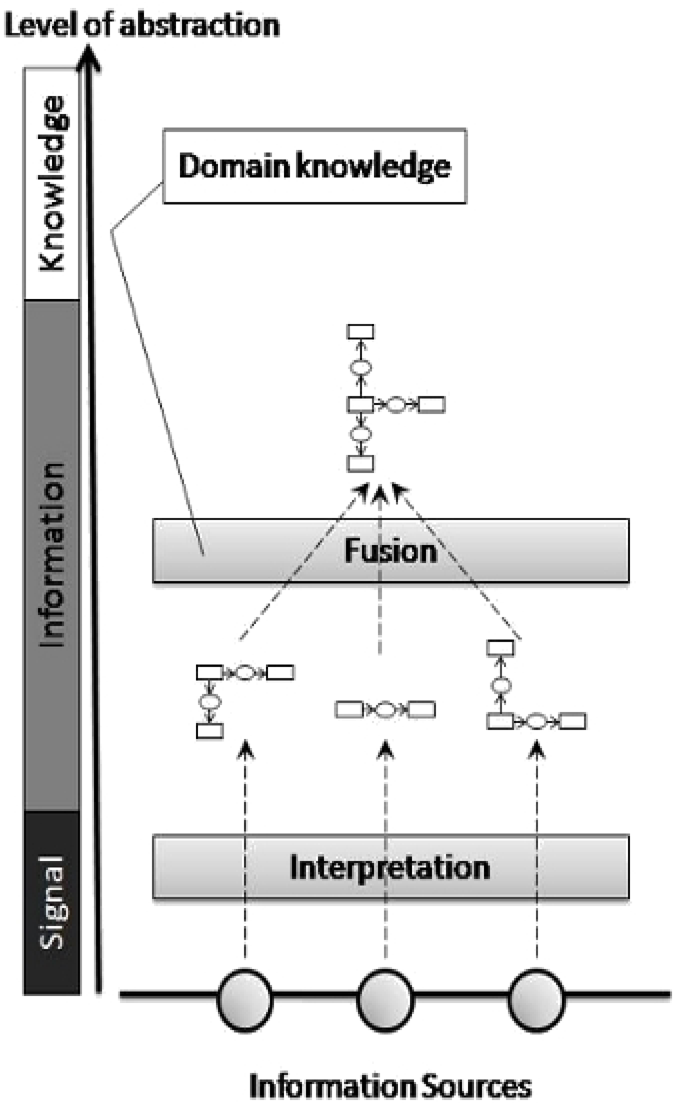
The Cognitive Hierarchy



"Data to INFORMATION"

Hard-Soft data/information sources



- **Nature:** hard information is quantitative - \numbers" (in finance these are balance sheet data, asset returns ...); soft information is qualitative - \words" (opinions, ideas, projects, comments ...); hard information is also rather \backward looking“ (e.g. balance sheet data) as soft information is rather \forward looking" (e.g. business plan, predictions, anticipations,…).
- **Collecting method:** collection of hard information is impersonal, and it does not depend upon the context of its production (hard information is therefore exhaustive and explicit), as collecting soft information is personal and includes its production and treatment context.
- **Cognitive factors:** subjective judgment, opinions and perception are absent in hard information, whereas they are integral components of soft information.

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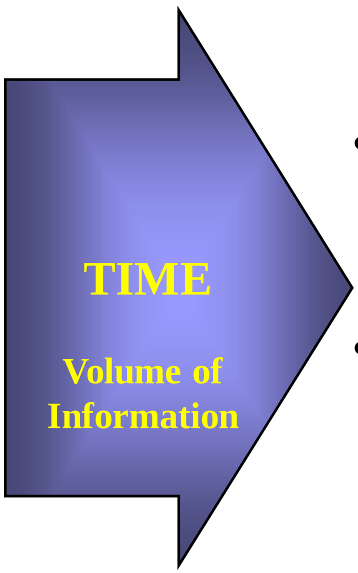
Distributed Sensor networks (1)



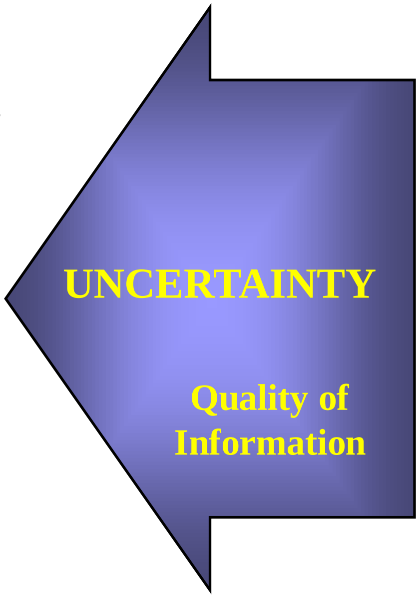
- A large number of important applications depend on **Distributed Sensor Networks** interfacing with the real world:
  - Medical, Military, Manufacturing, Transportation, Safety and Environmental planning systems.
- **Wireless sensor networks** are a trend of the past few years, and they involve deploying a large number of small nodes. – report to other nodes over a flexible architecture.
- In terms of complexity, in wireless sensor networks,
  - hundreds or thousands of microsensors are deployed in an uncontrolled way to monitor and gather information of environments.
  - Sensor nodes have **limited** power, computational capacities, memory, and communication capability.

Distributed Sensor Networks (2)

- The amount and variance of data is becoming quite overwhelming:
  - improved methods to deal with this **data overload**.

- Need **to extract useful features and properties** from the assorted data, without compromising its real-world and real-time nature.

- **Making sense of data** in the context of distributed sensor networks:
  - automated reasoning systems (cognitive)
  - Novel schemes for **data fusion, data mining and pattern recognition** must be proposed and evaluated through simulation experiments.



Defense and Security Applications

- Protection of critical infrastructures
  - Power plants
  - Military bases
  - Government HQs
  - Harbours and airports

- Piracy and terrorism domains

Public Health Informatics

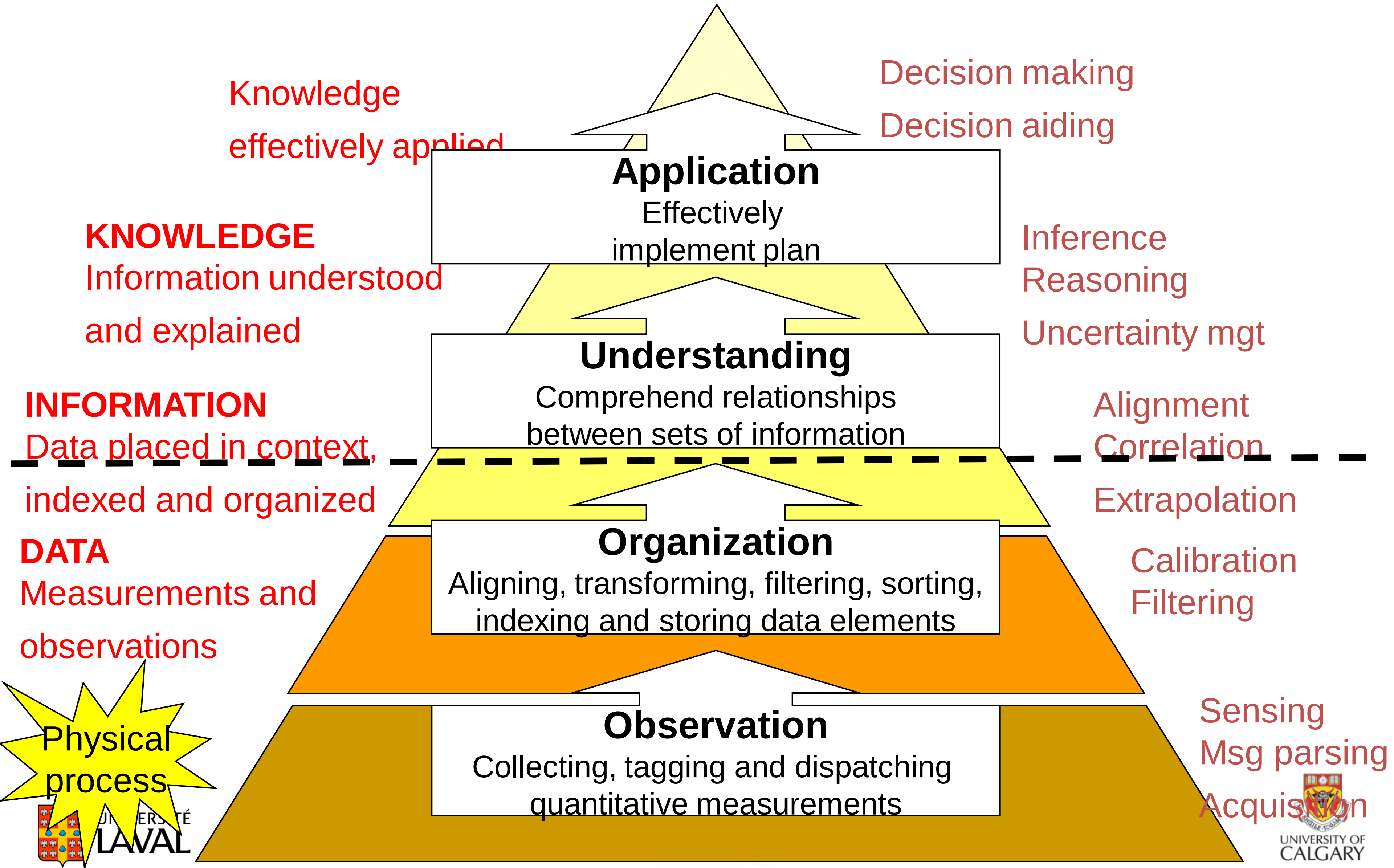
- Air Quality Effects on Health-Indicator Data in Disease Outbreak Surveillance;
- Drinking Water Security and Public Health Disease Outbreak Surveillance
- Biosurveillance
- The Potential Utility of Electronic Disease Surveillance Systems in Resource-Poor Settings
- Enhancing Public Health Disease Surveillance Capability
- Decision Support Models for Public Health Informatics

Optimization objectives

- Number of sensors
- Coverage
- Event occurrence probability
- Event detection probability
- Optimization of sensor placement
- Placement suitability
- Minimum distance to asset
- Optimization of pattern recognition systems

Information Hierarchy

Source: Information Warfare - Principles and Operations, by Edward Waltz



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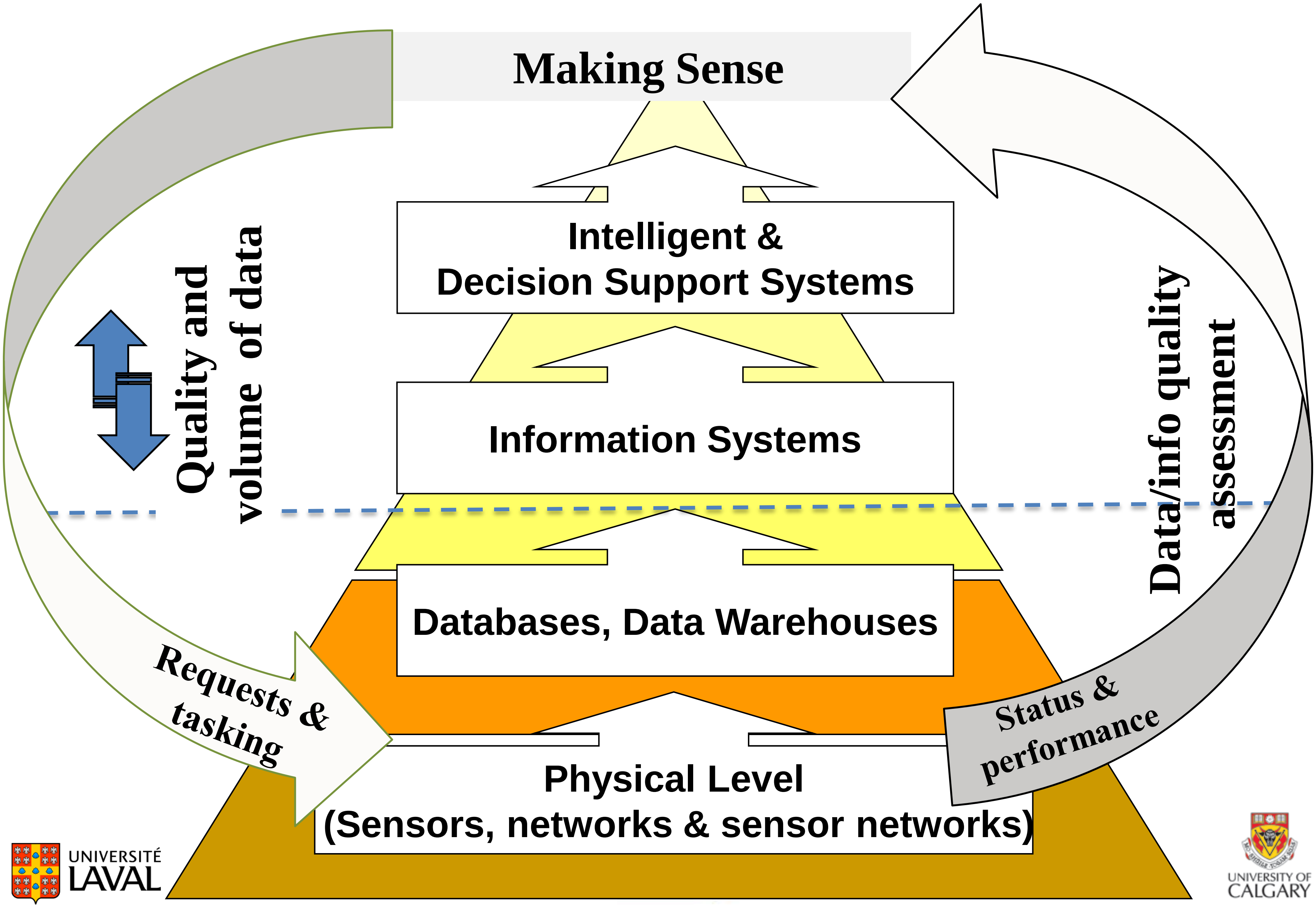
Systems Hierarchy



Examples of more smart sensing

- DARPA) Mind's Eye program Broad Agency Announcement (BAA). http://www.fedbizopps.gov.

2. Making sense:

Multi-sensor data/information fusion

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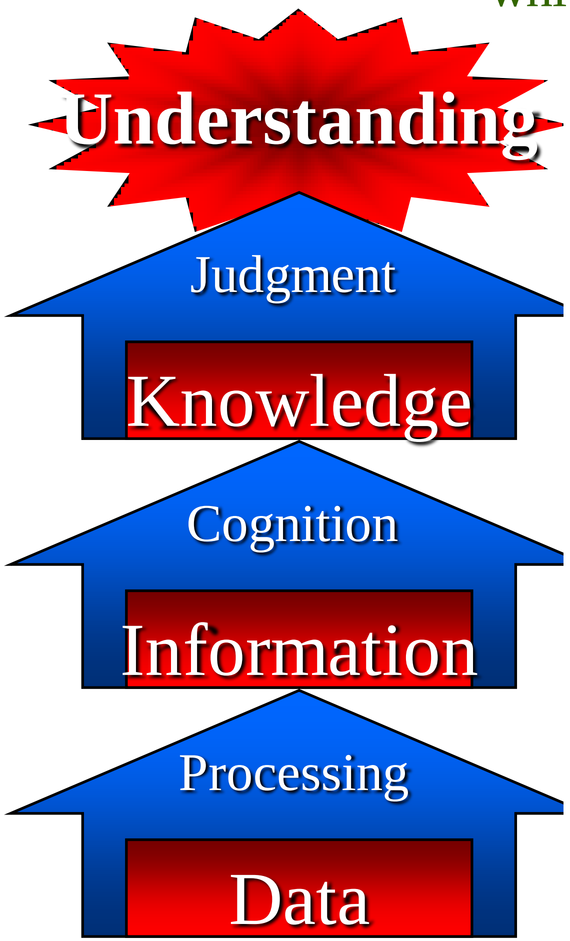
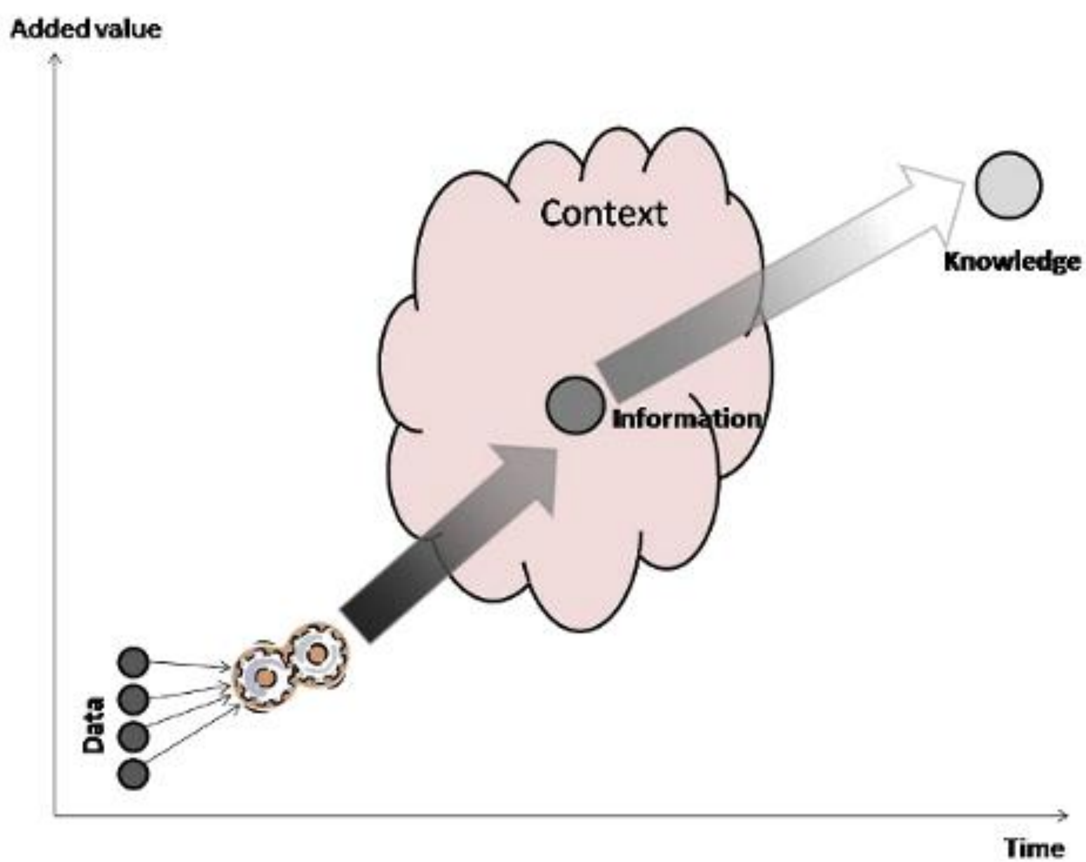
Context : key to understanding

No understanding is possible without knowing the context in which the process of perception of a situation occurs.





