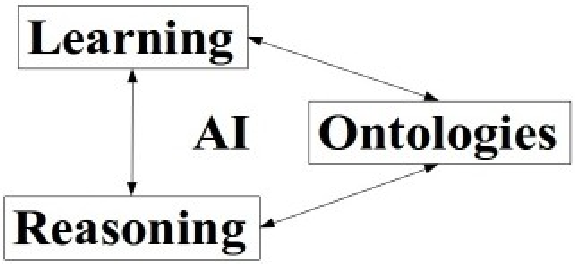


Toward Combining Ontologies and Machine Learning for Improving Decision Making

Ken Baclawski
Northeastern University

Track B Session 1
15 March 2017

Motivation

- From John Sowa

  “For intelligent systems, the cognitive cycle is more fundamental than any particular notation or algorithm.”

  “By integrating perception, learning, reasoning, and action, the cycle can reinvigorate AI research and development.”

Team

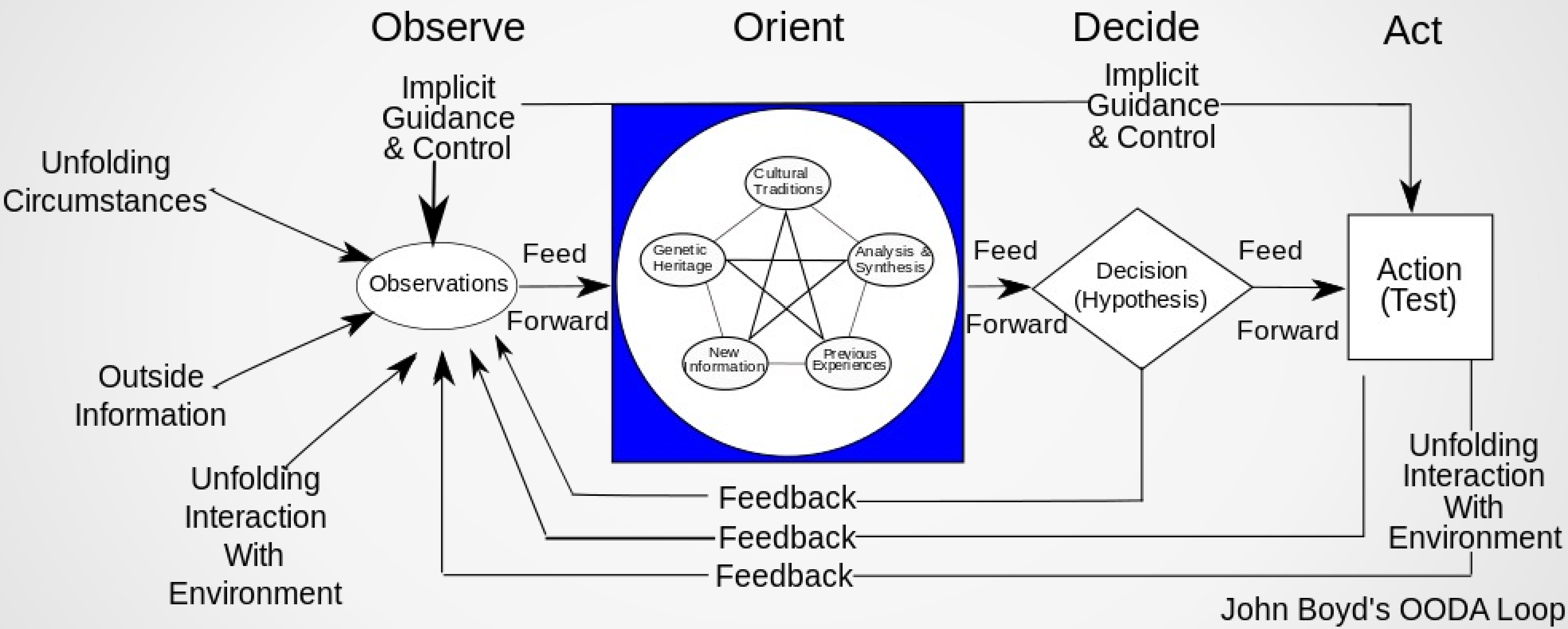
- Oracle
  - Eric S. Chan
  - Kenny C. Gross
  - Dieter Gawlick
  - Adel Ghoneimy
  - Zhen Hua Liu
- Northeastern University
  - Ken Baclawski
  - Ankit S. Agrawal (financial services)
  - Ranjita Bhattacharyya (cloud services)
  - Prasanna D. Deolankar (financial services)
  - Tongzu Ding (healthcare)
  - Saurabh Kumar Kulkarni (customer service)
  - Sahil Mehta (financial services)
  - Sumit Suresh Nair (customer service)
  - Mamata D. Prabhu (financial services)
  - Xing Zhang (customer service)

Outline

- Ontology for Decision Making Processes
  - Situation awareness
  - Decision making loop
- Use Cases
  - Simple applications
  - Multi-level applications
  - Recursive applications

OODA Loop

- Observe, Orient, Decide, and Act (OODA) Loop
  - Observe the entities and environment,
  - Orient the participant to the observations, by cultural tradition, generic heritage, previous experience, analysis and synthesis, new information
  - Decide on the directives based on the hypotheses that best explains the observations, and
  - Act on the directives to interact with the entities and environment, to test the hypothesis
- Developed by a fighter pilot: Colonel John Boyd
  - Now an important concept in litigation, business and military strategy



Observe
Orient
Decide
Act
Implicit Guidance & Control
Implicit Guidance & Control
Unfolding Circumstances
Observations
Feed
Forward
Cultural Traditions
Genetic Heritage
Analysis & Synthesis
New Information
Previous Experiences
Feed
Forward
Decision (Hypothesis)
Feed
Forward
Action (Test)
Outside Information
Unfolding Interaction With Environment
Unfolding Interaction With Environment
Feedback
Feedback
Feedback
John Boyd's OODA Loop

Situation Awareness

- Fundamental for decision making

  “The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.” (Endsley)

- Proceeds on multiple levels
  - Inferring relevance of data for a goal
  - Processing the relevant data to achieve a goal
- Situation awareness both creates its ontology and represents data within that ontology. (Klein, Moon and Hoffman 2006)