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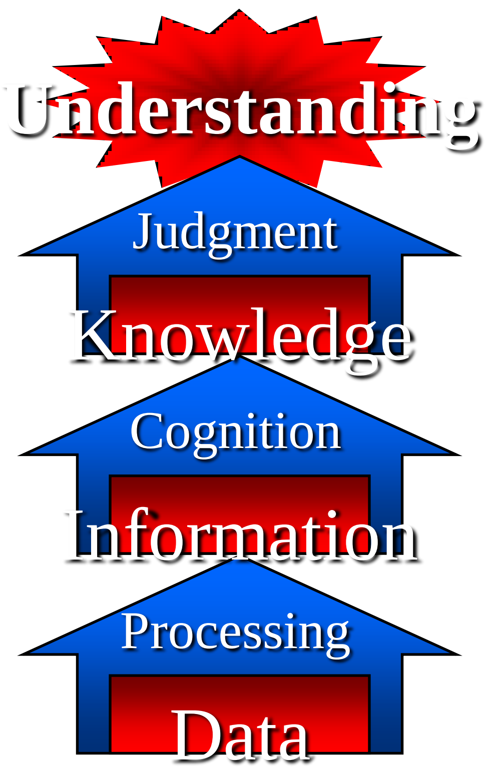
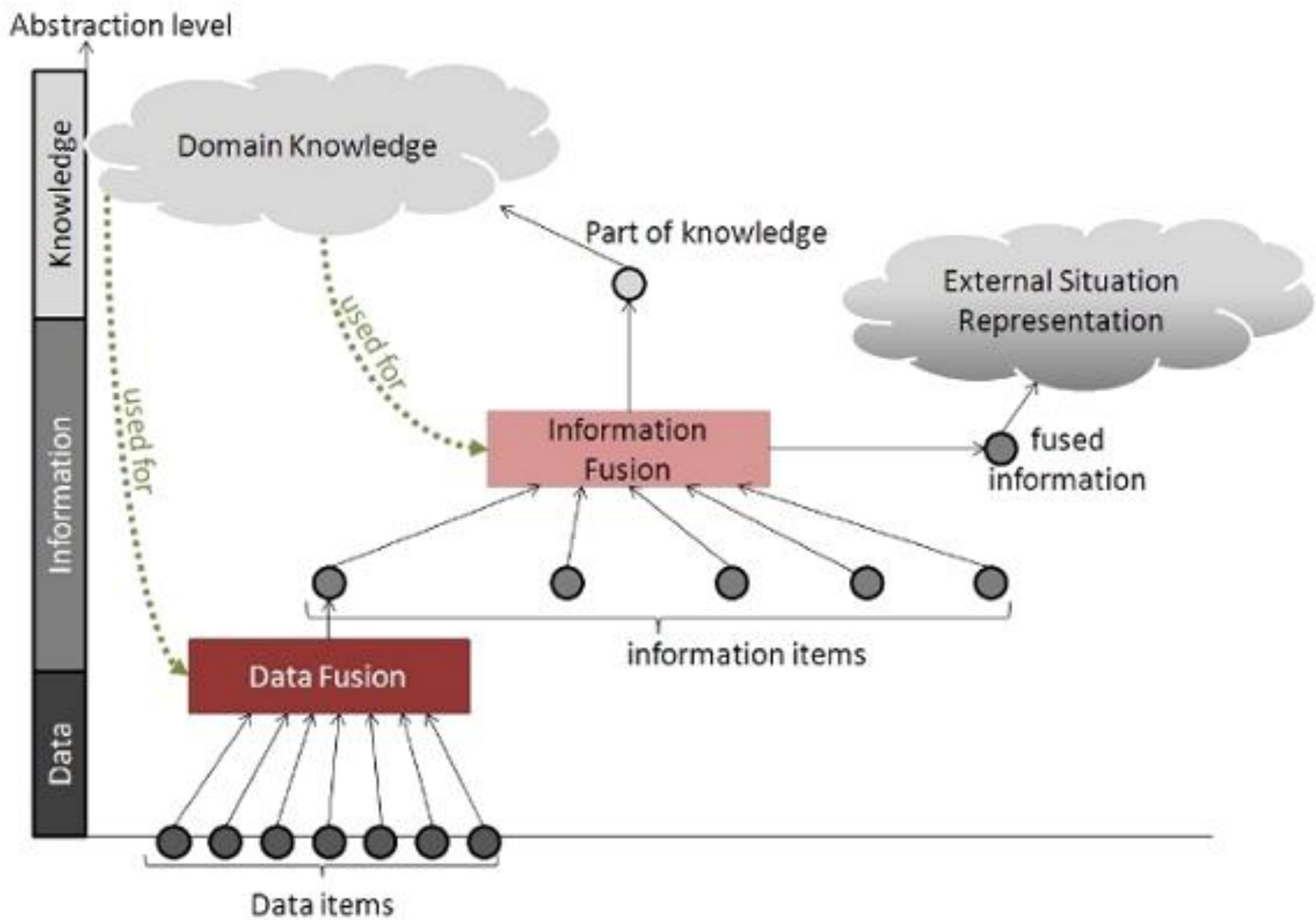
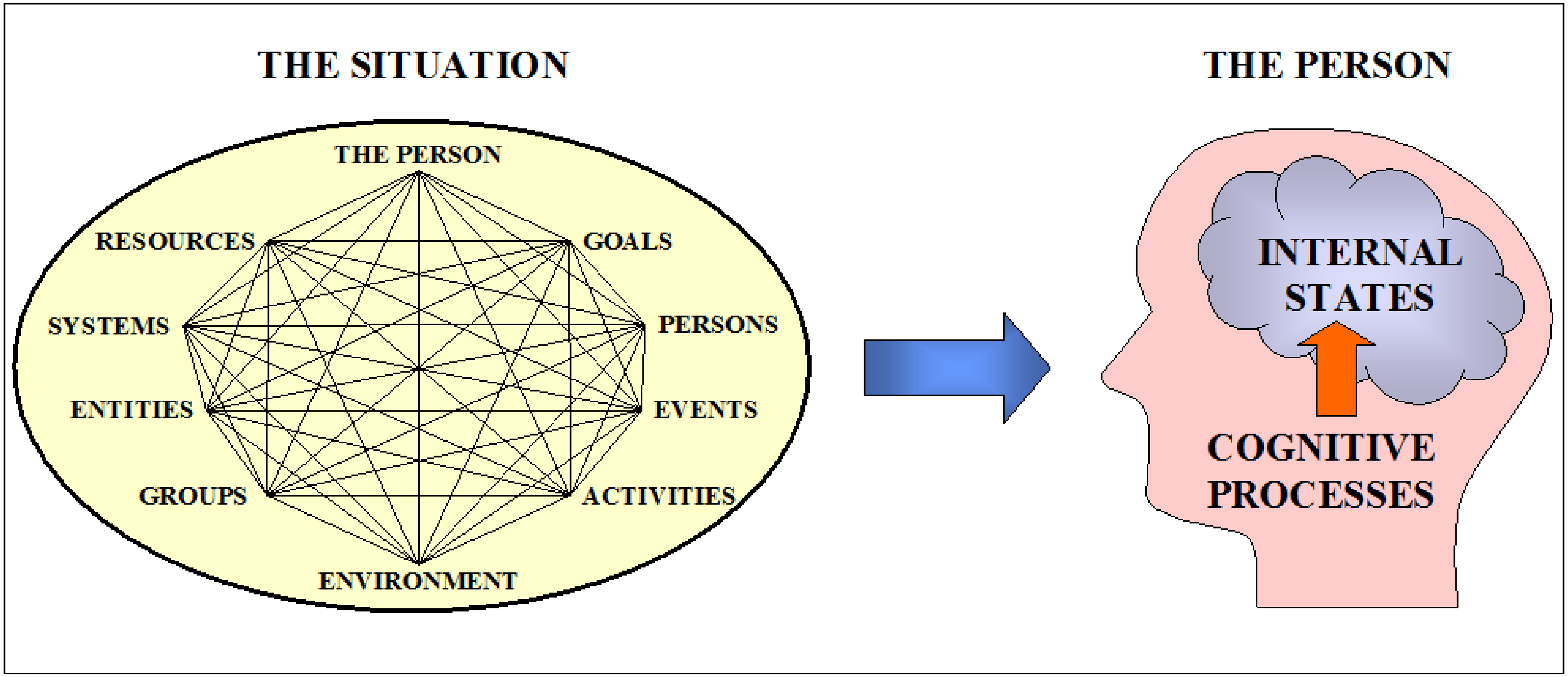
Domain Knowledge Representation