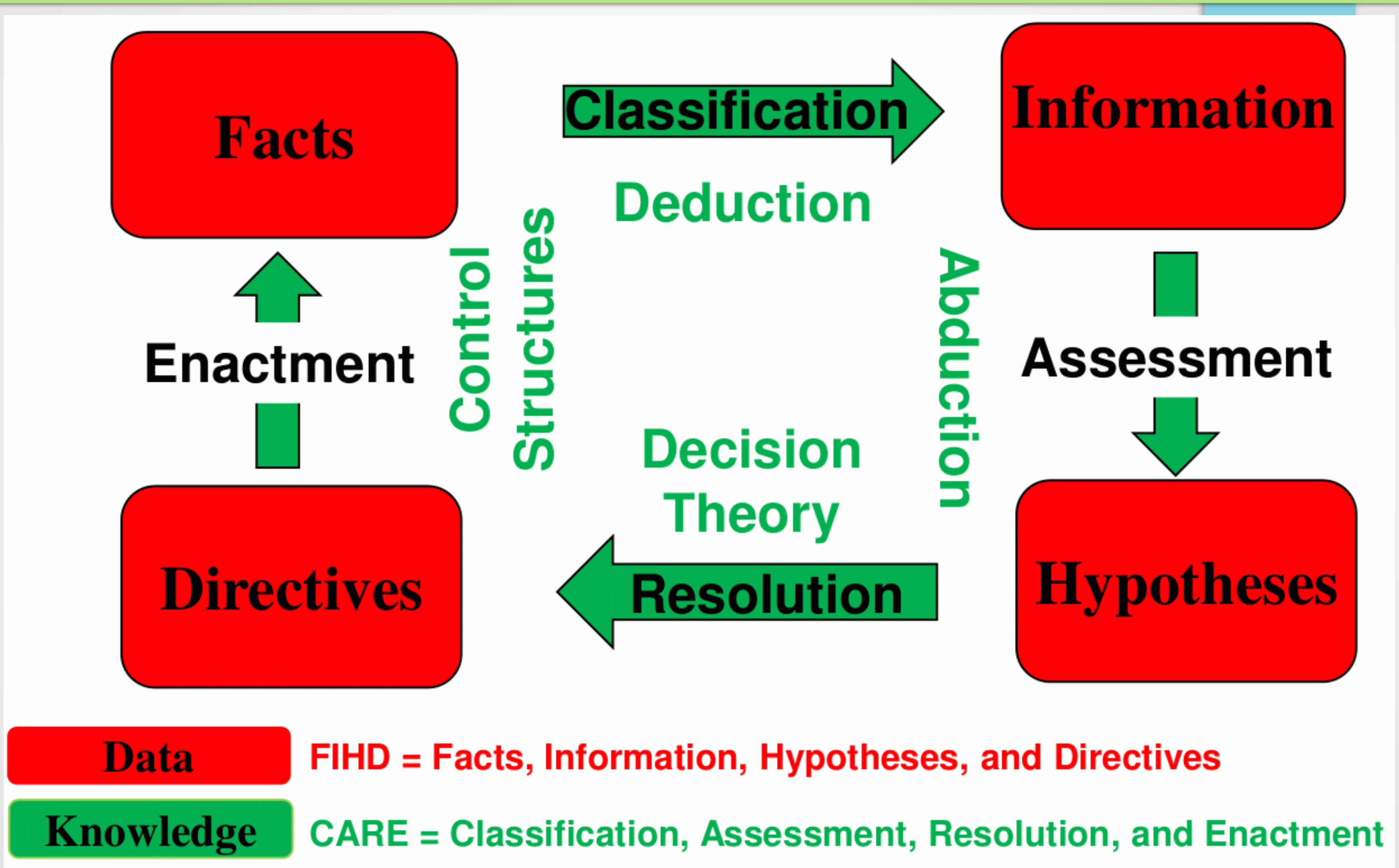
Situations

- A limited part of reality that can be perceived and reasoned about
- Theory developed by Barwise and Perry, extended by Devlin
- Facts supported by a situation are its *infons*
- Situations can be related to each other in several ways and are objects that can be part of infons
- A decision making process uses situations to produce other situations

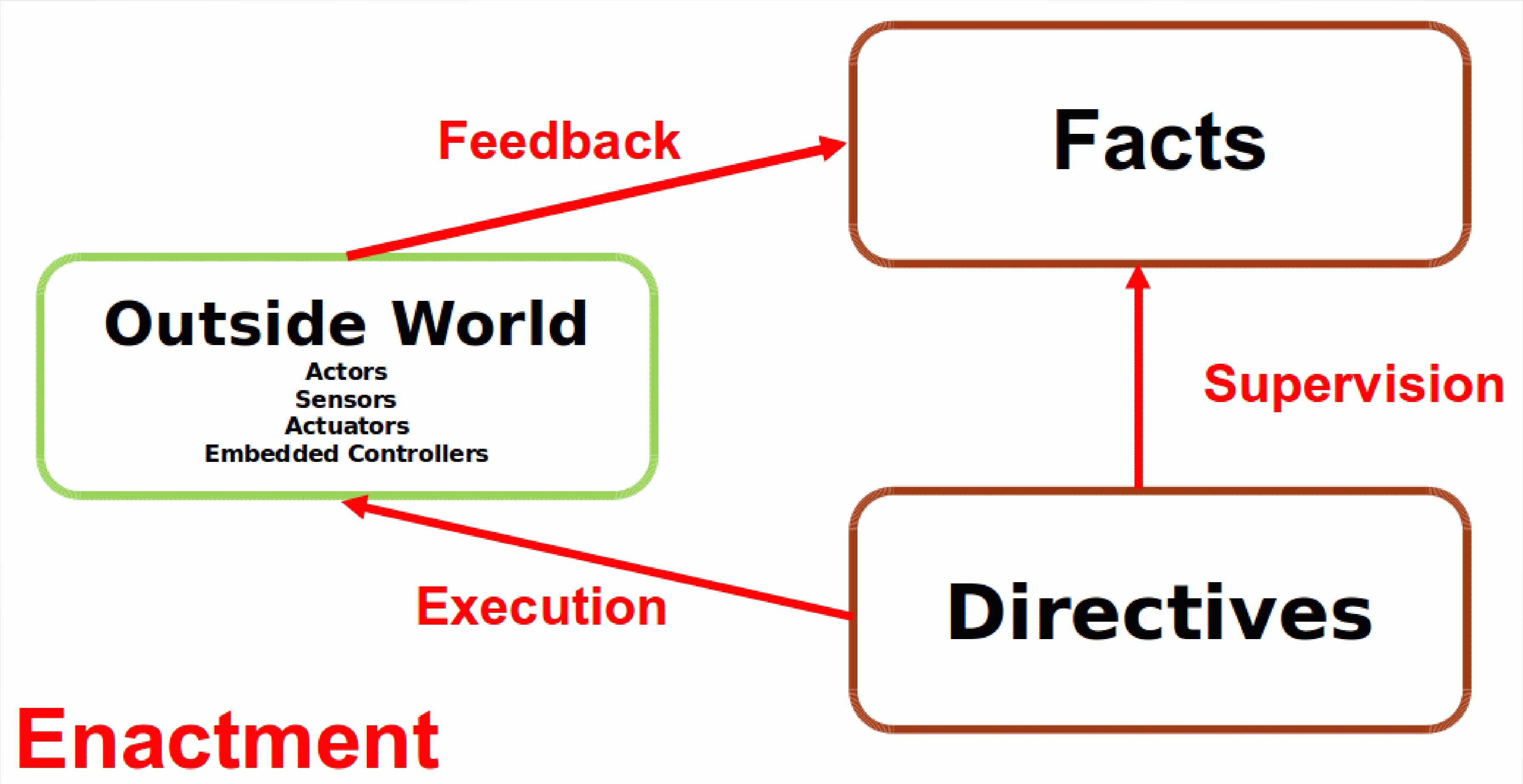
The Knowledge Intensive Data System

- The KIDS Framework is based on the OODA loop
- Categorization of data and reasoning processes
- State management of data, reasoning and process
- Process model for situation awareness and decision making
- Presented in Ontology Summits 2014 and 2015
- Formalized by the KIDS Ontology

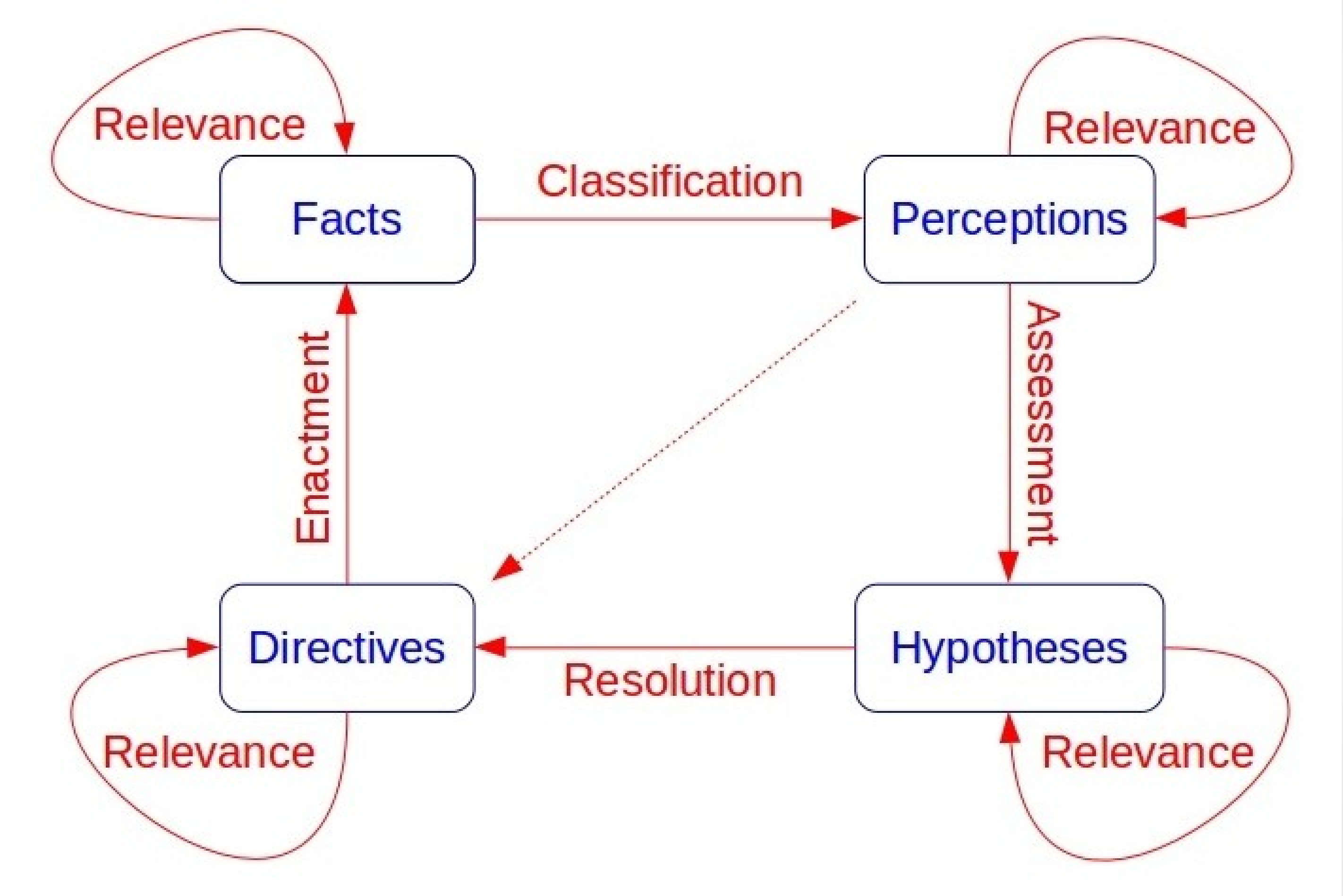
The KIDS CARE Loop



Interaction with the World



Relevance Reasoning



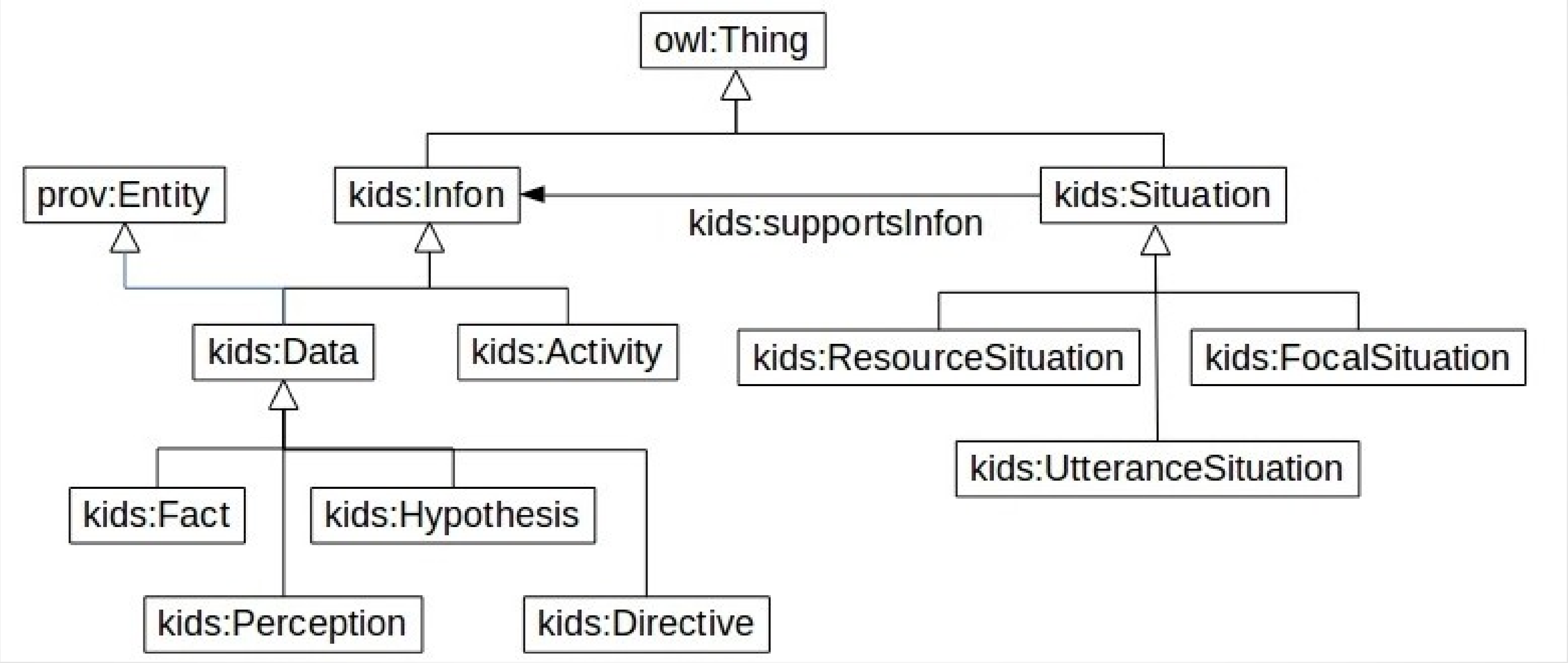
The KIDS CARE Loop

- Data Classification
  - Fact
  - Information
  - Hypothesis
  - Directive
- Behavior (transformation) Classification