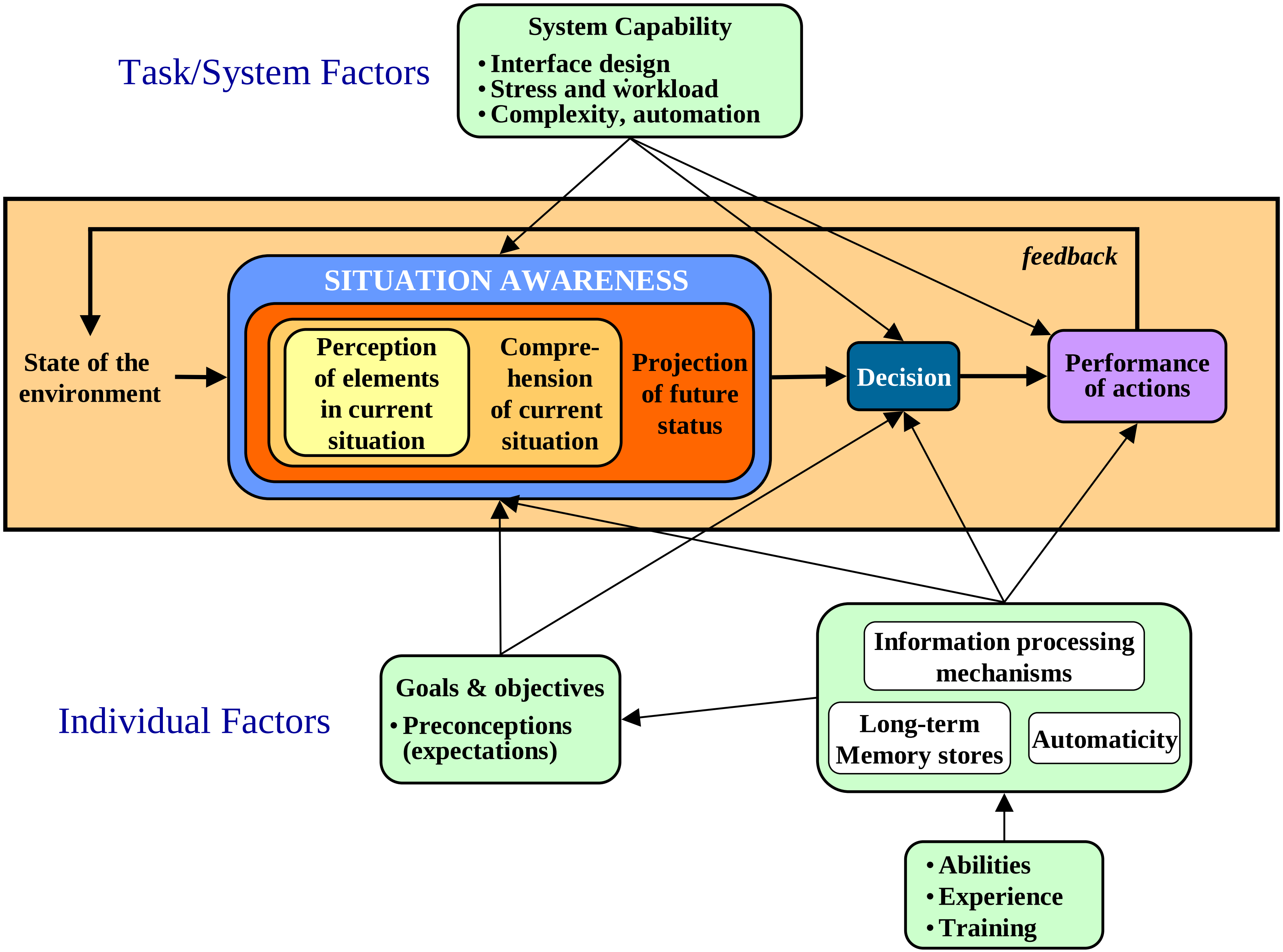




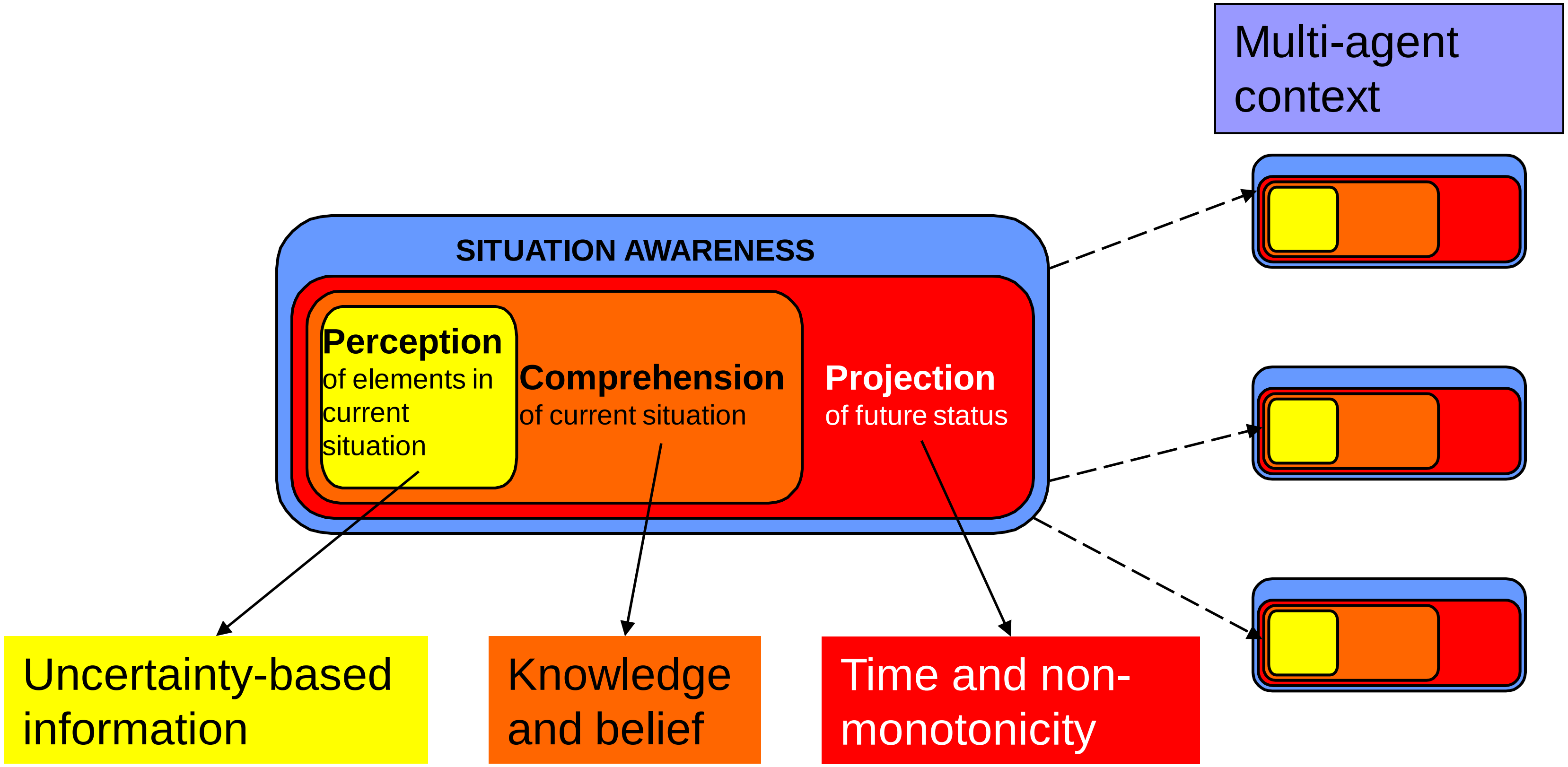
Situation awareness



Endsley's model of situation awareness



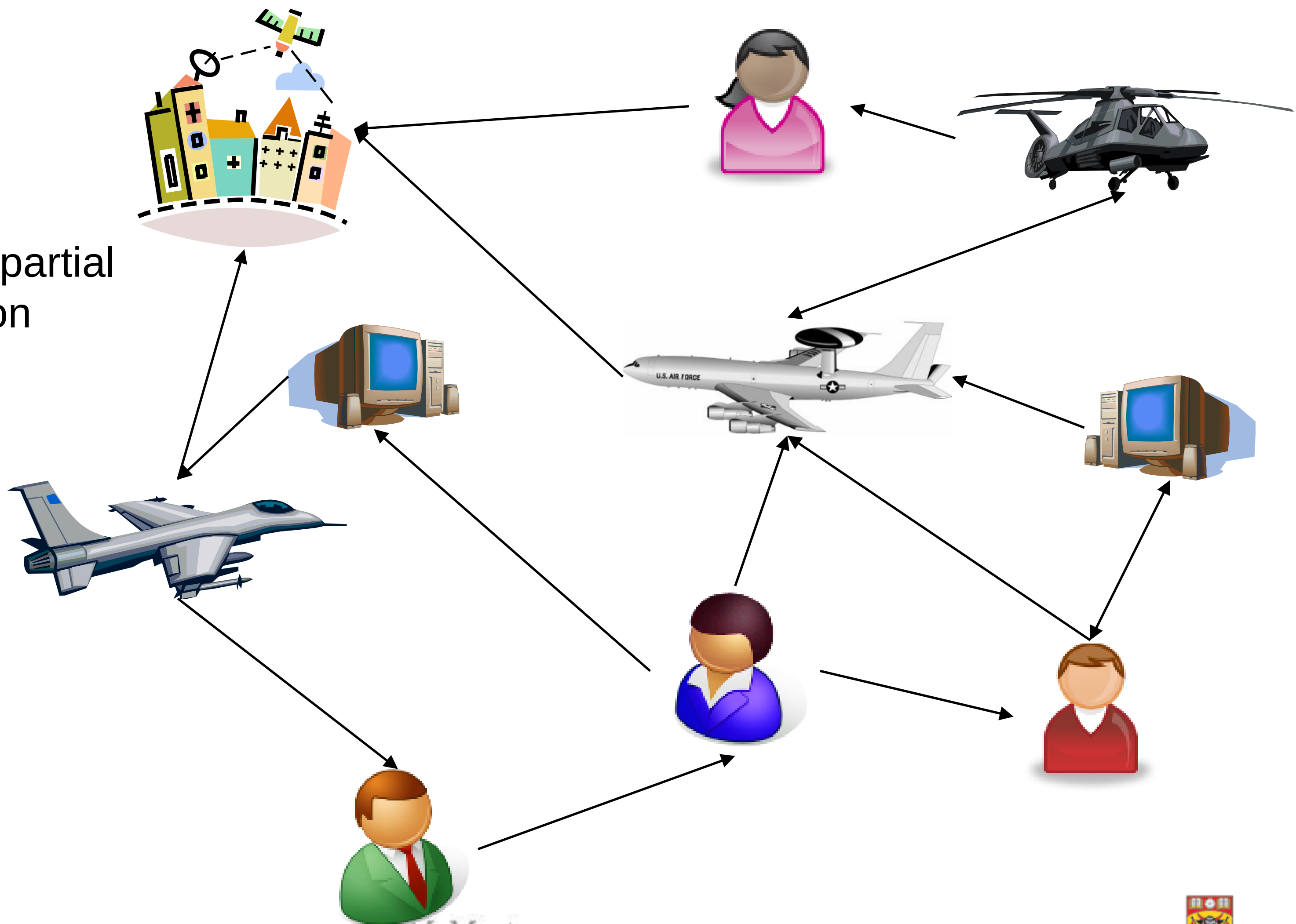
Multi-agent Situation Awareness



These aspects should be considered all together

Distributed system

Each agent has a partial view of the situation



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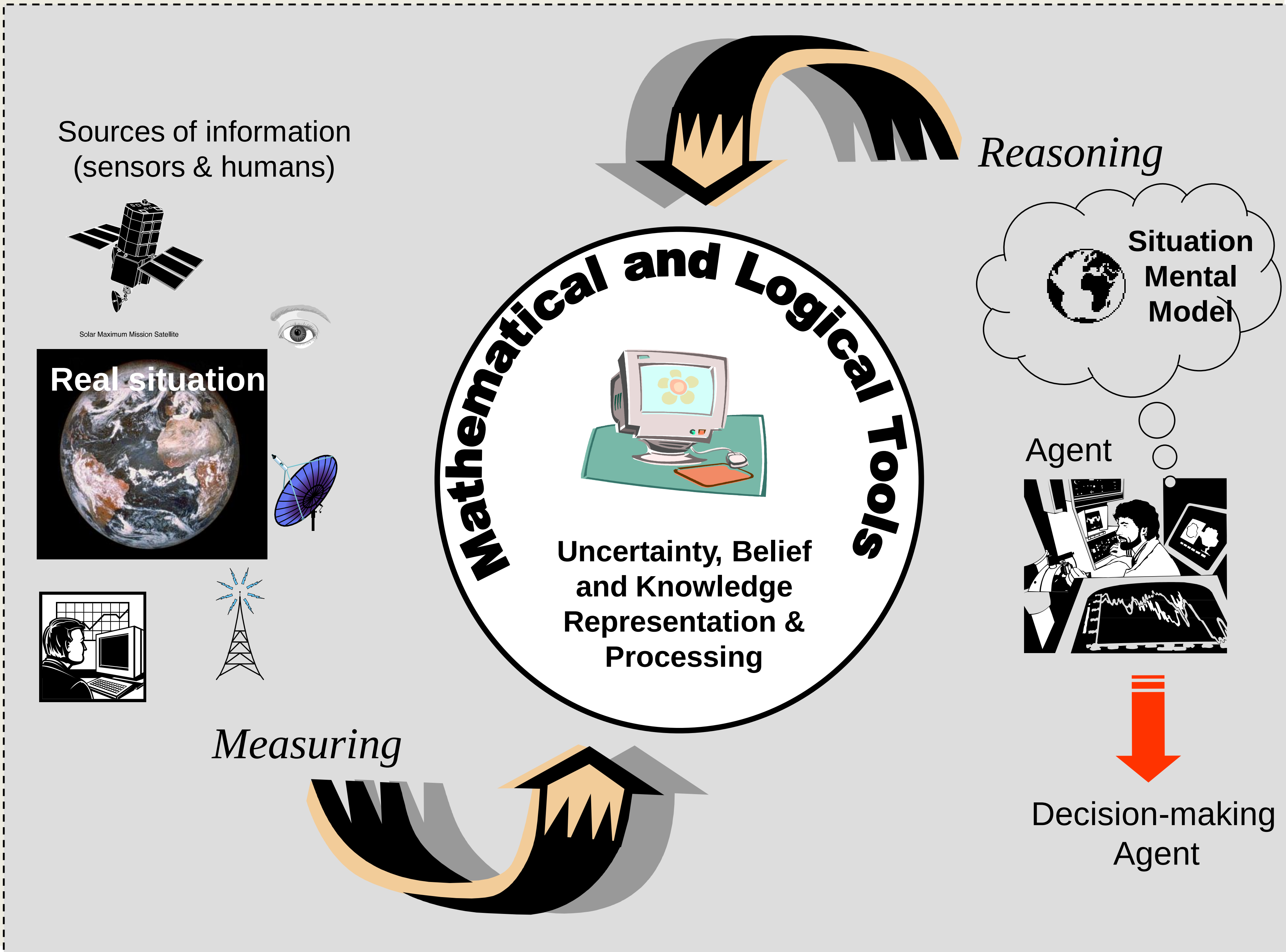
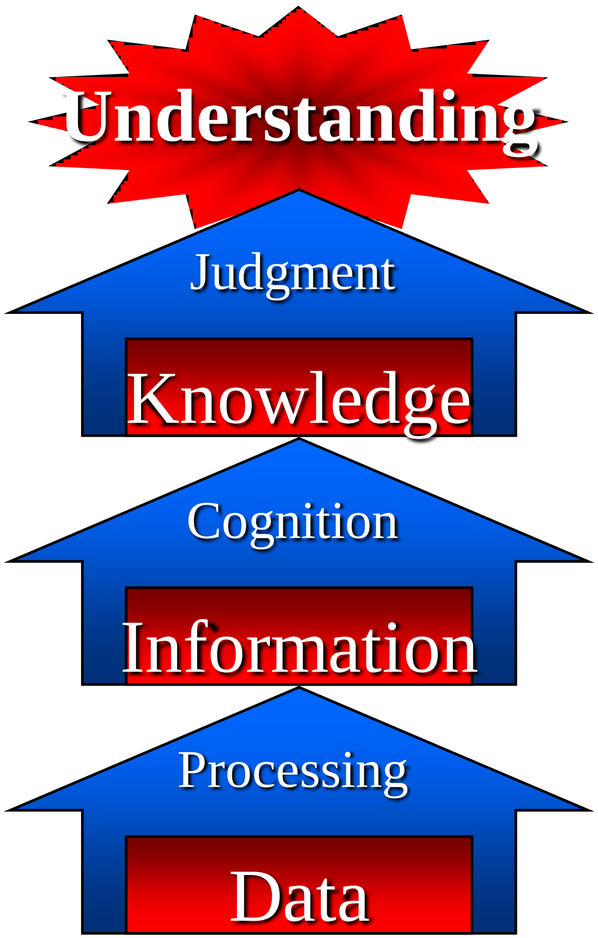


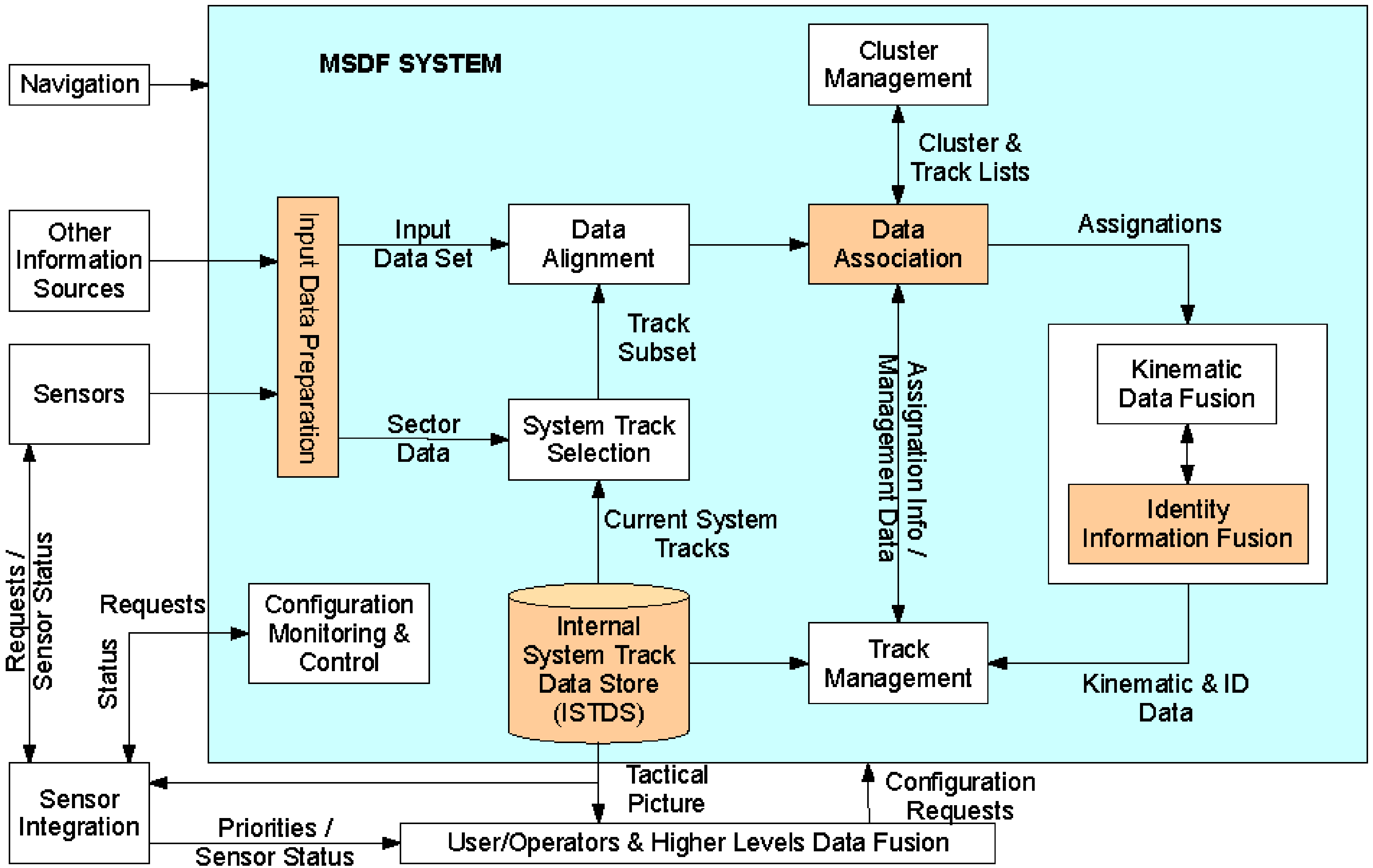
Sources of information
(sensors & humans)
Solar Maximum Mission Satellite
Real situation
Mathematical and Logical Tools
Uncertainty, Belief and Knowledge Representation & Processing
Reasoning
Situation Mental Model
Agent
Decision-making Agent
Measuring

Data/Information Fusion

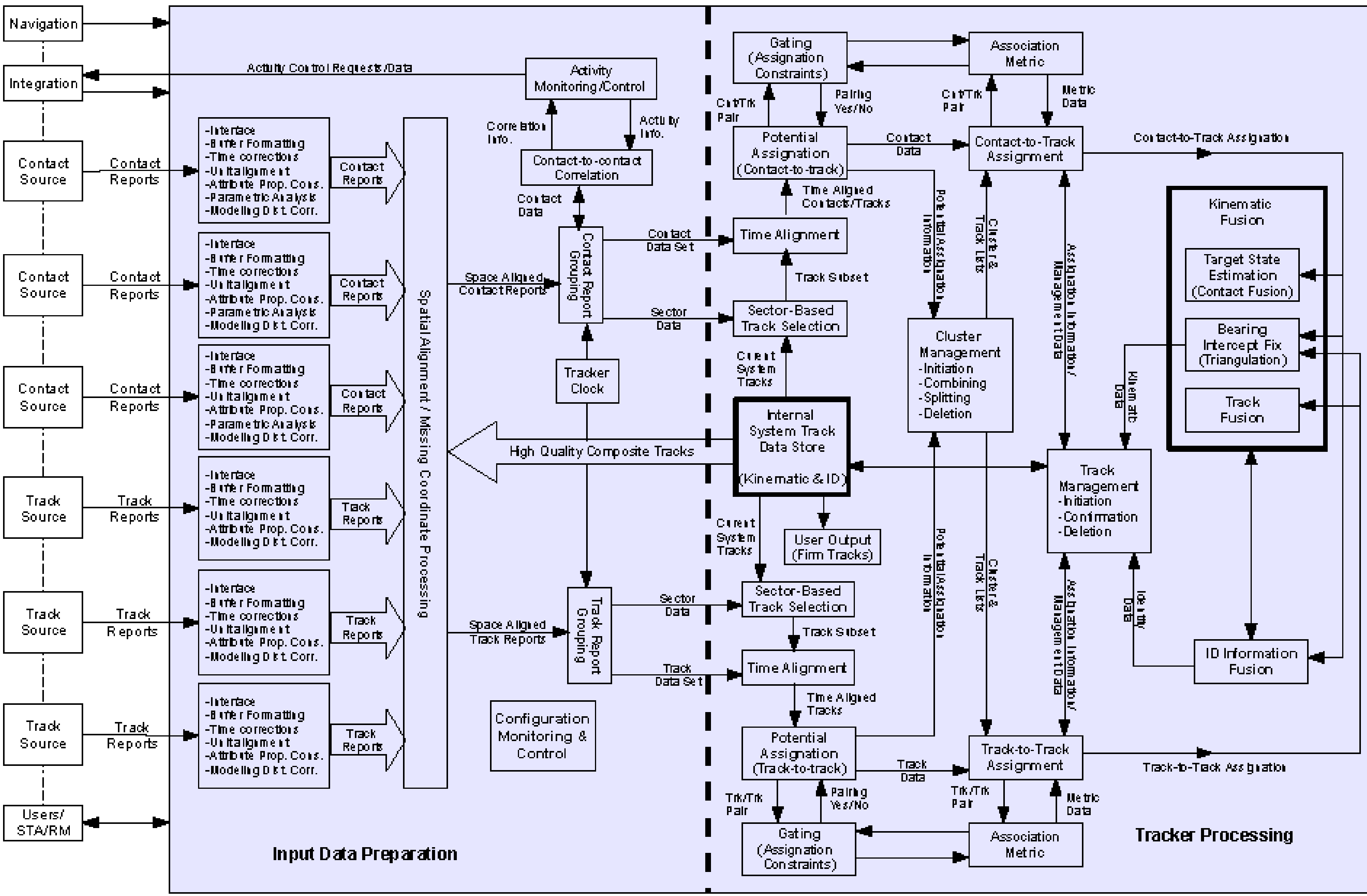


- Multi-sensor data fusion
- High-levels information fusion:
  - situation analysis - understanding
  - making sense
- **Data/Information Fusion** is a key enabler for **Situation Analysis** that aims to support the decision maker in constantly improving his situation awareness

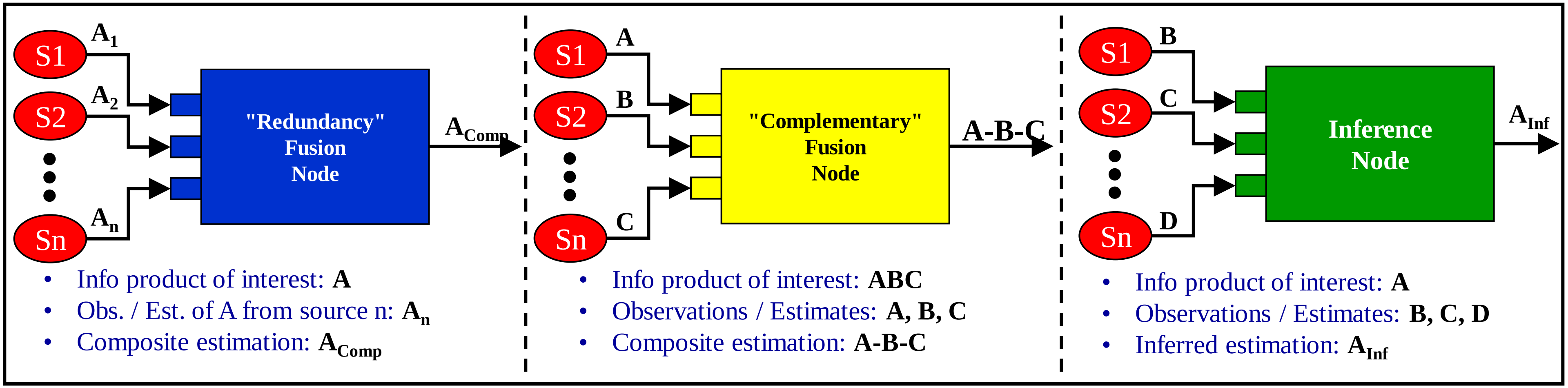
MSDF architecture



MSDF detailed architecture

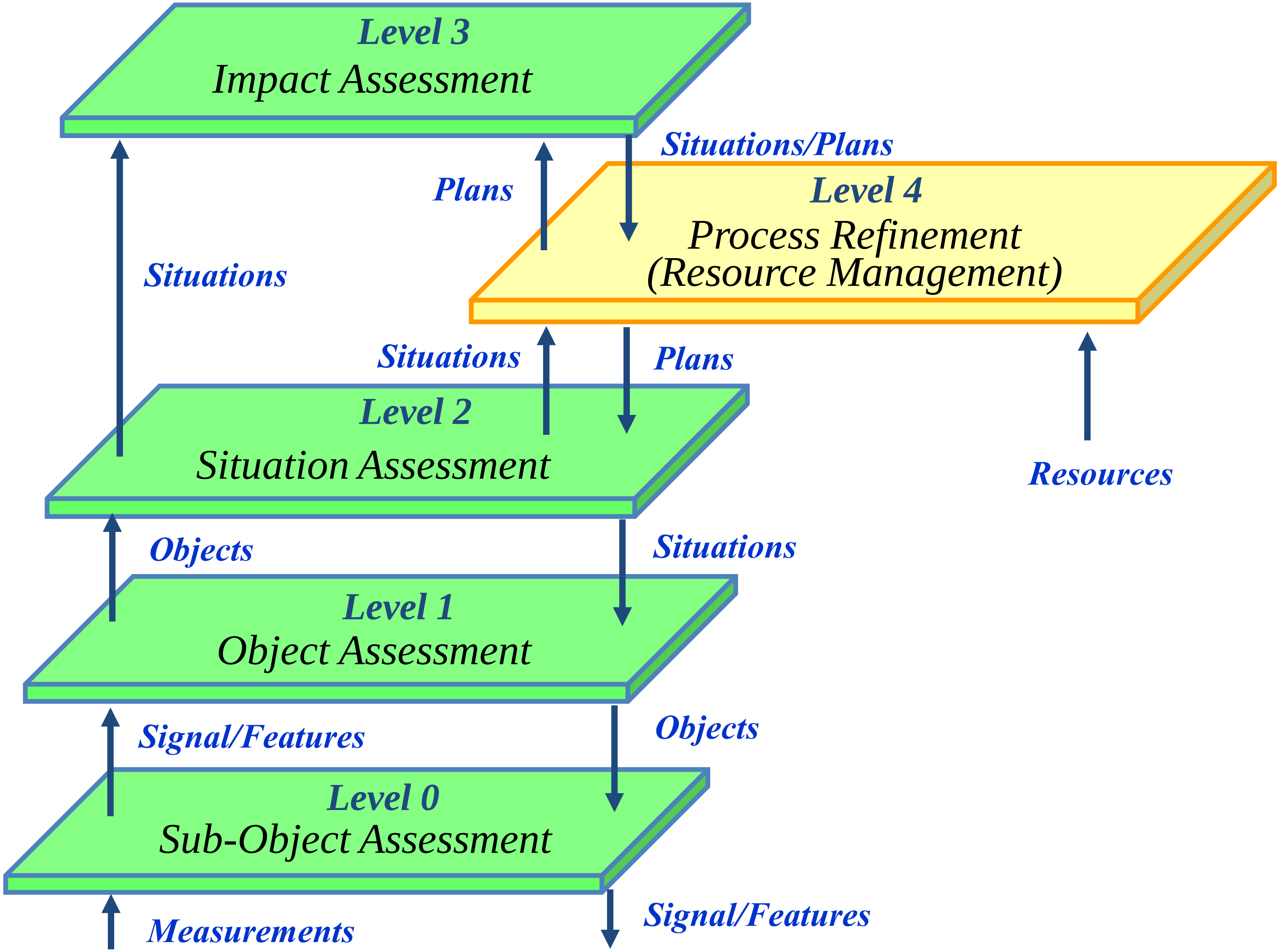


Fusion and reasoning inference nodes



The JDL Data Fusion Model

(Revised JDL Model: A. Steinberg/C. Bowman/F. White, 1998)



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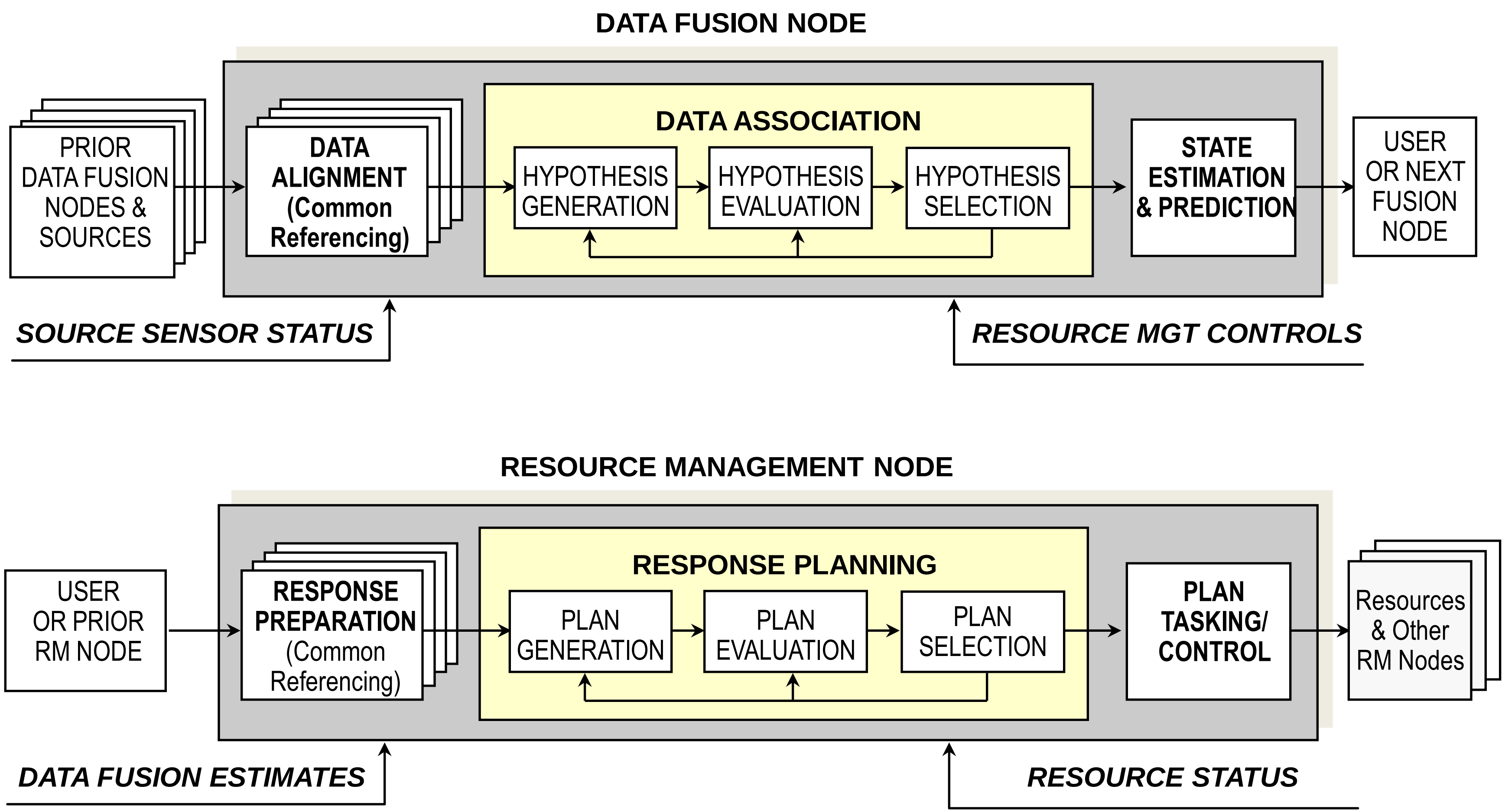

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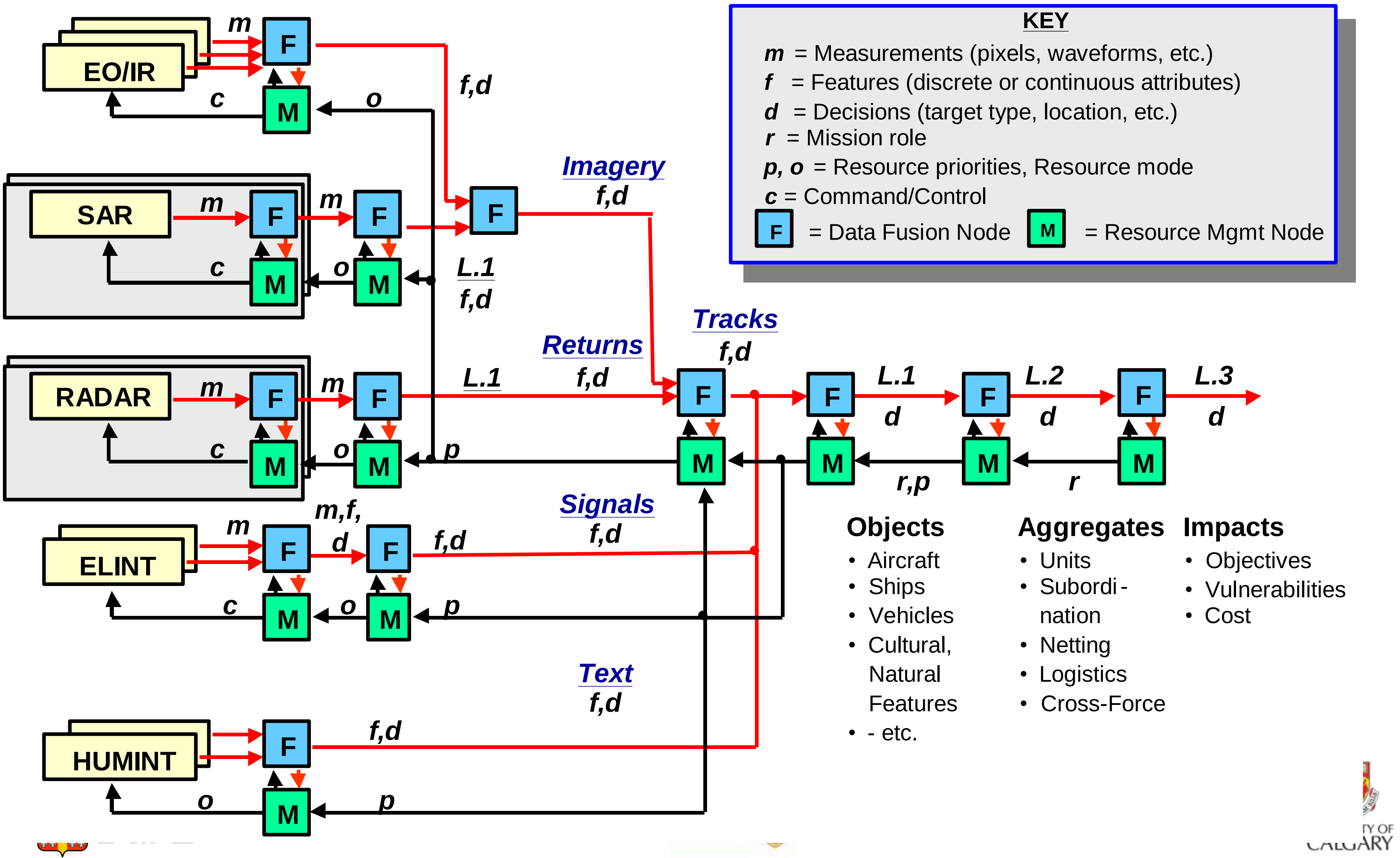
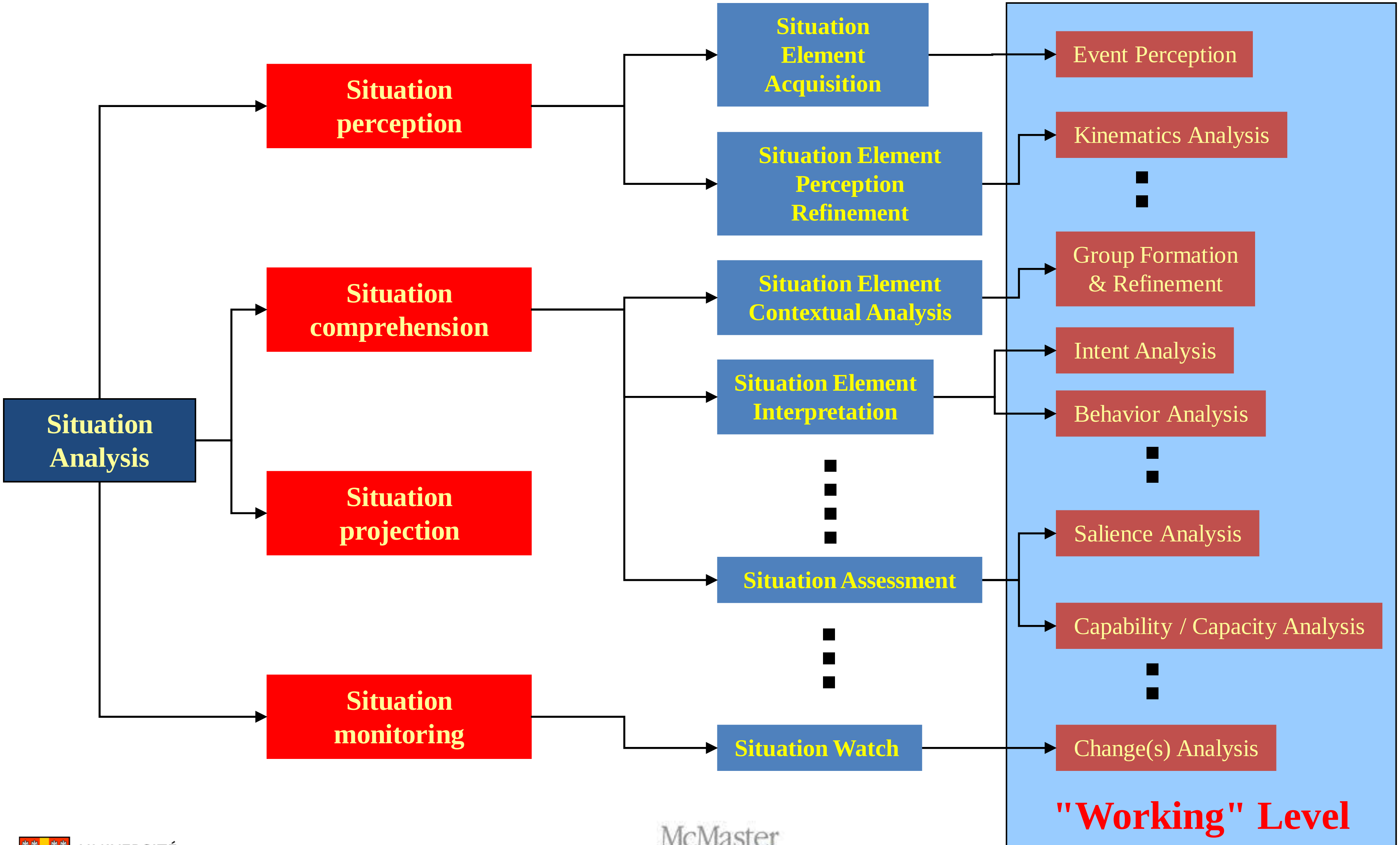
Integrated data fusion/resource management trees ([Steinberg, Bowman, White, 1998])



Hierarchical decomposition



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Five basic tasks for SA

1. Detection:

   Object

2. Enumeration:

   (Objects) $\longrightarrow \mathbb{N}$

3. Classification:

   Object $\longrightarrow$ Class

4. Tracking:

   Object(t) $\longrightarrow$ Object(t +1)

5. Linking up:

   Object_i $\longleftrightarrow$ Object_j

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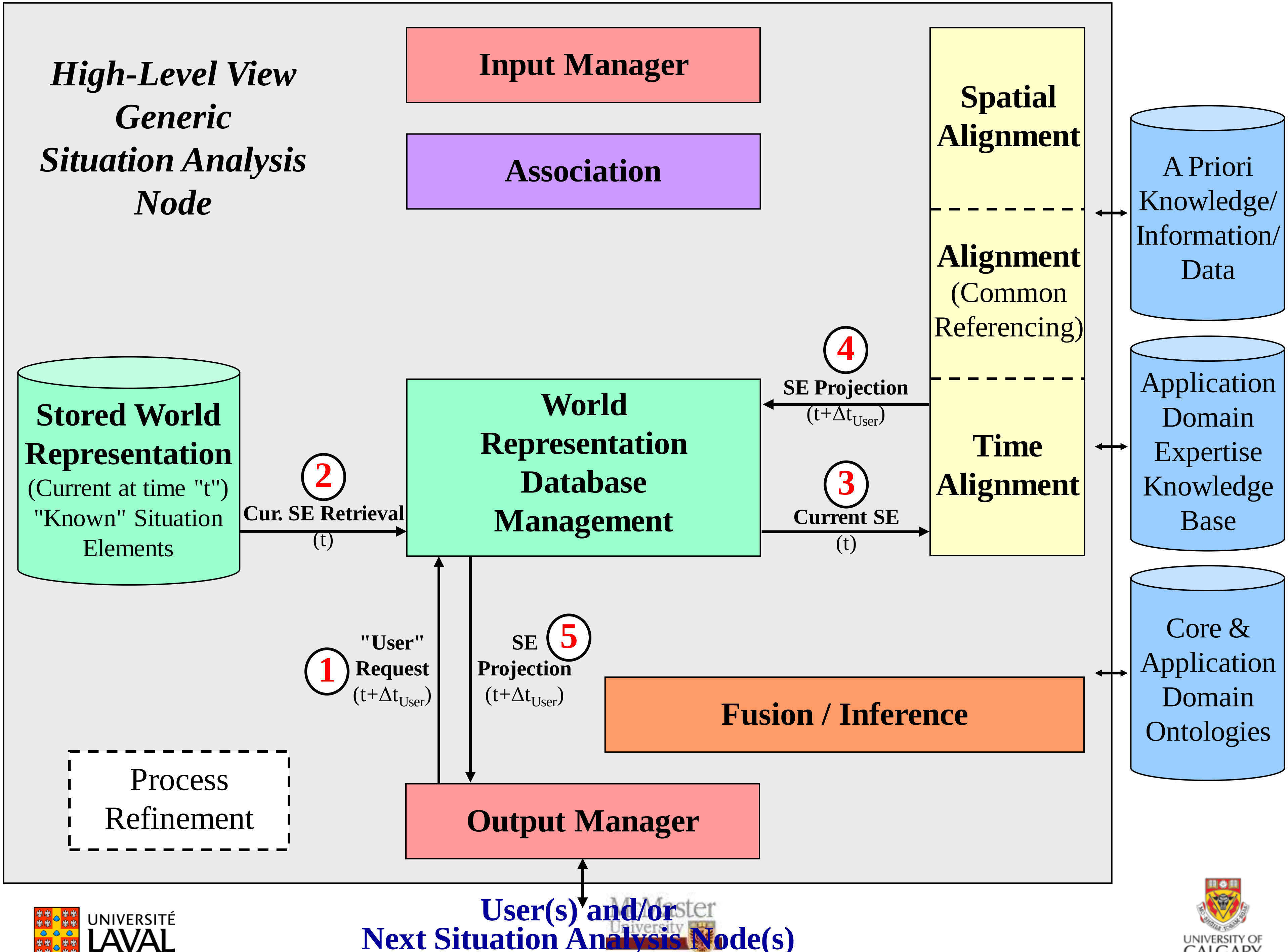

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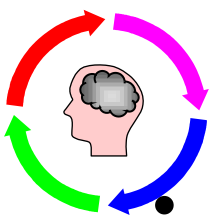
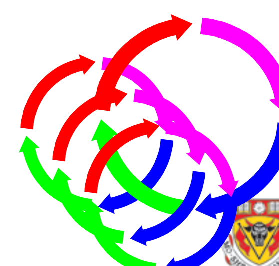
Information fusion/SA needs:

- A framework in which knowledge, information and uncertainty can be represented, combined, managed, reduced, increased, interpreted (e.g. GIT);
- Decision theories to explicitly account for the actions and their impact on the environment (to go beyond the open-loop treatment);



- Multi-agent systems theories to formalize the distributed aspect;
- Measures of performance --- ‘so what’



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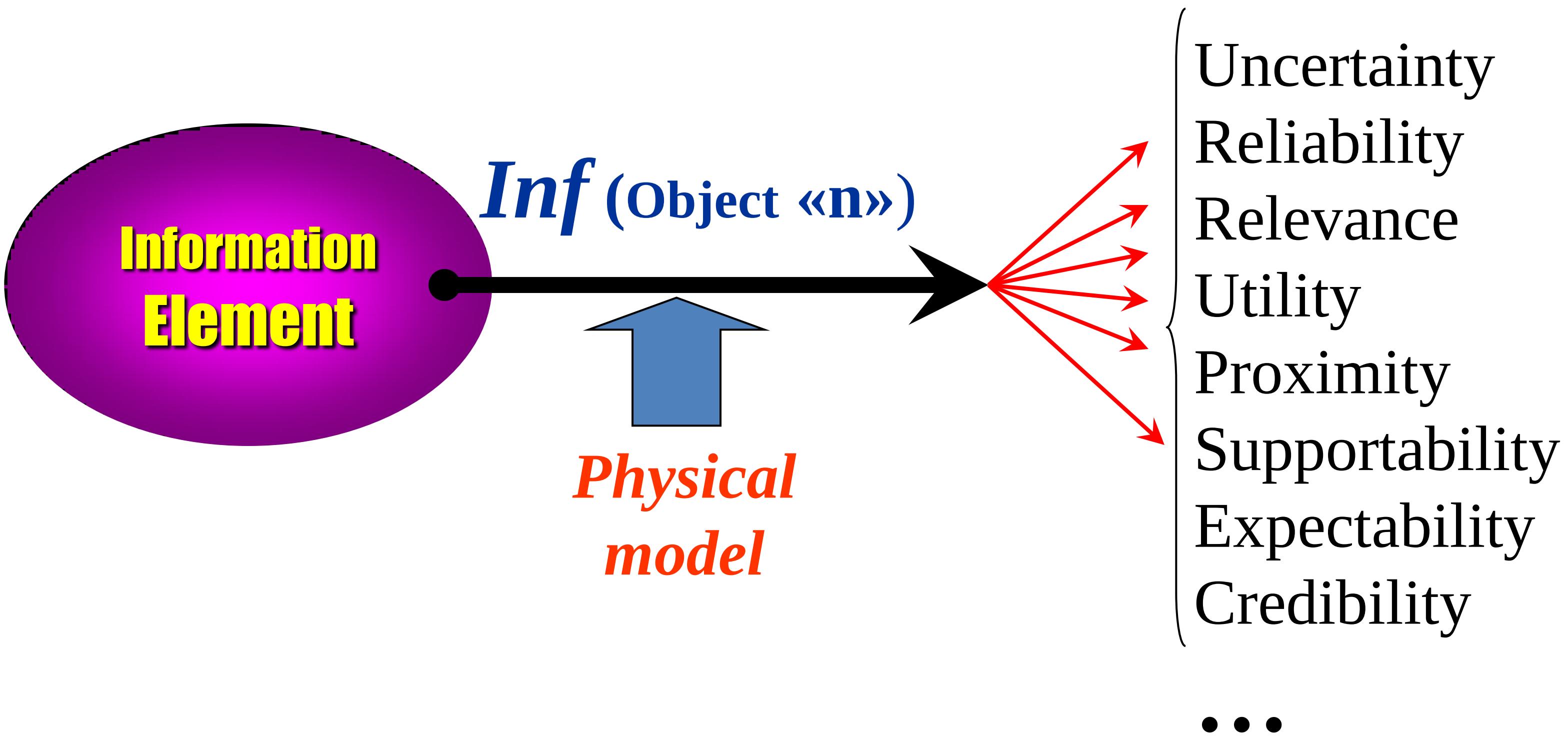
'Key to decisions is information'