  - Classification
  - Assessment
  - Resolution
  - Enactment

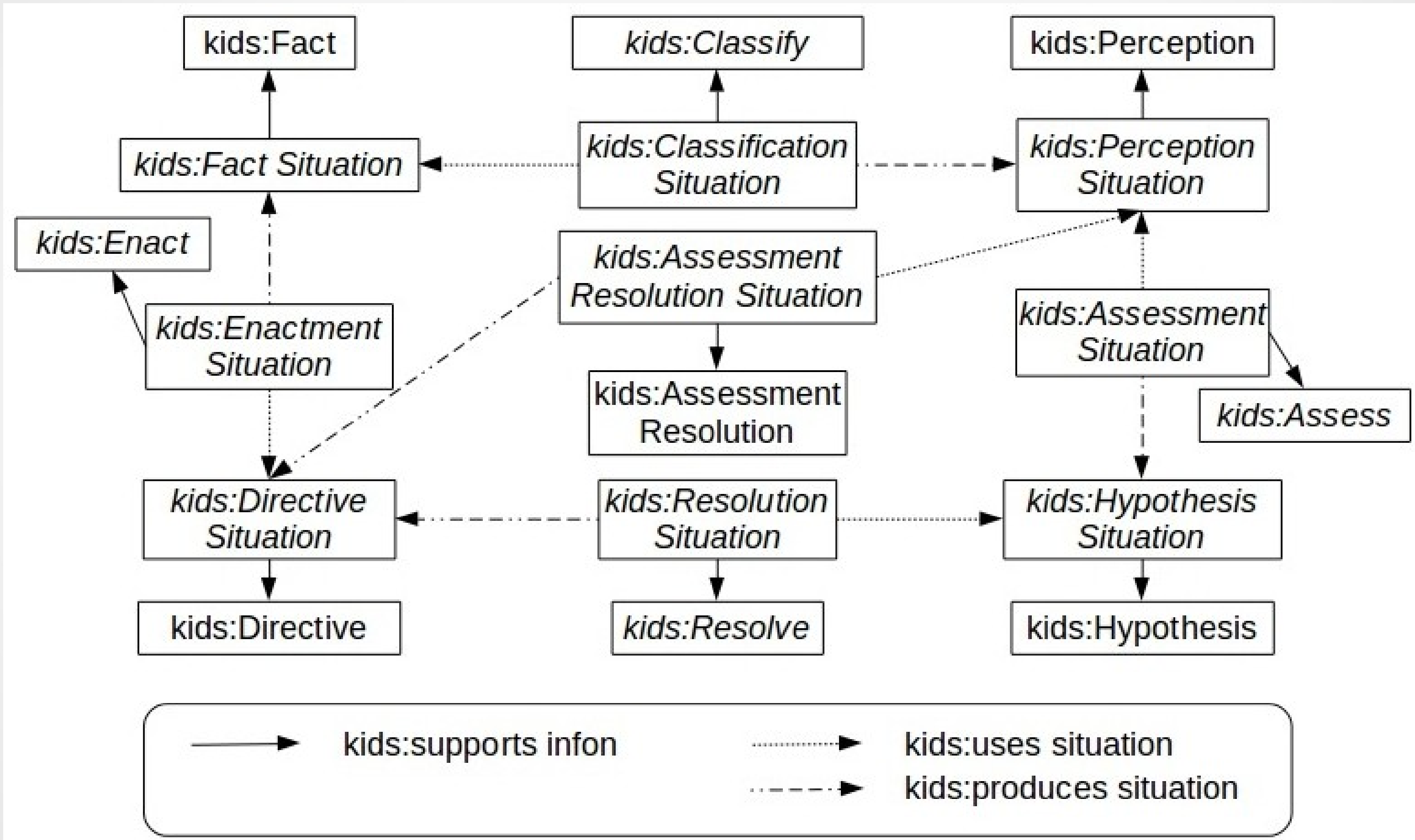
KIDS Ontology

- Theoretical framework for KIDS
- Based on the Situation Theory Ontology
- Integrated with the PROV-O provenance ontology
- Allows for data and process flexibility and diversity