'Information enables Situation Awareness'

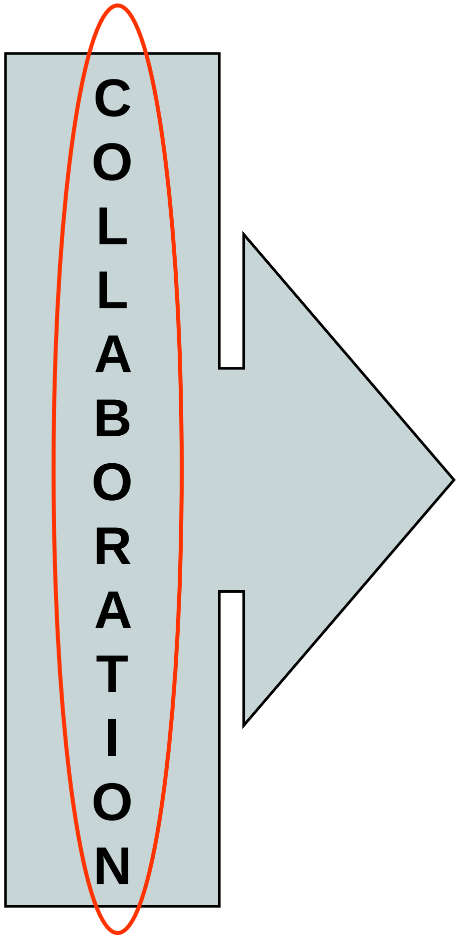
Collaboration in the NATO SAS-050 C2 Conceptual Reference Model (1 of 2)

INPUT
(21)

- Information Networks
- Information Accuracy
- Information Completeness
- Information Correctness
- Information Currency
- Information Consistency
- Information Precision
- Information Relevance
- Information Timeliness
- Information Uncertainty
- Shared Understanding Accuracy
- Shared Understanding Completeness
- Shared Understanding Consistency
- Shared Understanding Correctness
- Shared Understanding Currency
- Shared Understanding Precision
- Shared Understanding Relevance
- Shared Understanding Timeliness
- Shared Understanding Uncertainty
- Quality of Interactions
- Uncertainty of Situation

COLLABORATION

Collaboration in the NATO SAS-050 C2 Conceptual Reference Model (2 of 2)



OUTPUT
(19)

- Communications Interoperability
- Shared Awareness Accuracy
- Shared Awareness Completeness
- Shared Awareness Consistency
- Shared Awareness Correctness
- Shared Awareness Currency
- Shared Awareness Precision
- Shared Awareness Relevance
- Shared Awareness Timeliness
- Shared Awareness Uncertainty
- Decision Accuracy
- Decision Completeness
- Decision Consistency
- Decision Correctness
- Decision Currency
- Decision Precision
- Decision Relevance
- Decision Timeliness
- Decision Uncertainty

1. Two meanings for uncertainty

Sense I - Uncertainty as a state of mind

Ex: I'm not certain that the cat is in the bedroom

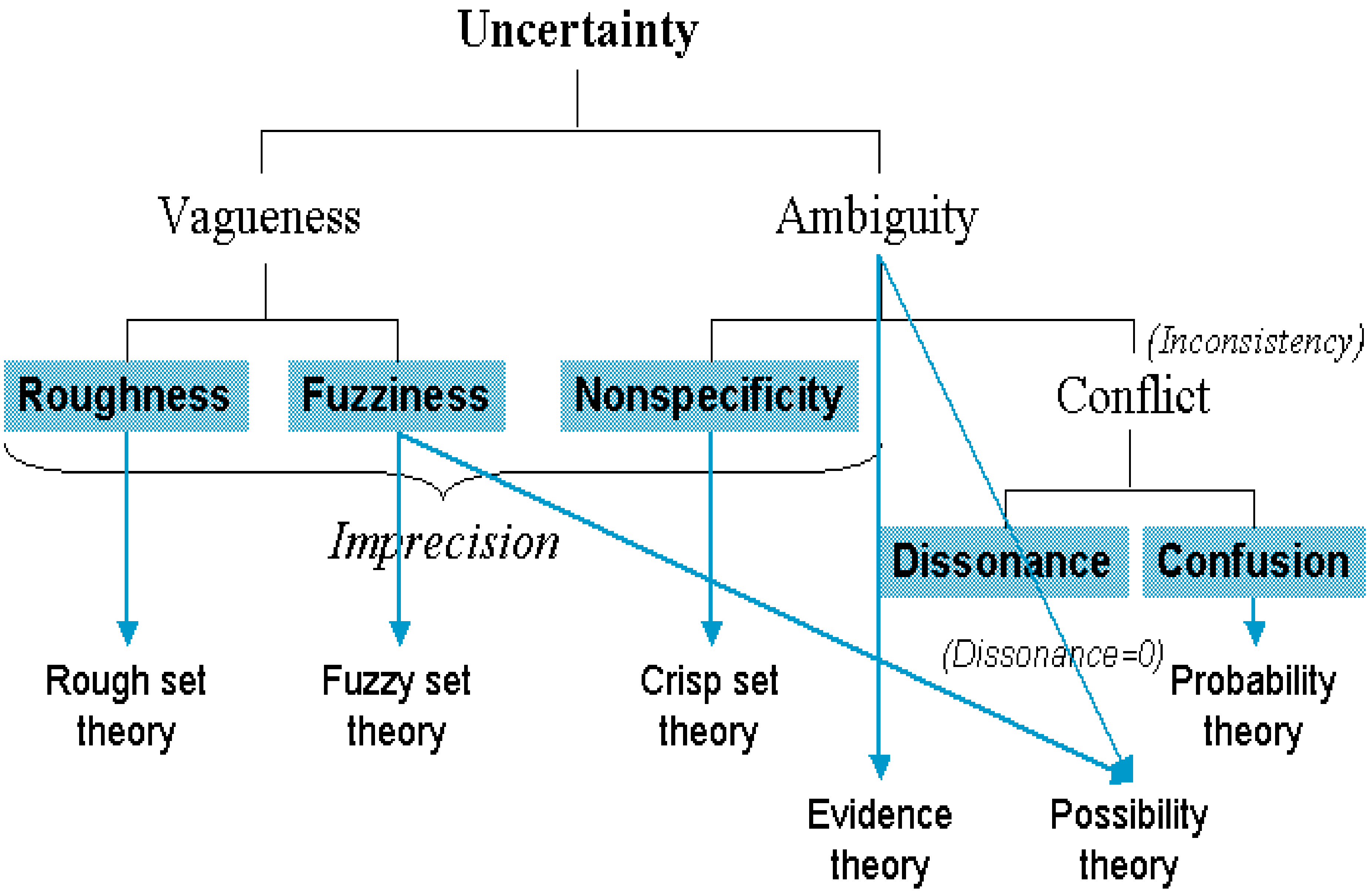
Ignorance - Knowledge

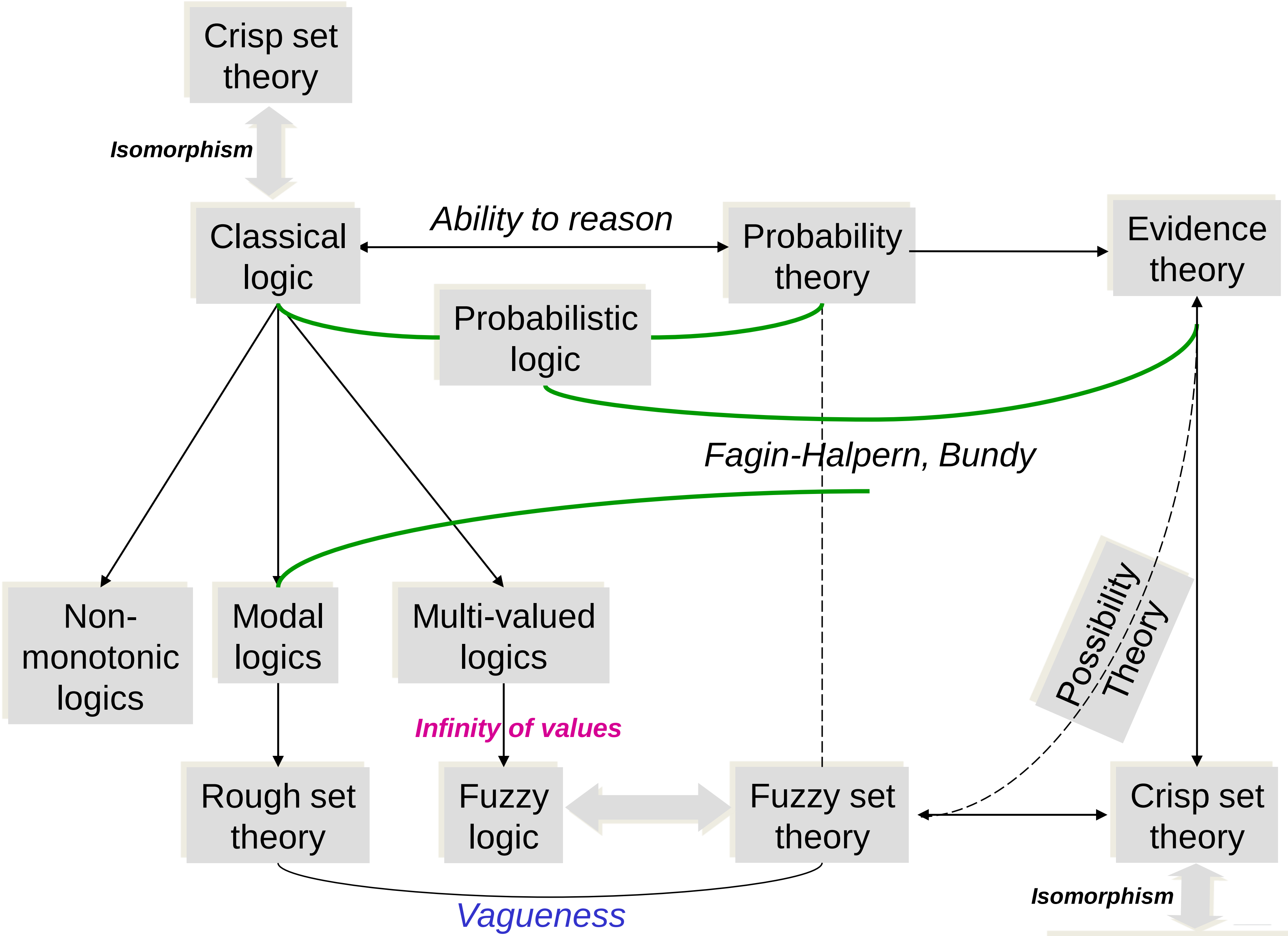
Sense II - Uncertainty as a property of the information

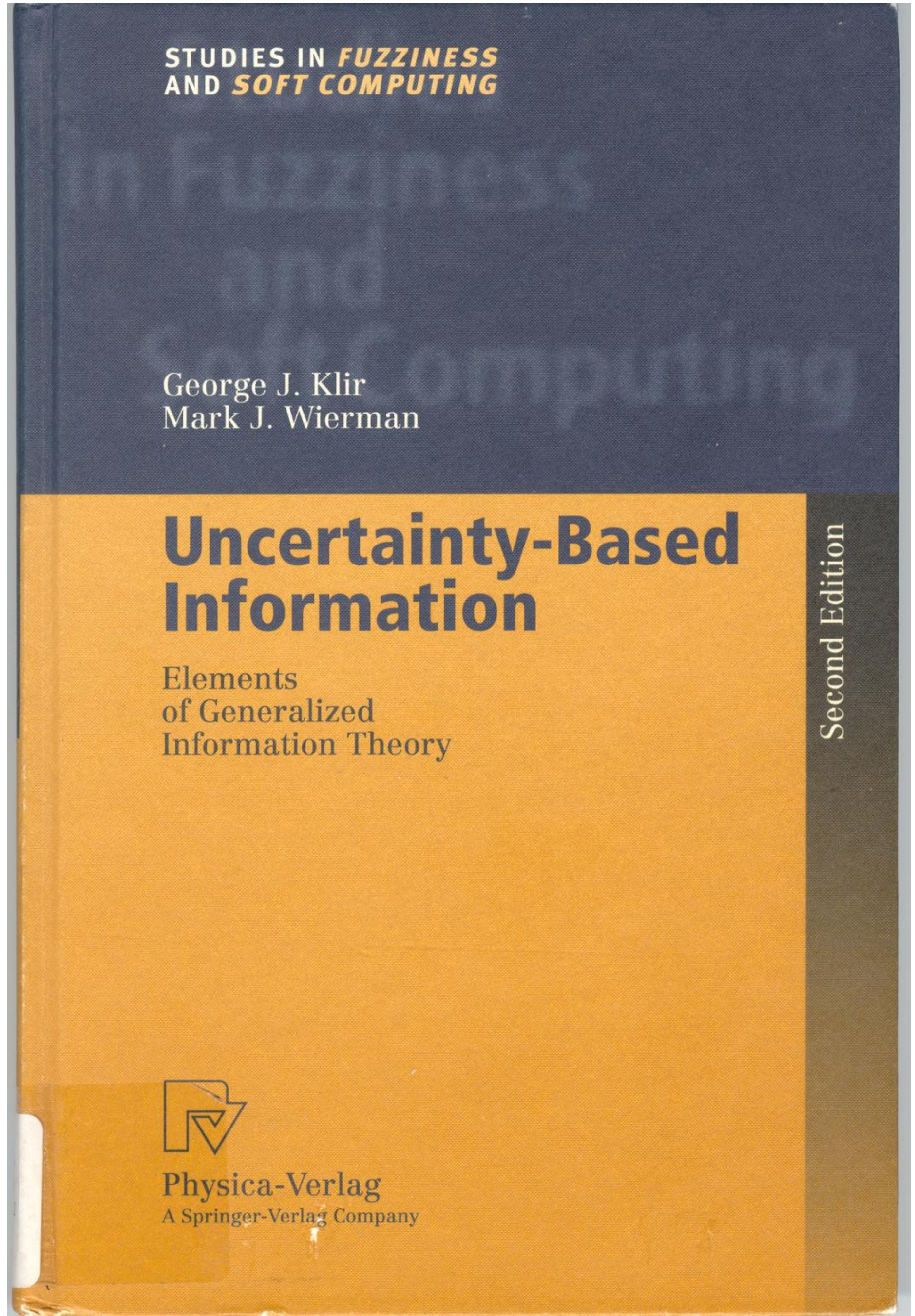
Ex: This cat is gray (the color of the cat is uncertain)

(gray in RGB=[55 55 55] or [98 90 99]?)

Uncertainty - Information


Uncertainty
Vagueness
Ambiguity
Roughness
Fuzziness
Nonspecificity
(Inconsistency)
Conflict
Imprecision
Dissonance
Confusion
(Dissonance=0)
Rough set theory
Fuzzy set theory
Crisp set theory
Probability theory
Evidence theory
Possibility theory


Crisp set theory
Isomorphism
Classical logic
Ability to reason
Probability theory
Evidence theory
Probabilistic logic
Fagin-Halpern, Bundy
Non-monotonic logics
Modal logics
Multi-valued logics
Possibility Theory
Infinity of values
Rough set theory
Fuzzy logic
Fuzzy set theory
Crisp set theory
Isomorphism
Classical logic
Vagueness


STUDIES IN FUZZINESS
AND SOFT COMPUTING
George J. Klir
Mark J. Wierman
Uncertainty-Based
Information
Elements
of Generalized
Information Theory
Second Edition
Physica-Verlag
A Springer-Verlag Company

Combine different pieces of uncertain information

Need for manipulation of numerous theoretical frameworks of different natures

1. Making the different frameworks "communicate" between each other

    Ex.: Fuzzy information and probabilistic information

2. Using "general" frameworks (a single formalism):

    2.a. Numerical **OR** symbolic

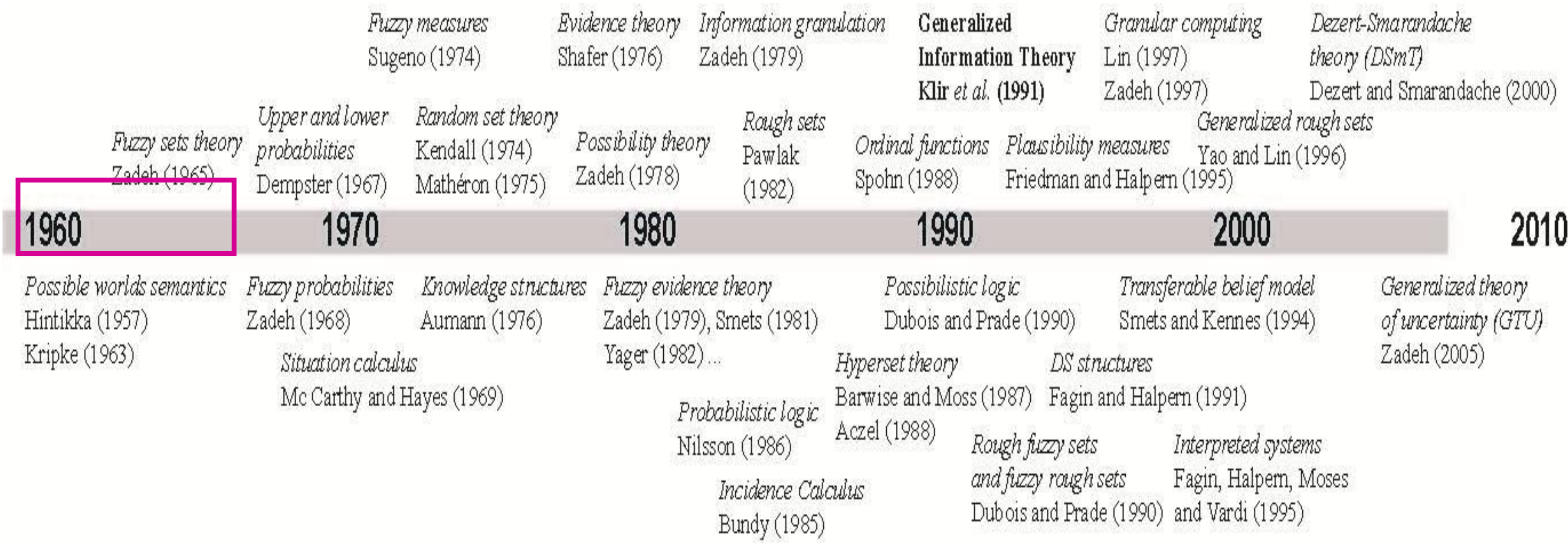
    Ex.: Random sets, autoepistemic logic

    2.b. Numerical **AND** symbolic

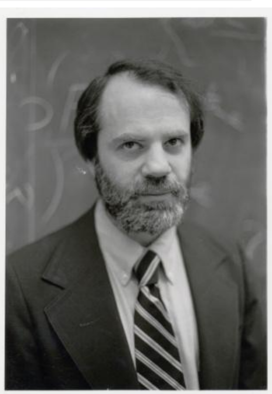
    Ex.: Modal logic with possible worlds or random worlds semantics

    Ex.: Incidence calculus, Fagin-Halpern structures…

Towards a unified theory…



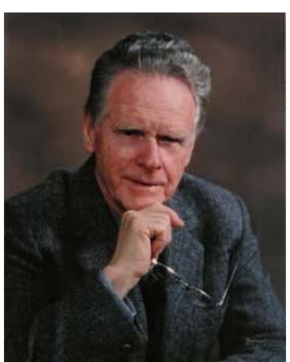
Saul Kripke



Jaako Hintikka

Lotfi Zadeh

Arthur Dempster

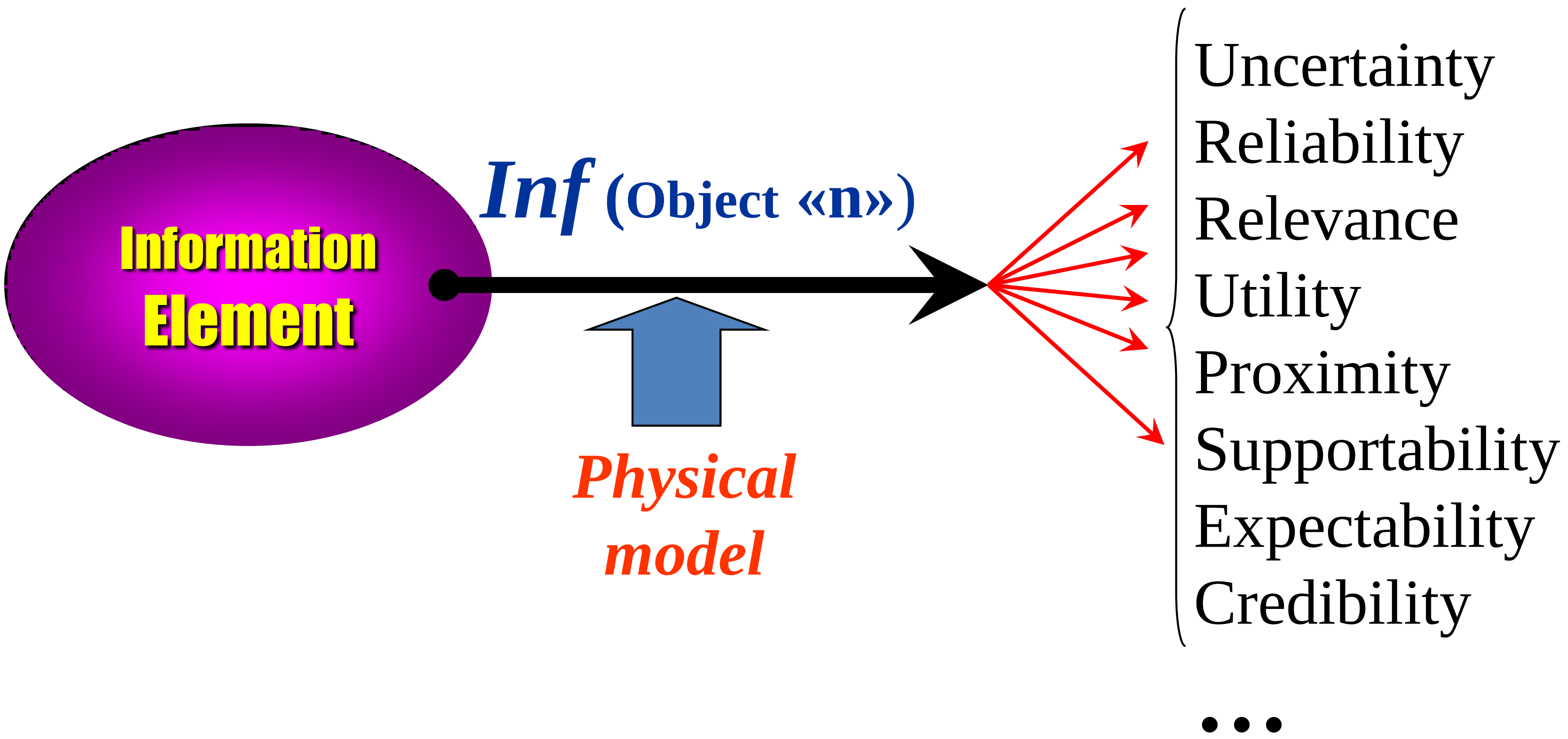


Glenn Shafer

Ronald Fagin

Joseph Y. Halpern

‘We need to formalize’



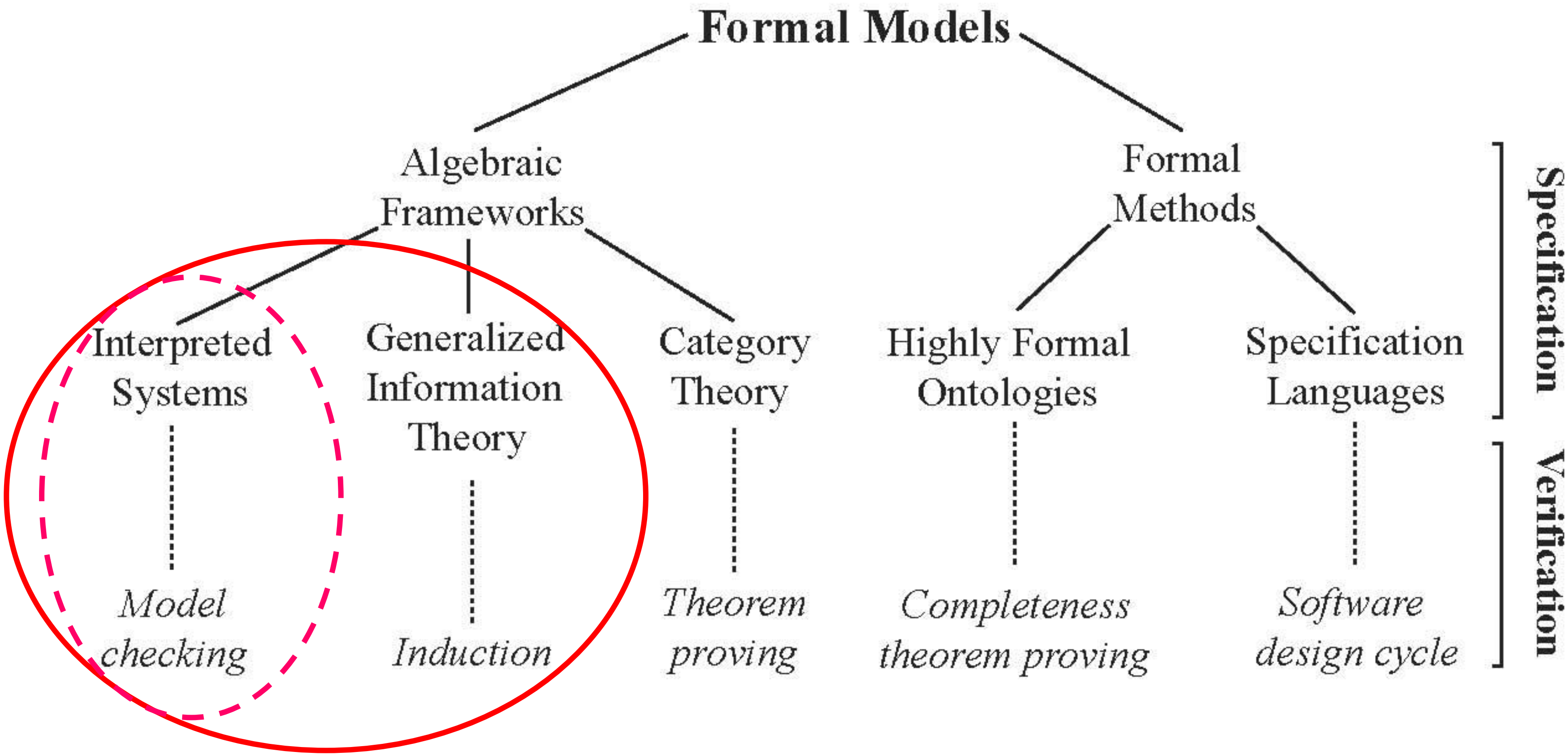
‘Information enables Situation Awareness’

Why a Formal Framework

A highly formal approach for the design of situation analysis and decision support systems is unavoidable if one is interested in:

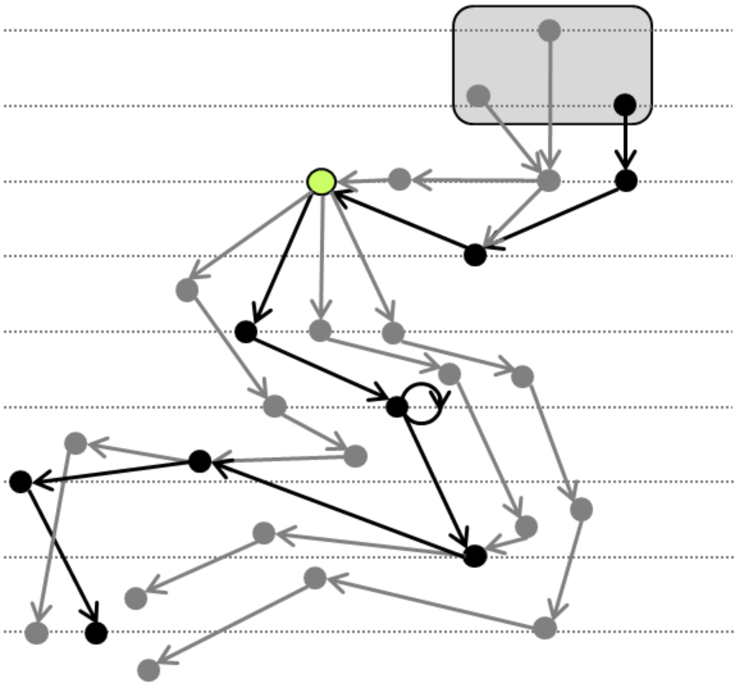
- the reproducibility/traceability of results (e.g. explanations);
- satisfaction of constraints (e.g. how much time and memory are needed);
- a language to represent and reason about dynamic situations.

Formal Models for Information Fusion



Interpreted systems – *State transition systems*

Our approach of SA is to base our analysis on the production of ***state transition systems*** consisting of the set of all temporal trajectories possibly obtained upon the execution of a given set of agents' ***protocols*** (strategies).



A General Algebraic Framework for IF

- Hypothesis: ***Interpreted Systems Semantics*** *is a general framework for* ***situation analysis*** *and high-level data fusion applications*
- Arguments:
  - Designed for **distributed systems** analysis;
  - **Situations** are adequately represented by transition states systems;
  - The notions of Situation, Situation Awareness and Situation Analysis can be **formally defined;**
  - Allows reasoning about **knowledge**, **uncertainty** and **time;**
  - The framework is general enough so that **Generalized Information Theory** can be **framed** into ISS;
  - Can take advantage of both **model checking** and inference decision **procedures**.

Abstract State Machines: The Idea

- ASM is a machine model for representing algorithms at higher levels of abstraction
  - Like pseudo code but with precise semantics

- High-level descriptions at earlier stages in design
- Stress on essential aspects rather than insignificant details
- Precise semantics and executable specifications
- Expressing the original idea behind algorithms at the same level of complexity

Abstract State Machines

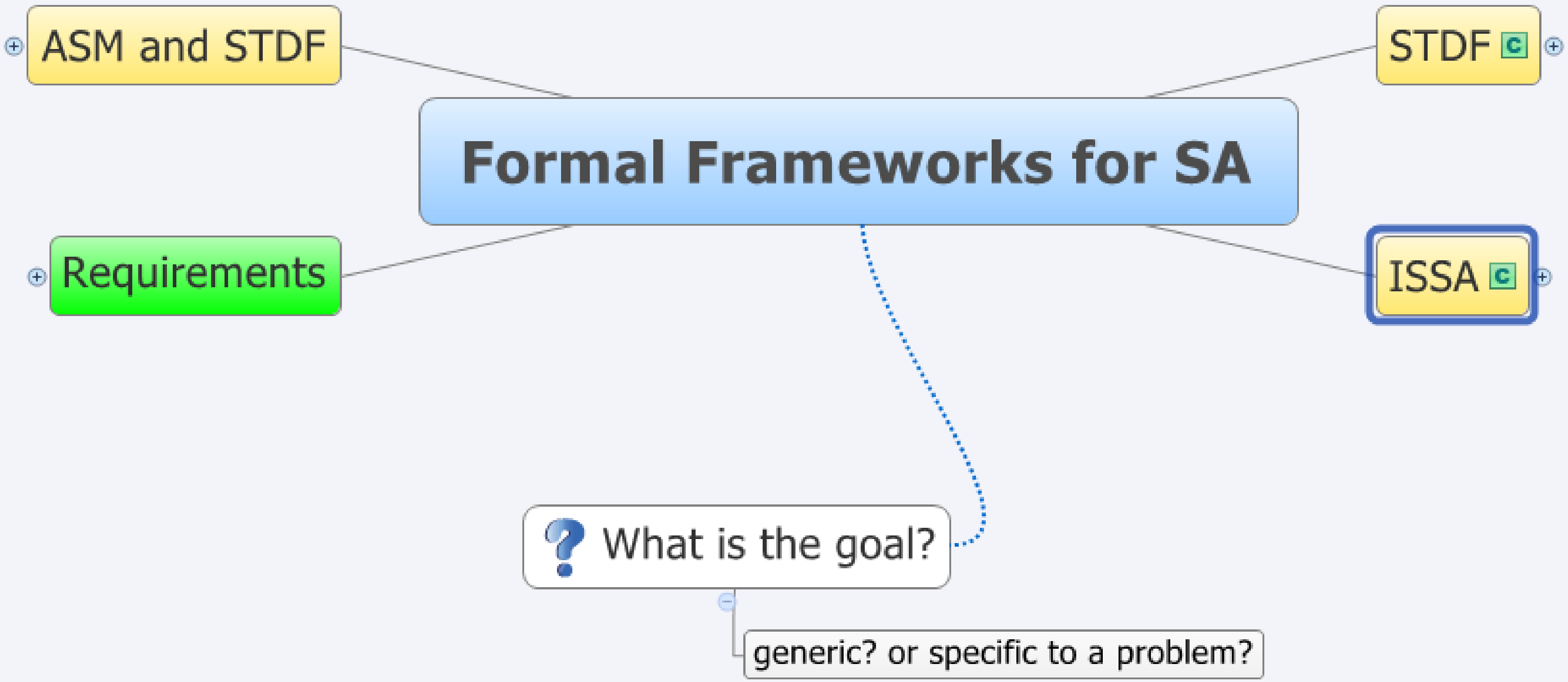
- Abstract State Machines (ASM) are known to be effective in *specifying* and *modeling* a variety of systems:
  - Languages, protocols, comm. architectures, web services, embedded control systems, computational modeling of social systems, etc.
  - Several books and papers published with examples
- Several compilers and interpreters for various ASM dialect exist

Combining ASM and IS

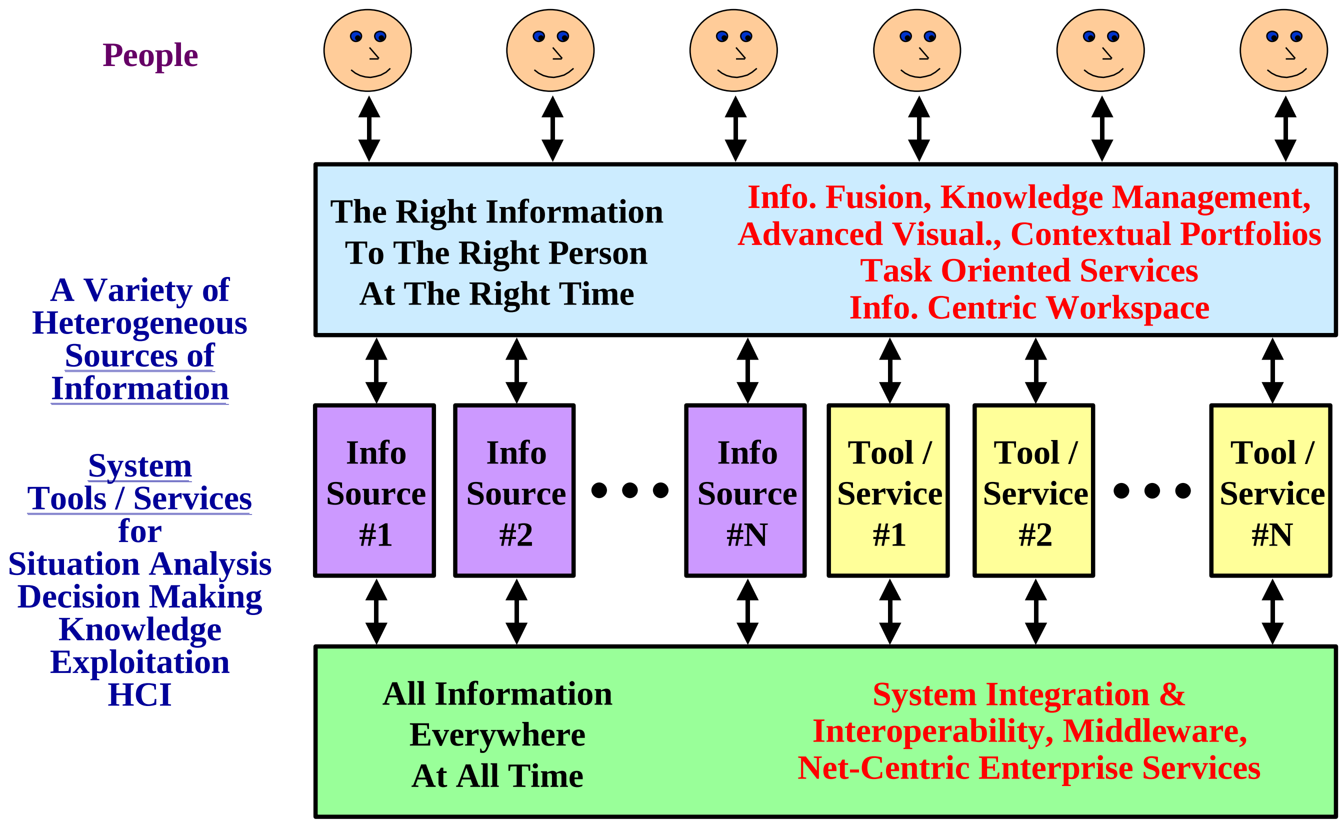
- Interpreted Systems
  - The underlying view is geared toward theoretical aspects of system modeling
    - Global state transformer, protocol, loose notion of concurrency
- ASMs are known for their practical side of formal semantic modeling
  - Refinement and modularization techniques
- Combined, they can provide a comprehensive semantic framework for design and development of novel decision support systems

CoreASM Goals

- An *extensible executable ASM language* which is faithful to its mathematical definition
- An *extensible, platform-independent* execution engine
- A supporting *tool environment* for
  - Design exploration
  - Experimental validation, fast prototyping
  - Formal verification


Formal Frameworks for SA
ASM and STDF
Requirements
STDF
ISSA
What is the goal?
generic? or specific to a problem?