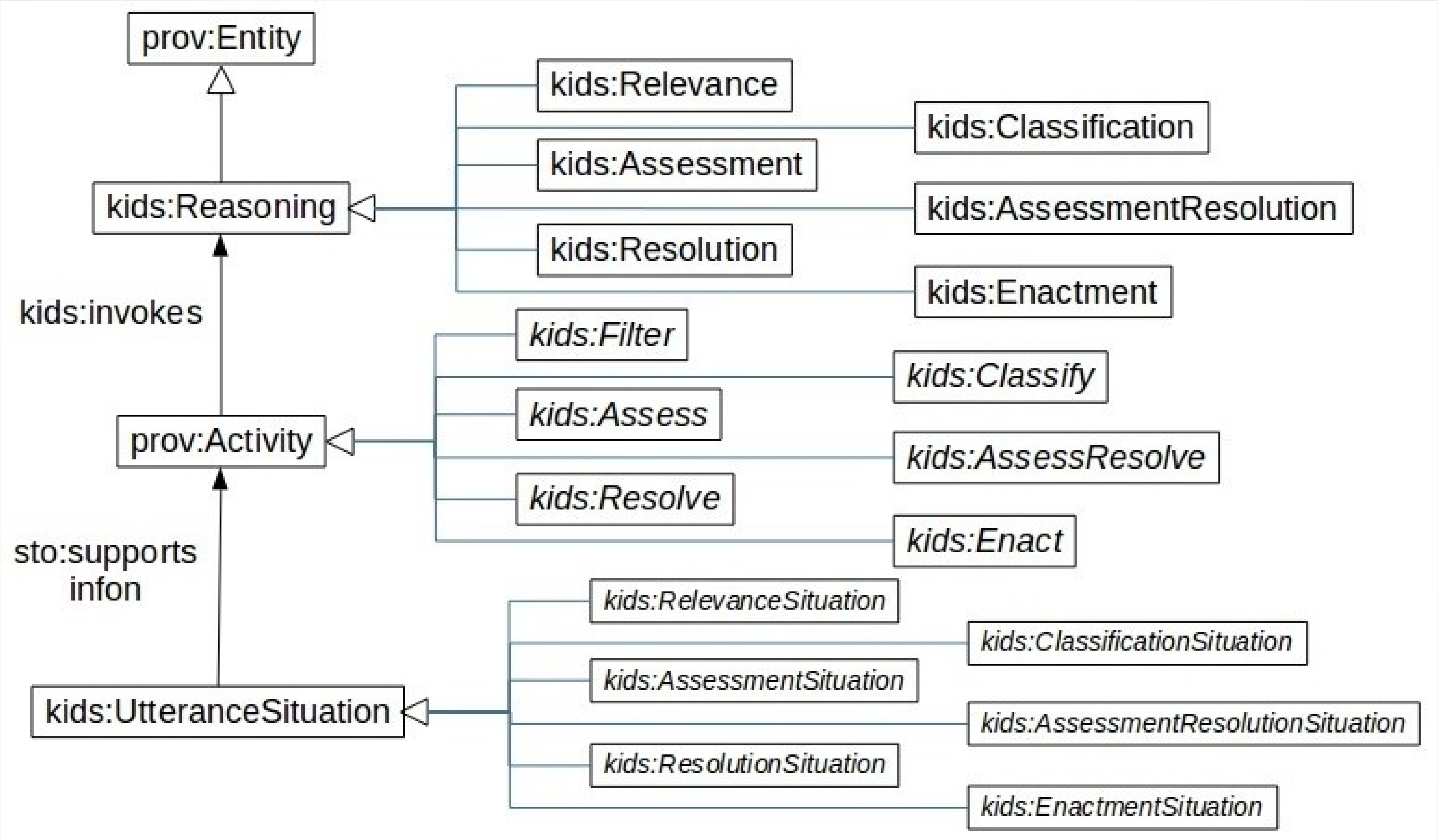
KIDS Hierarchy



KIDS Properties



KIDS Properties



Commutativity Conditions

$$
\begin{tikzcd}
\text{sto:FocalSituation} \arrow[r, "\models"] & \text{sto:ElementaryInfon} \\
\text{sto:UtteranceSituation} \arrow[u, "\text{kids:usesSituation}"] \arrow[d, "\text{kids:producesSituation}"'] \arrow[r, "\models"] & \text{prov:Activity} \arrow[u, "\text{kids:usesInfon}"'] \arrow[d, "\text{kids:producesInfon}"] \\
\text{sto:FocalSituation} \arrow[r, "\models"] & \text{sto:ElementaryInfon}
\end{tikzcd}
$$

Use Cases

- Simple applications
  - Healthcare
  - Complex system prognostics
  - Financial services
- Multi-level applications
  - Cloud services
- Recursive applications
  - Emergencies
  - Customer service

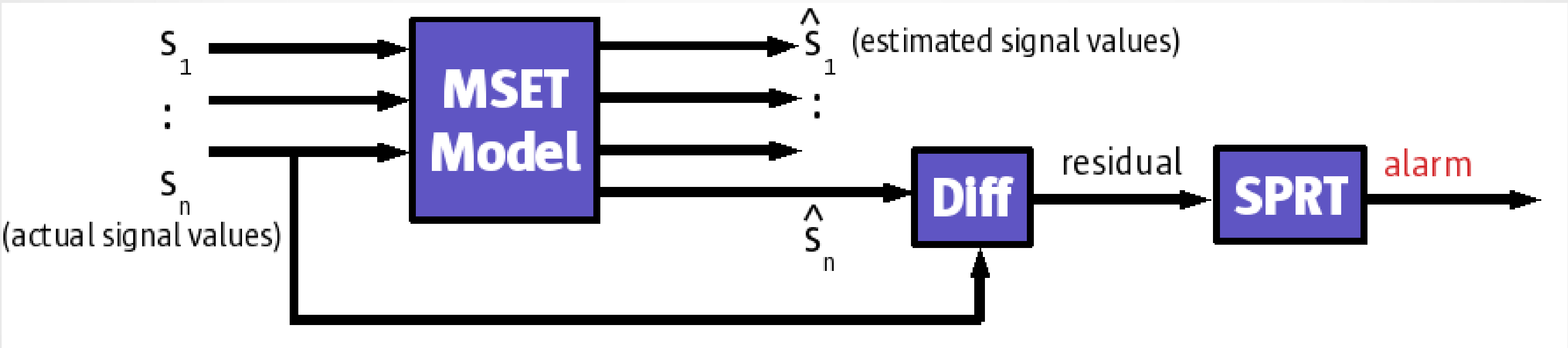
Complex System Prognosis

- Human-in-the-loop control systems
  - Complex business-critical systems
  - Mission-critical systems
  - Systems with large sensor networks
- Requirements
  - Mitigate and avoid cognitive overload situations for the human operators
  - Ultra-low false alarm probabilities for all monitored transducers, components, machines, systems, and processes
  - Fastest mathematically possible decisions regarding the incipience or onset of anomalies in noisy process metrics
  - The ability to unambiguously differentiate between sensor degradation events and degradation in the systems/processes under surveillance