Exploiting information sources and tools/services in a support system



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3. Decision support:
Reach the humain brain

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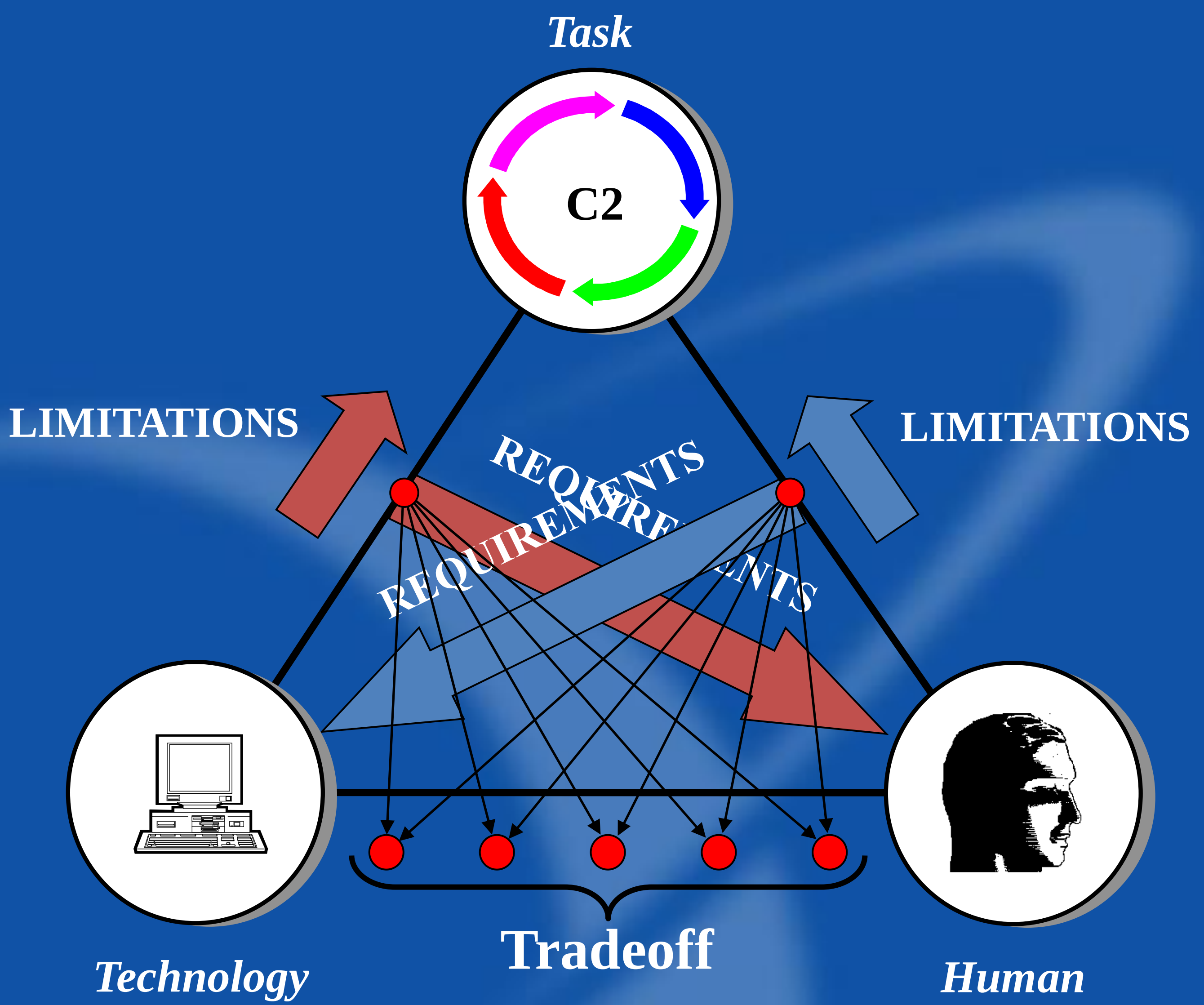
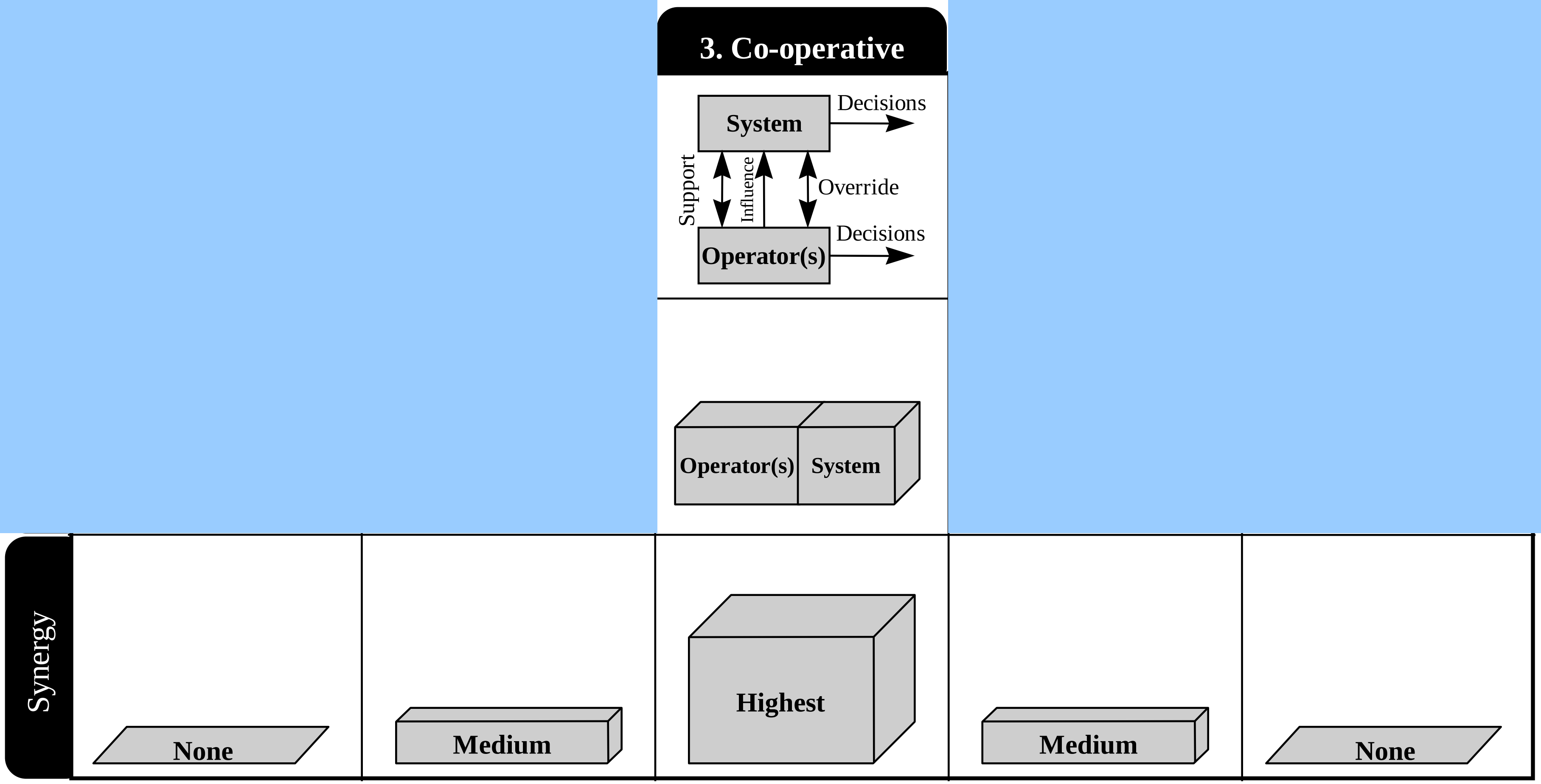
"TASK/HUMAN/TECHNOLOGY" TRIAD MODEL*



*Rousseau: Laval University

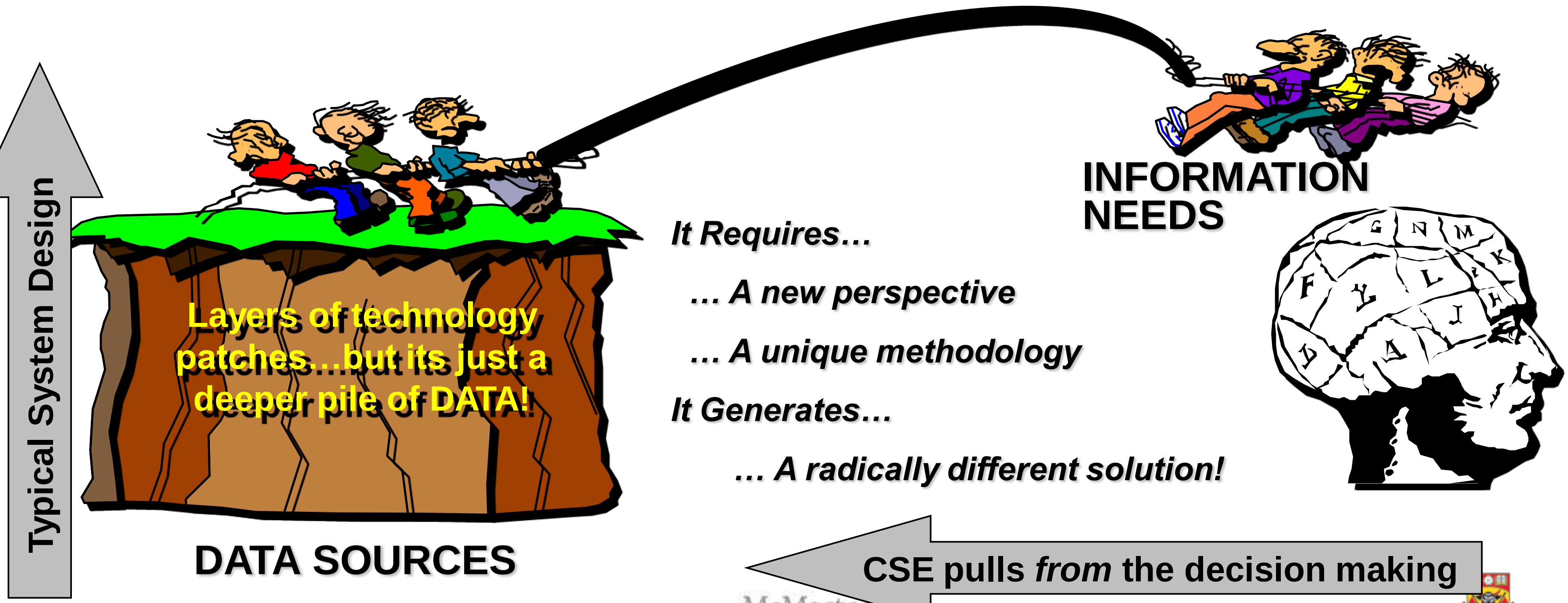
Human-Technology Tradeoff Spectrum



CSEC

User Driven vs. Data Driven

- The ‘chasm’...where you start often determines where you finish
- Building the bridge is hard



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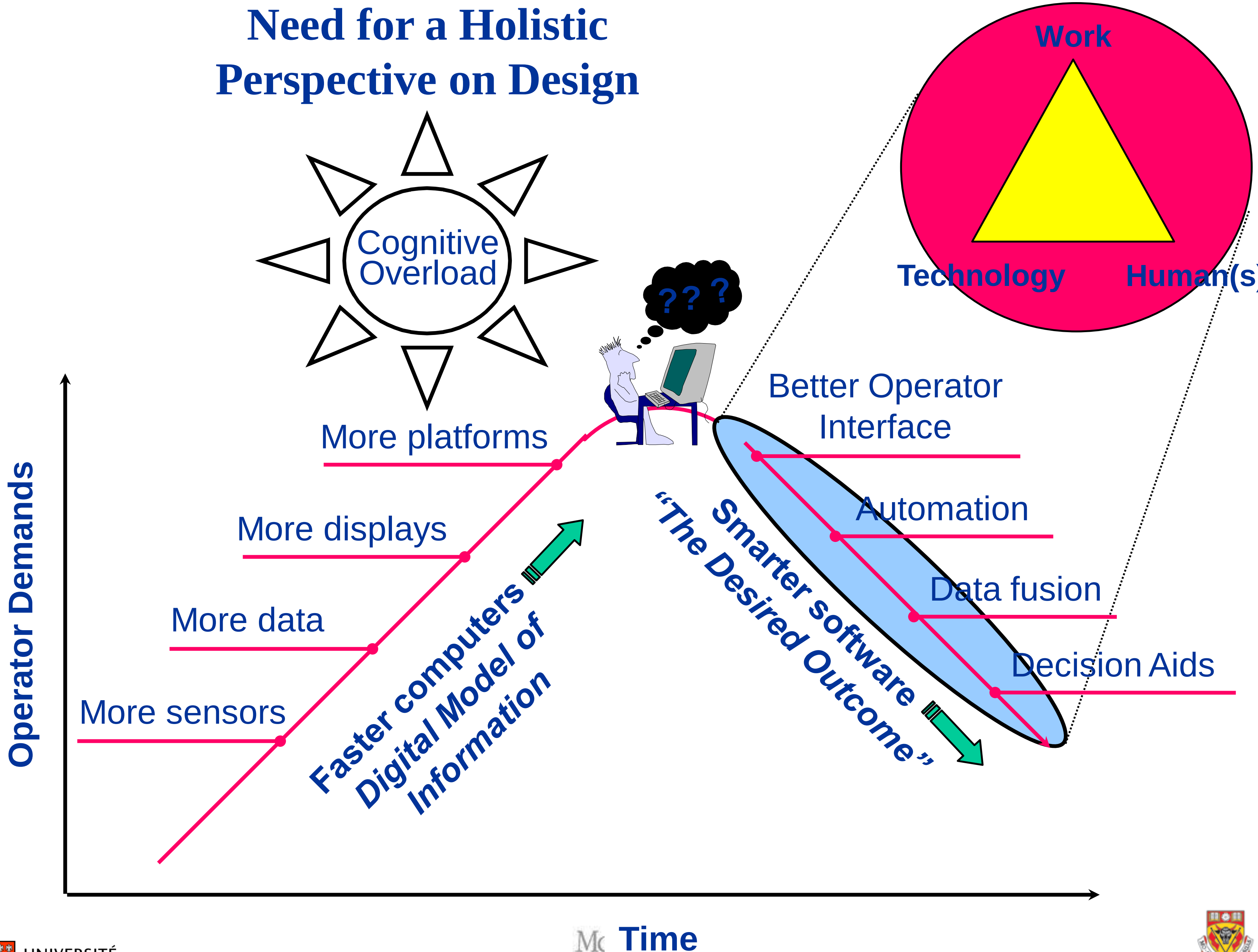
Need for a Holistic Perspective on Design



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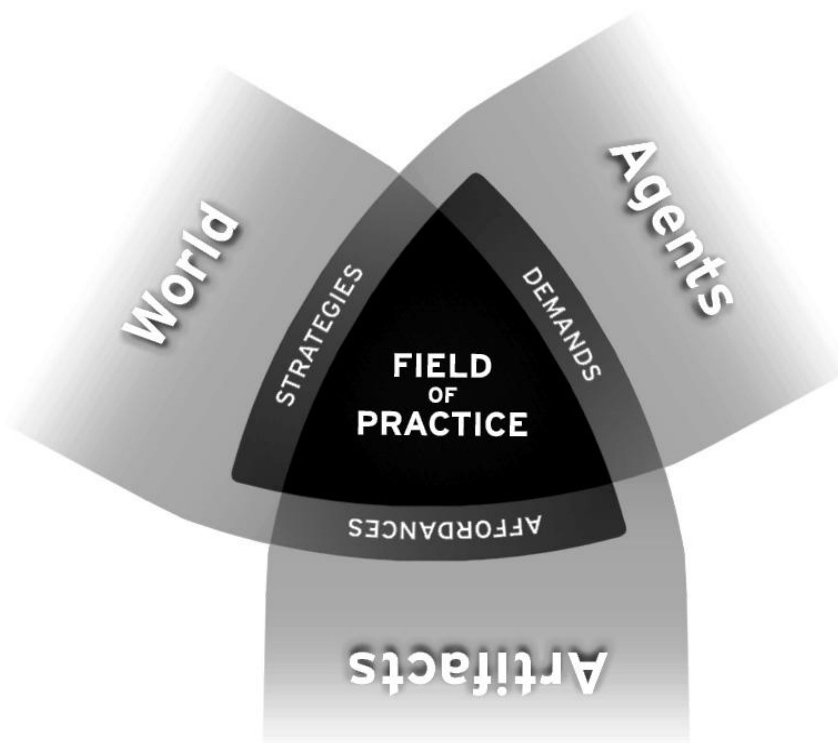
What is Cognitive Systems Engineering?
The Cognitive Triad



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- Dr. David D. Woods, OSU Cognitive Systems Engineering Lab describes Cognitive Systems Engineering as;

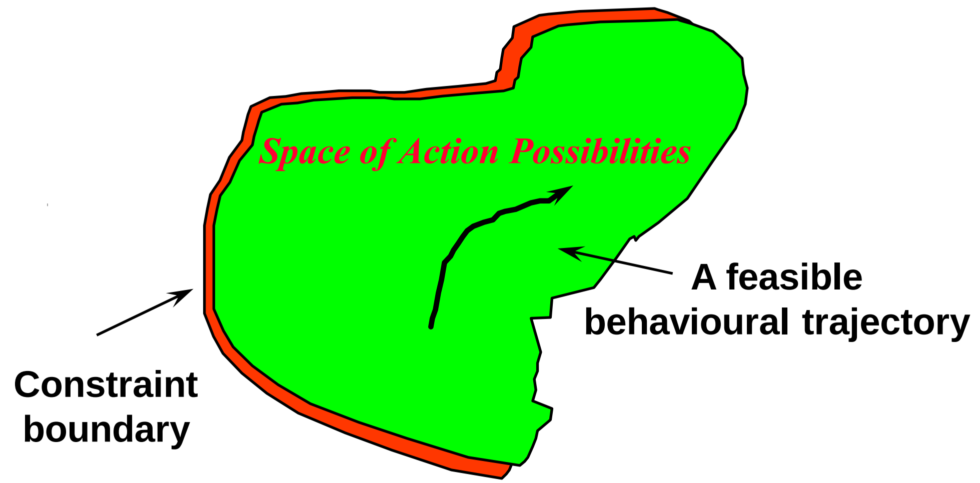
“working at the intersection of the problems imposed by the world, the needs of agents (both human and machine) and the interaction with the various technologies (affordances) to affect the situation”

- *Note that each interacts with the other two, for example the user interface must allow the user to control the world as well as control any automation*

A Cognitive Systems Engineering Approach

ß Design for adaptation

- Joint H/M system must be highly <u>adaptive</u>
- Familiar, unfamiliar, unanticipated events
- Primary value of human is to play an adaptive role
- Computer-based tools to <u>support human adaptation</u>



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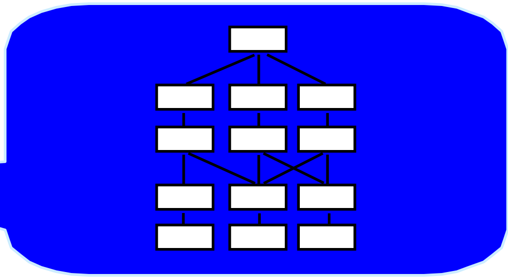
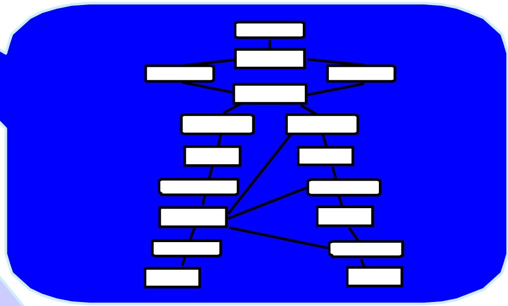
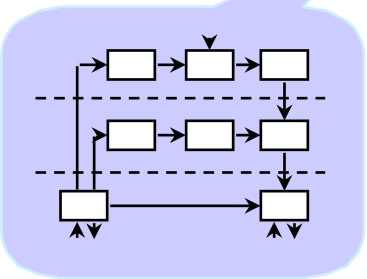
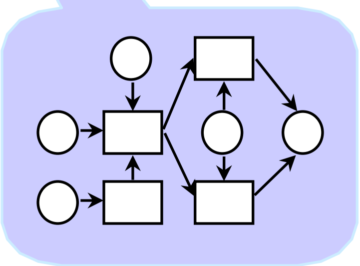
Cognitive Work Analysis Framework

Phases of CWA	Kinds of Information	Modeling Tools
Work Domain Analysis	Purpose and structure of work domain	Abstraction-decomposition space
Control Task Analysis	Goals to be satisfied, decisions/cognitive processing req'd	Decision ladder templates
Strategies Analysis	Ways that control tasks can be executed	Information Flow Maps
Social Organisation and Cooperation Analysis	Who carries out work and how it is shared	Annotations on all the above
Competencies Analysis	Kinds of mental processing supported	Skills, Rules and Knowledge models

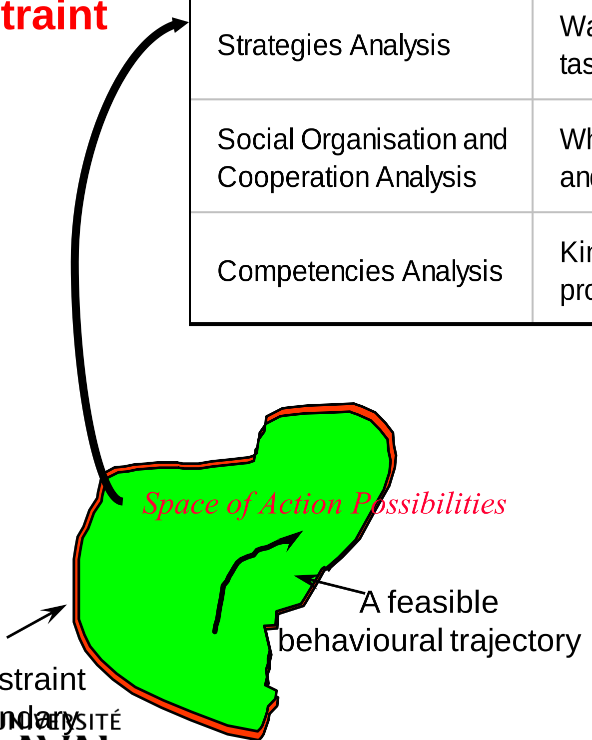








Increasing Constraint



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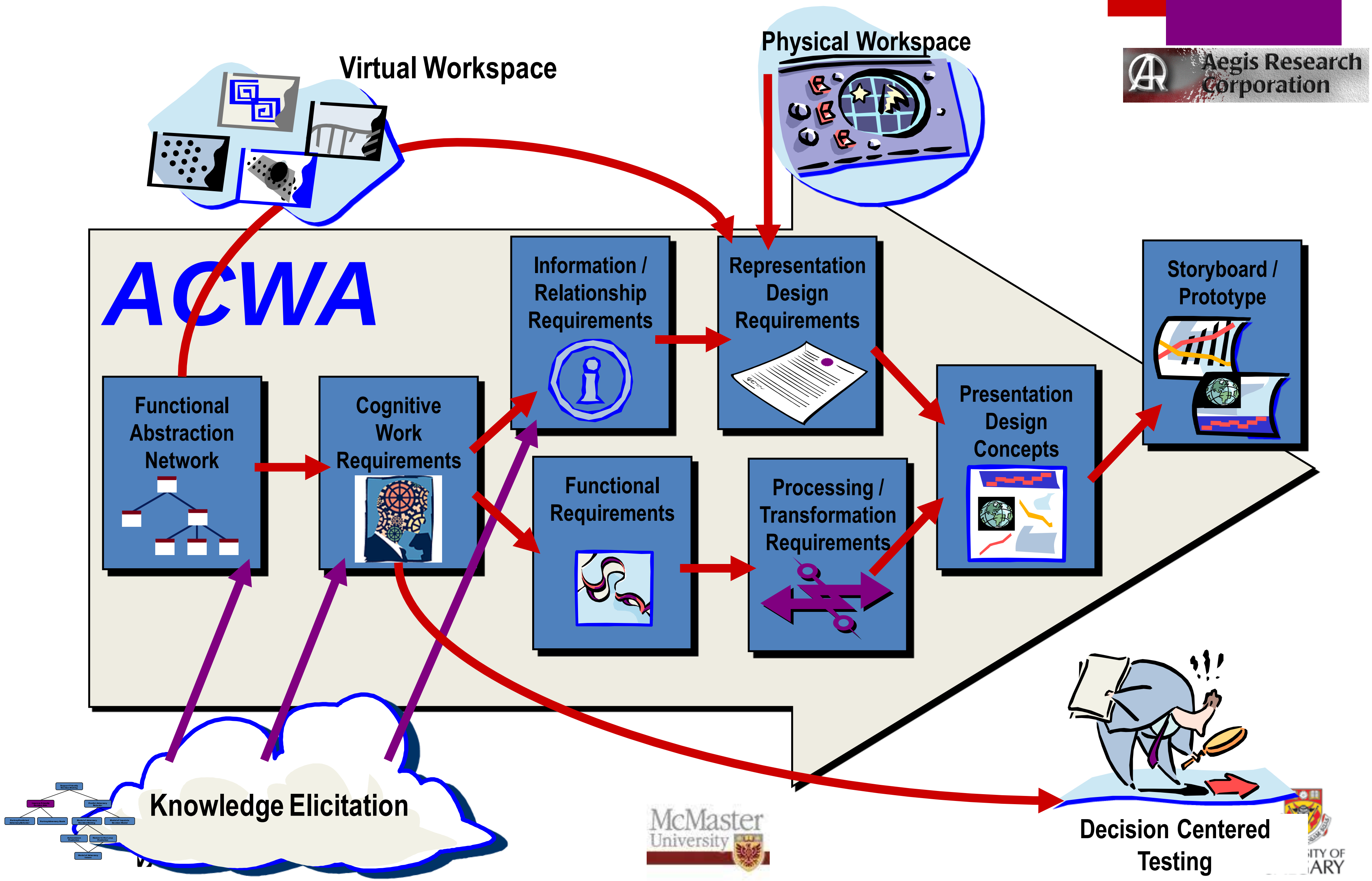
Applied CWA



Virtual Workspace
Physical Workspace
ACWA
Functional Abstraction Network
Cognitive Work Requirements
Information / Relationship Requirements
Representation Design Requirements
Functional Requirements
Processing / Transformation Requirements
Presentation Design Concepts
Storyboard / Prototype
Knowledge Elicitation
Decision Centered Testing
Aegis Research Corporation
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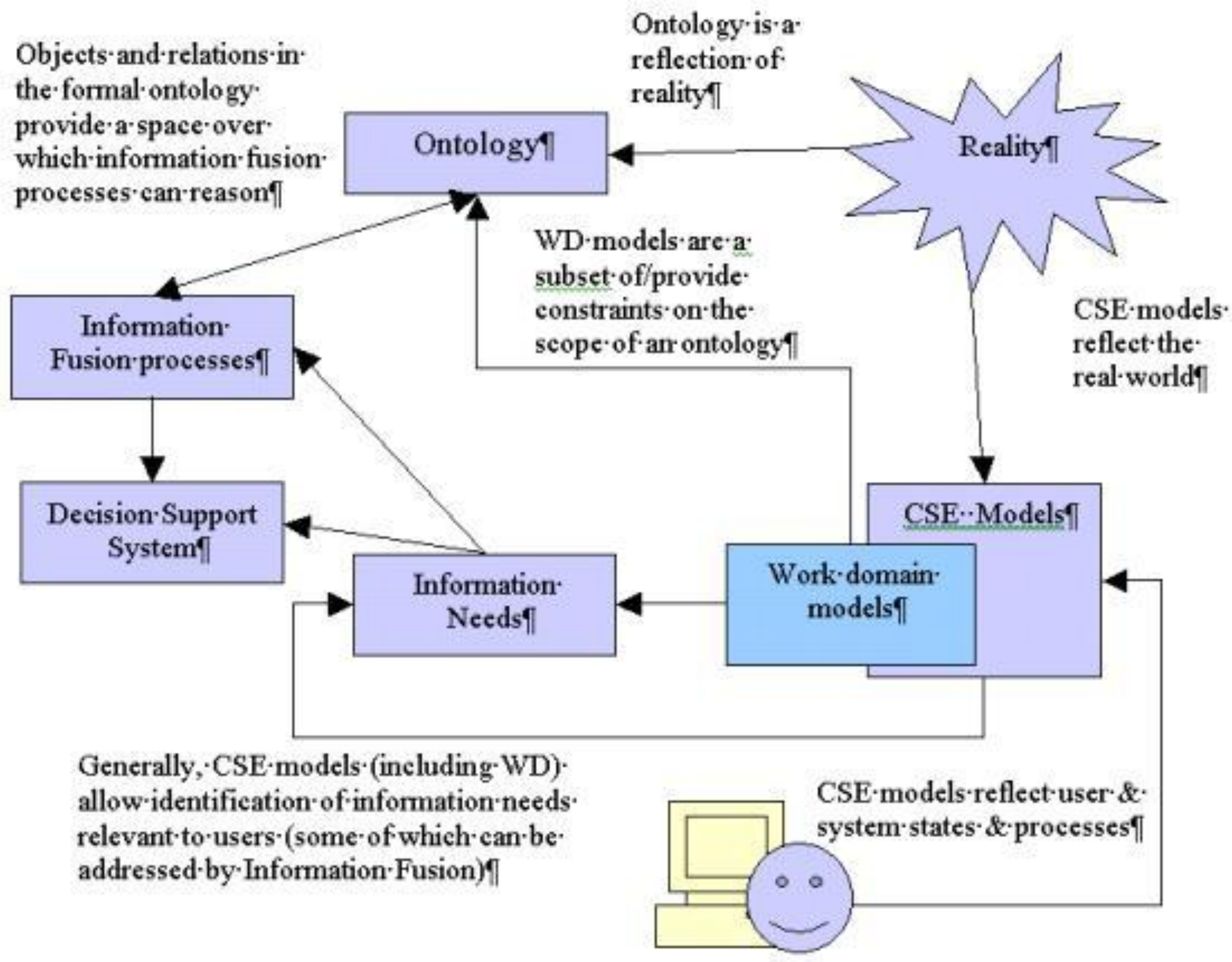
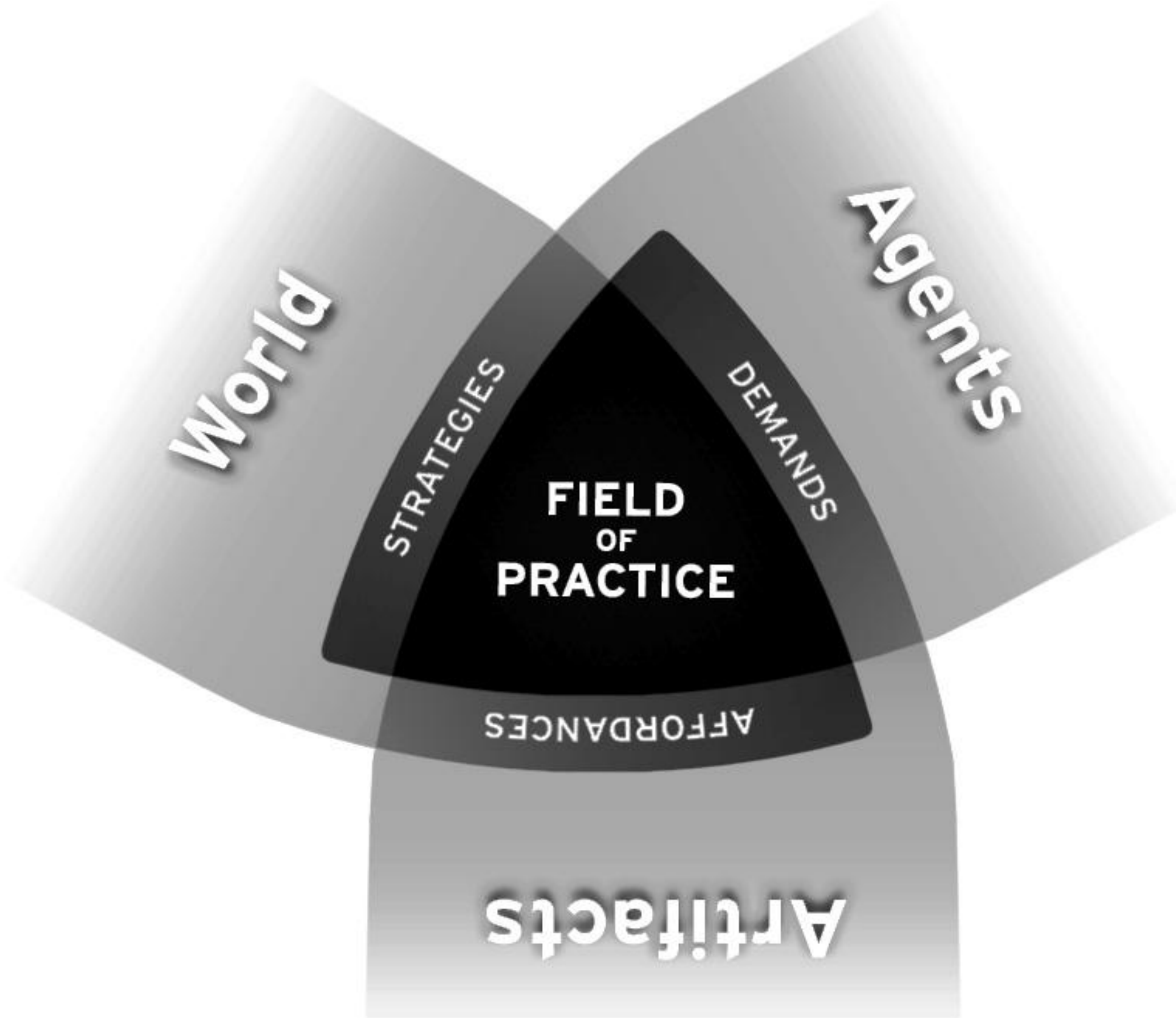
Ontological Engineering & Cognitive System Engineering



Information Visualization



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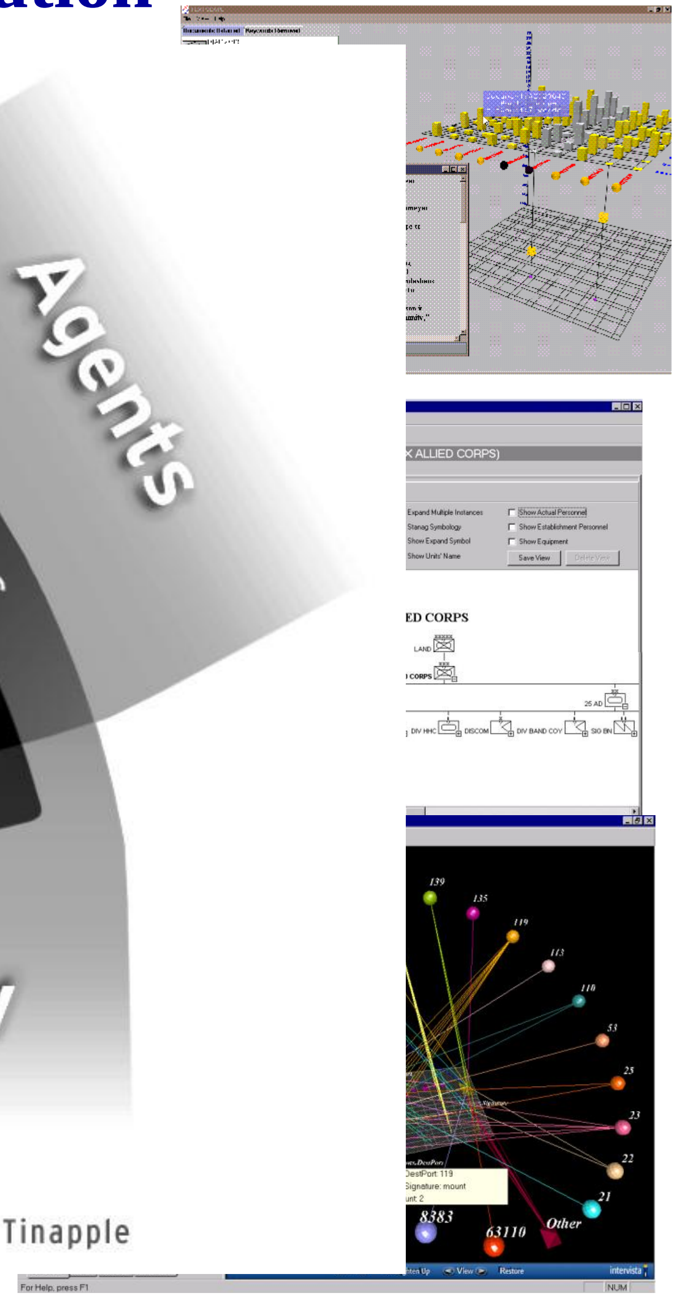

SOME CRITICAL RESEARCH ISSUES (1)

- **Information quality assessment approaches**
- **Knowledge modeling and representation: exploitation of efficient machine representations of relevant aspects of the world.**
- **Visualisation and human-system integration**
- **Fusion of structured and unstructured information – hard/soft fusion**
- **Formal methods to identify and represent relevant and critical information to support decisions**
- **Formal methods of ontological engineering to produce defensible representations of the world (e.g., situational constructs).**
- **Work domain models could be constructed based on cognitive engineering techniques in order to understand and formally document the information needs of decision makers.**
- **Distributed or social aspects: architecture SoS, open systems**

SOME CRITICAL RESEARCH ISSUES (2)

- **Decision support involves both people and machines. Three distinct types of processes are involved:**
  - **– psychological processes associated with people;**
  - **–technological processes characteristic of machines;**
  - **–and integration processes facilitating interaction between the psychological and technological processes.**
- **Information fusion is a key enabler to situation awareness:**
  - **– there is a need to define a framework where knowledge, uncertainty and belief can be handled – a reference fusion model that could be used for design computer-based support systems**
- **Performance of support systems**
  - –Along two (2) axes:
    1. Theoretical: *Conceptually correct?*
    2. Applicable: *Able to address large problems? Complexity? Computer tractable? Useful for the user? Notion of trust? Support? Cognitive fit?*

Questions

eloibosse@yahoo.ca

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