Solution

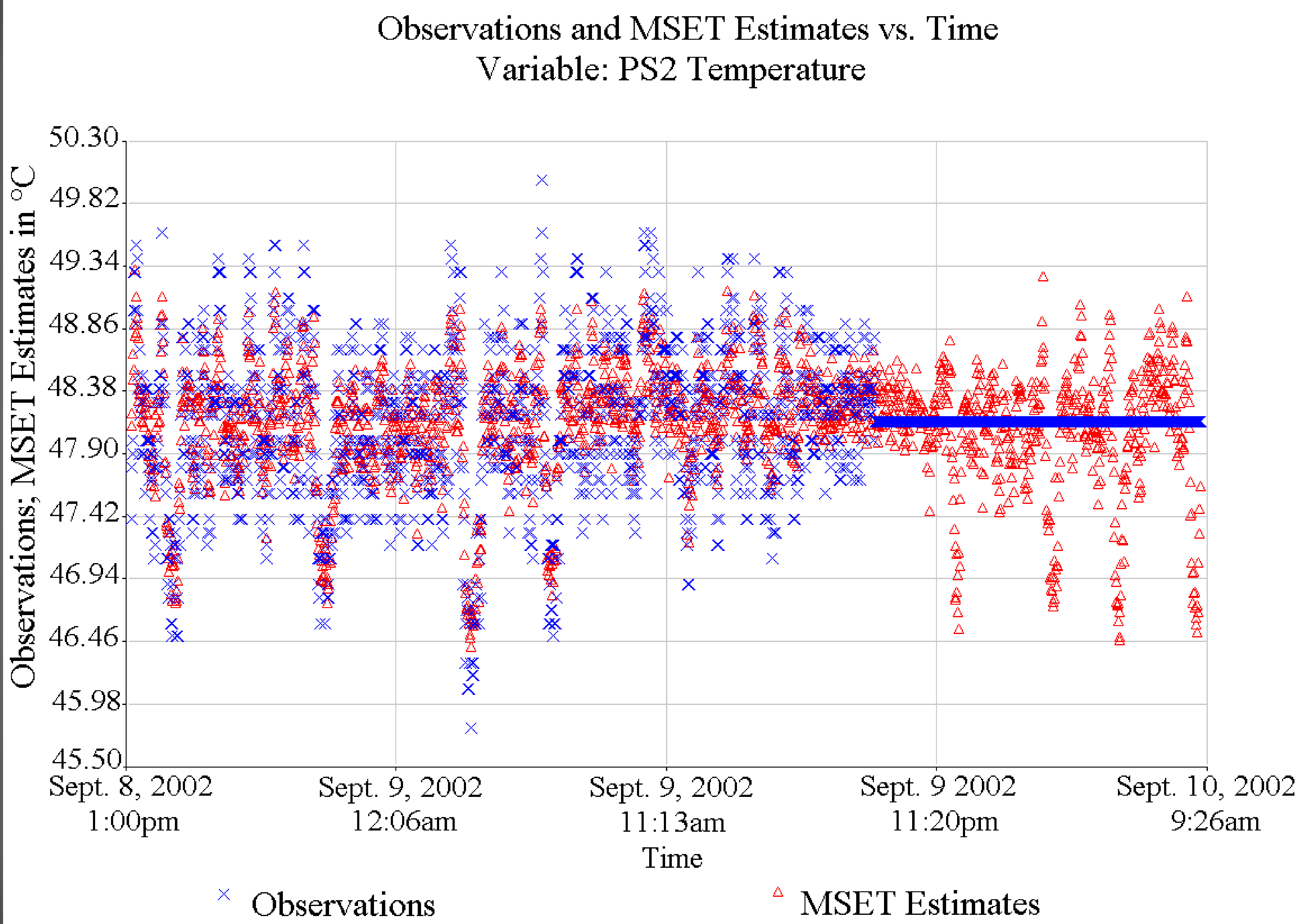
- Approach
  - Supervisory loop for situation awareness and control
  - Machine learning technique that is especially well suited to this control problem
- KIDS provides situation awareness and control
- ML technique is Multivariate State Estimation Technique (MSET)
- Decision making uses Sequential Probability Ratio Test (SPRT)
- MSET features
  - Detects problems and sounds alarms
  - Detects deteriorating sensors
  - detects failed sensors and infers their values

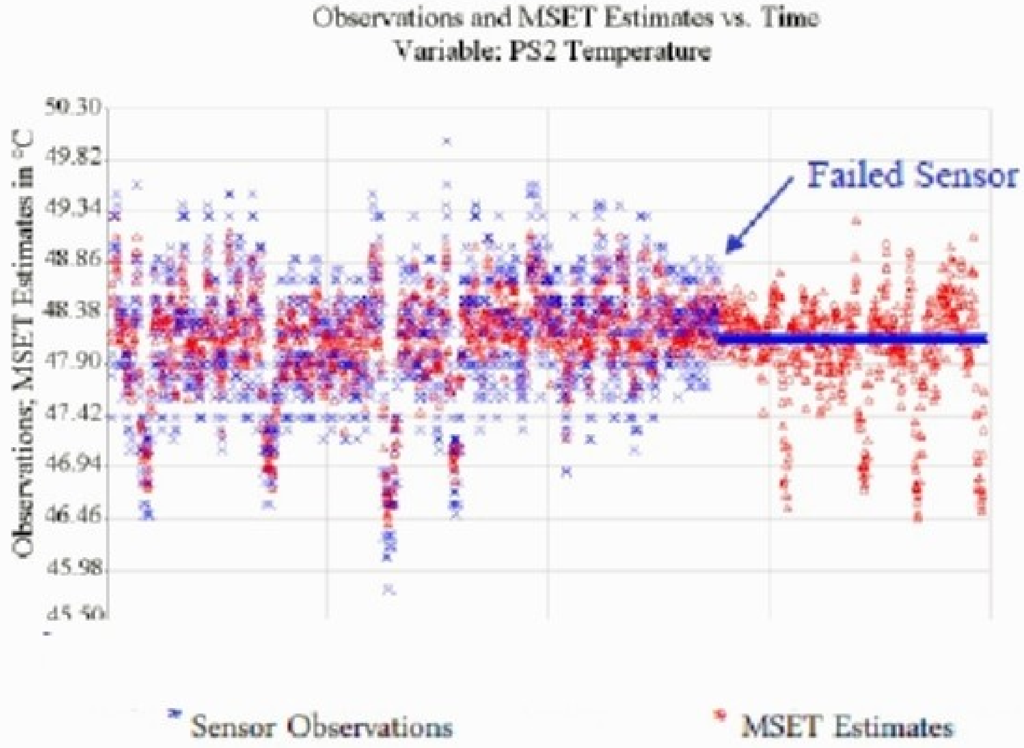
MSET Surveillance Phase Block Diagram



Example

- An actual ``stuck at'' sensor fault
- Business-critical enterprise computer server
  - Over 600 physical sensors
  - 16 internal power supplies
- The metric plotted is a real-time temperature signal of one power supply
  - The blue signal is the real digitized time series measured sensor signal
  - The red signal is the inferential signal

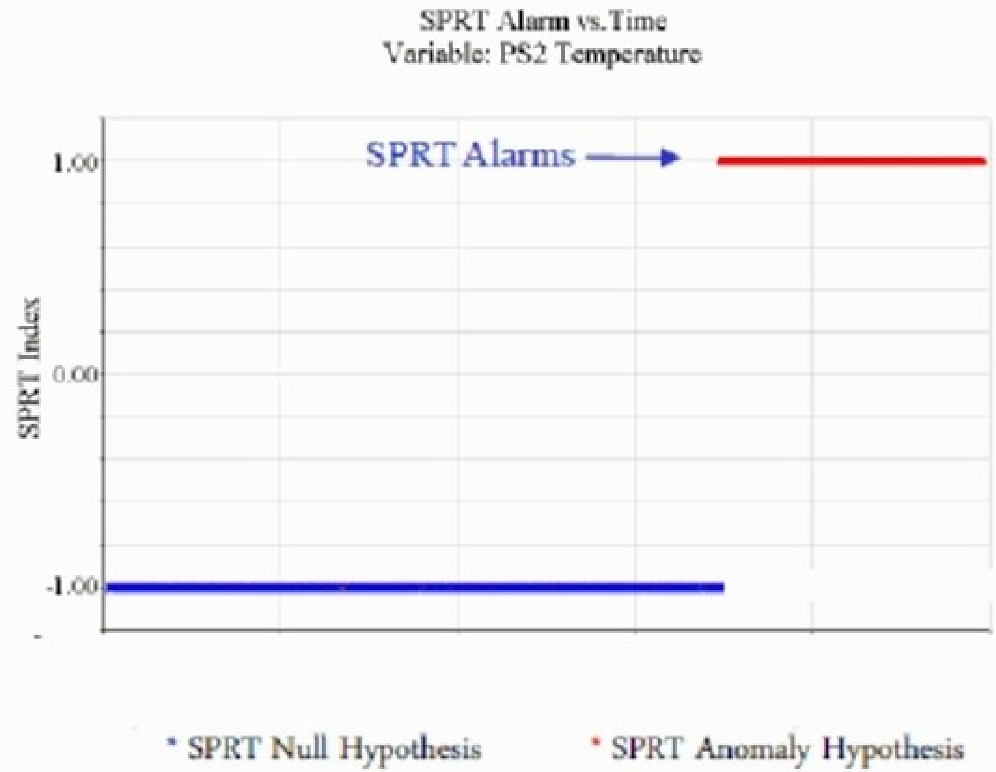

Observations and MSET Estimates vs. Time
Variable: PS2 Temperature
Observations; MSET Estimates in °C
50.30
49.82
49.34
48.86
48.38
47.90
47.42
46.94
46.46
45.98
45.50
Sept. 8, 2002 1:00pm
Sept. 9, 2002 12:06am
Sept. 9, 2002 11:13am
Sept. 9 2002 11:20pm
Sept. 10, 2002 9:26am
Time
Observations
MSET Estimates



Inferential Sensors via MSET

Physical sensors can fail. In many cases, the physical sensors have a shorter Mean Time Between Failure than the assets the sensors are supposed to protect.

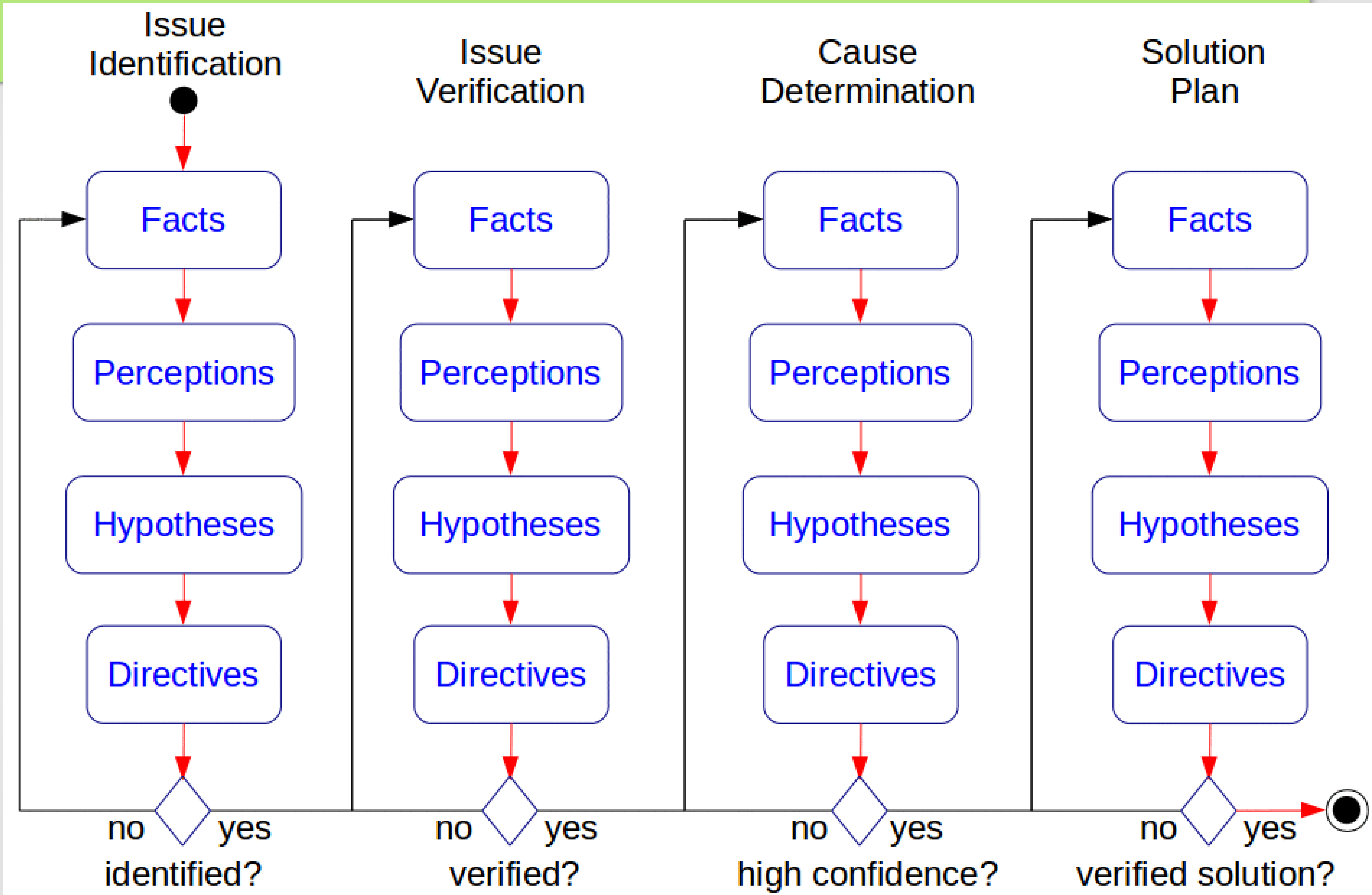
With MSET, if a physical sensor fails or degrades in service, MSET can mask the sensor signal and swap in the MSET estimate (red variable in figure).



Immediate SPRT alarms observed.

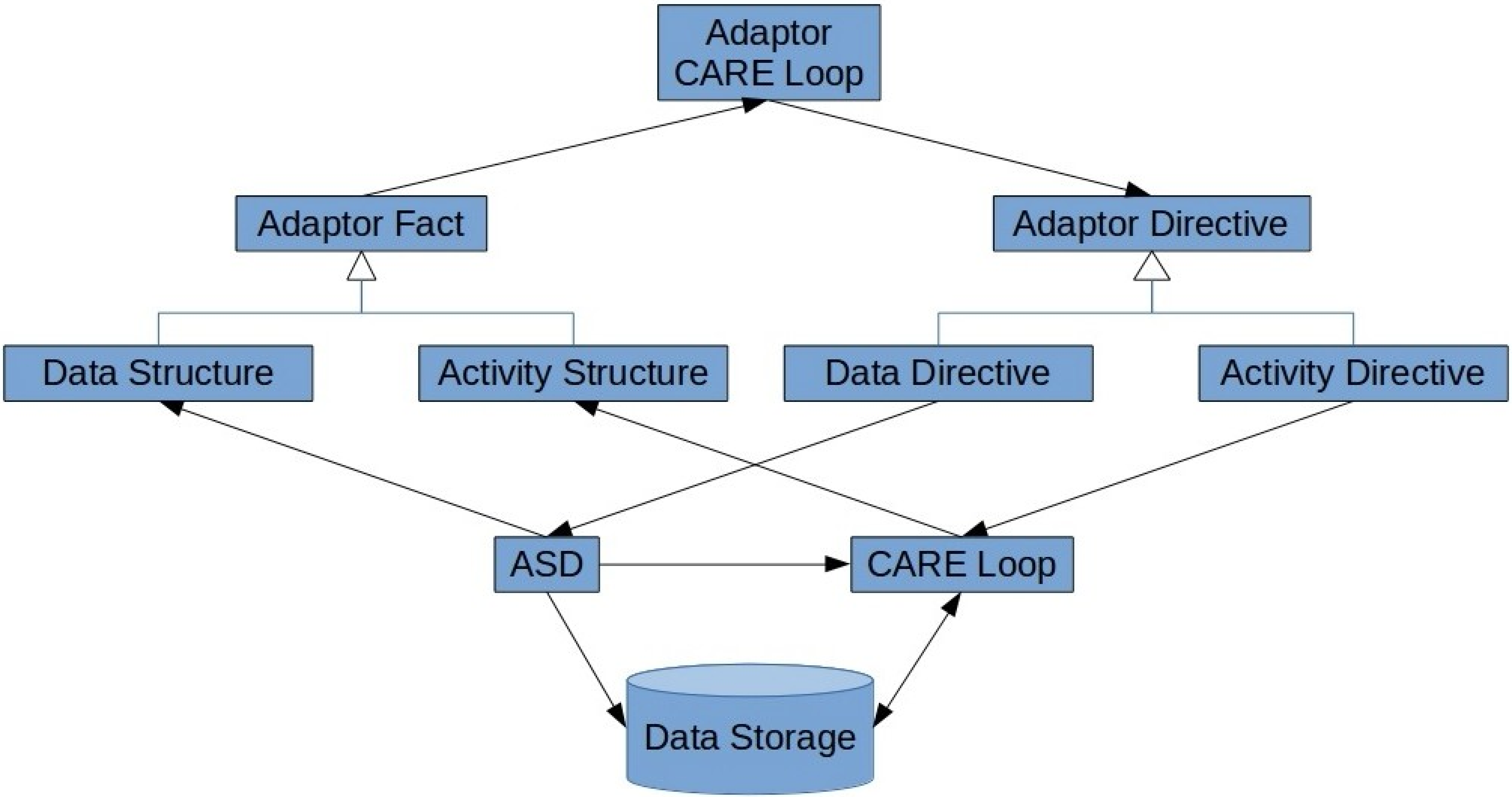
Customer Service

- Customer service is an important service provided by major service-oriented corporations
- Specialized teams are responsible for the steps in customer service responses
- Large amounts of data may be provided, generated and analyzed in each step
- Provenance data is recorded
- Each step of customer service is itself a decision making loop


Issue Identification
Issue Verification
Cause Determination
Solution Plan
Facts
Perceptions
Hypotheses
Directives
Facts
Perceptions
Hypotheses
Directives
Facts
Perceptions
Hypotheses
Directives
Facts
Perceptions
Hypotheses
Directives
no
yes
identified?
no
yes
verified?
no
yes
high confidence?
no
yes
verified solution?

Self-Adaptive Decision Making Processes

- The self-adaptation is another decision making loop
- The adaptor level modifies another decision making loop
  - Both processes and data structures are modified or even newly created
- Important for emergency scenarios and any process whose goals or environment has significantly changed


Adaptor CARE Loop
Adaptor Fact
Adaptor Directive
Data Structure
Activity Structure
Data Directive
Activity Directive
ASD
CARE Loop
Data Storage

Aircraft Control Scenario

- Aircraft control requires a series of decisions
  - Many have been automated
  - There are still situations that require pilot knowledge and experience
- US Airways Flight 1529 in 2009
  - Piloted by “Sully” Sullenberger
  - Total engine failure due to bird strike
  - Ultimately landed in the Hudson River
- Similar to many other emergency situations
  - Nuclear power plant emergencies
  - Automobile driving emergencies

USA 1549 Scenario

- What did Sully have to do?
  - Establish situation awareness
  - Select among alternatives
  - Discover and develop a novel river landing procedure
  - Verify safety constraints
  - Complete this in a matter of only a few seconds.
- Modern autopilots are not (yet) sufficiently adaptable for such a scenario

Example of OODA loop

- *Observe* the bird strike and the subsequent instrument readings
- *Orient:* Condense this information into an hypothesis
  - The hypothesis was: the plane had suffered a loss of power in both engines.
- *Decide:* Verify their conclusion
- *Actions:* Instrument checks, restarting engines, etc.

Relevance Reasoning Example

- Complex systems have large numbers of sensors
  - In some cases over a million
- Most of the data is not relevant to a particular goal
- For Flight 1549, only a few sensors were relevant
  - Aircraft thrust, altitude, velocity, location were relevant
  - Cabin temperature and pressure were not relevant

Decision Cycle

- Reasoning occurs in a cognitive cycle
- Emergency situations require restructuring the process
  - Goals must be modified
  - Previously irrelevant data becomes relevant
- The Flight 1549 emergency
  - Saving the aircraft was abandoned
  - Multiple iterations of the decision loop were necessary to find a suitable landing location
  - Many situations were considered
  - Presence of rescue ships was relevant

Provenance

- Important for operation, regulation and investigation
- Operators require provenance to achieve situation awareness and to make decisions
  - Understanding is important
- Regulators are tasked with protecting lives and properties
  - Optimizing corporate profits are not primary concerns
- Investigators require provenance to determine the causes for accidents

Forms of Reasoning

- Both logical and statistical reasoning are necessary
- The KIDS ontology provides for both forms of reasoning
  - Logical reasoning within a situation and between them
  - Statistical reasoning when generating and evaluating situations
- Risky situations are intrinsically probabilistic

What about Learning?

- There was no opportunity for the pilots to practice their novel river landing procedure
  - Not easily repeated because of loss of aircraft
  - Flight simulators do not have such a capability
- At first it appears that learning does not play any role
- Exploration techniques (such as in reinforcement learning) only explore within the known set of parameters
- Nevertheless ML and ontologies both have roles

Roles of ML and Ontologies

- How can ML be used?
  - Optimizing normal decision making processes
  - Detecting problems and sounding alarms
  - Detecting and correcting faulty sensors
  - Providing the components for novel procedures
- How can ontologies be used?
  - Relevance reasoning
  - Achieving situation awareness
  - Verifying compatibility of components of processes
  - Verifying safety and regulatory compliance