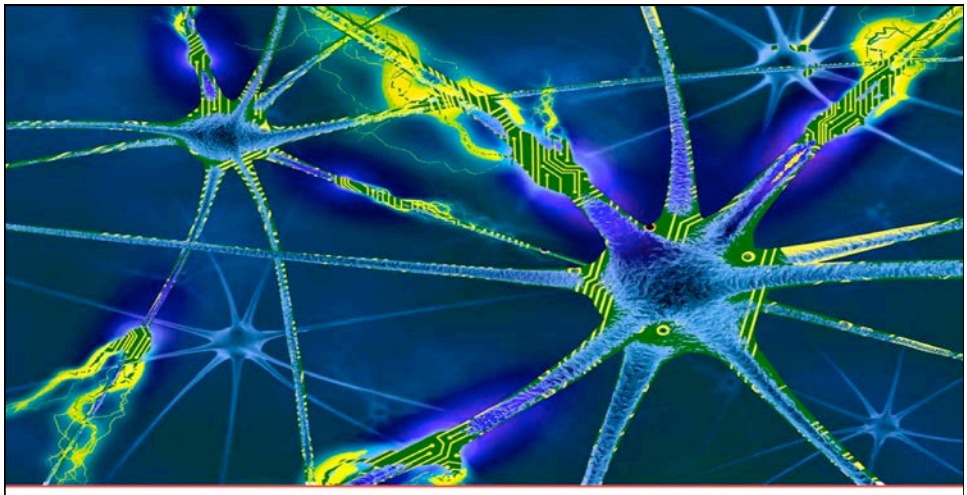

Approaches to Intelligent Systems

Department of Computer Science & Engineering
University of Nebraska-Lincoln
Tuesday 8 October, 2013

Jens Pohl, PhD

CADRC
Collaborative Agent Design Research Center

Approaches to Intelligent Systems

University of Nebraska-Lincoln (8 October 2013)

1. AI Interests and Approaches.
2. Need for Intelligent Systems.
3. Logical Reasoning Approach (Top Down).
4. Connectionist Approach (Bottom Up).
5. Subsumption Approach (Bottom Up).
6. Conclusions and Path Ahead.

Approaches to Intelligent Systems

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AI Research Objectives and Results

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Initial Objectives

- Understanding and imitation of human intelligence.
- Self-learning through experience and experimentation.
- Automated reasoning within the context of knowledge.

Early Results

- Connection networks learn a little but are not intelligent.
- Symbolic systems have embedded expertise, but no common sense.
- Subsumption systems are very complex and may not scale well.

Overly Concern for

- Logical correctness and mathematical precision.
- Verifiable accuracy and reliability in all situations.
- Elegance and simplicity of unified theories.

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Artificial Intelligence (AI) Approaches

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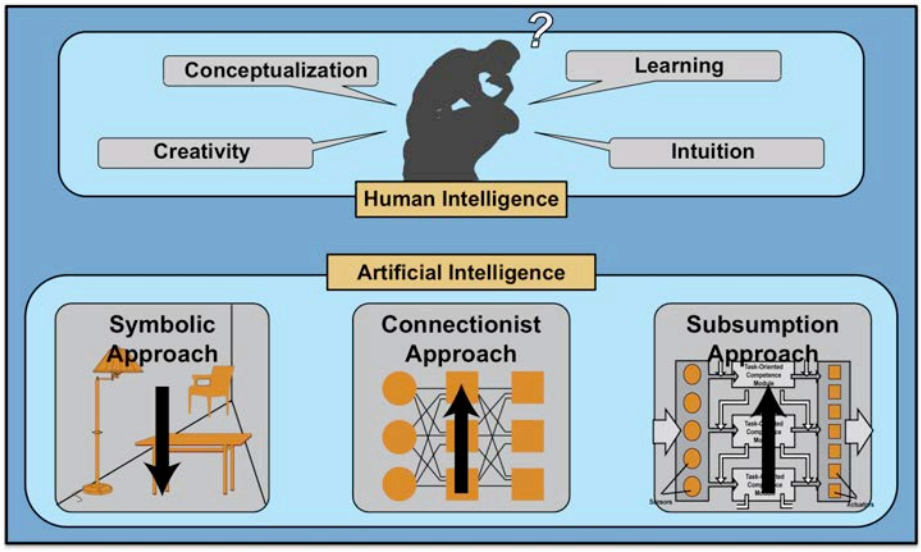

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AI Approaches and Concerns

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Top-Down Approach

- Explicit representation of information and knowledge.
- Symbolic reasoning with the structure of a context model.
- Decomposition of complex problems into specialized agents.
- Unrealistic assumption of an orderly and predefined world.

Bottom-Up Approach

- Connection of many simple elements or capabilities.
- Capabilities depend on the connectivity and interactions.
- Hidden representation of information and knowledge.
- Pattern matching without logical understanding.

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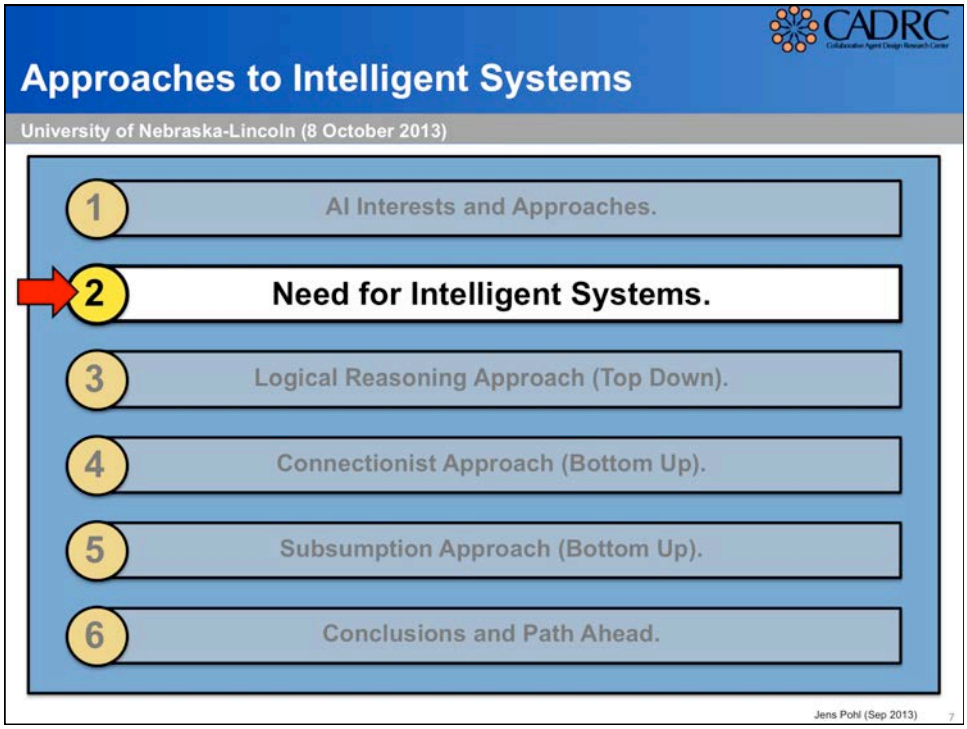
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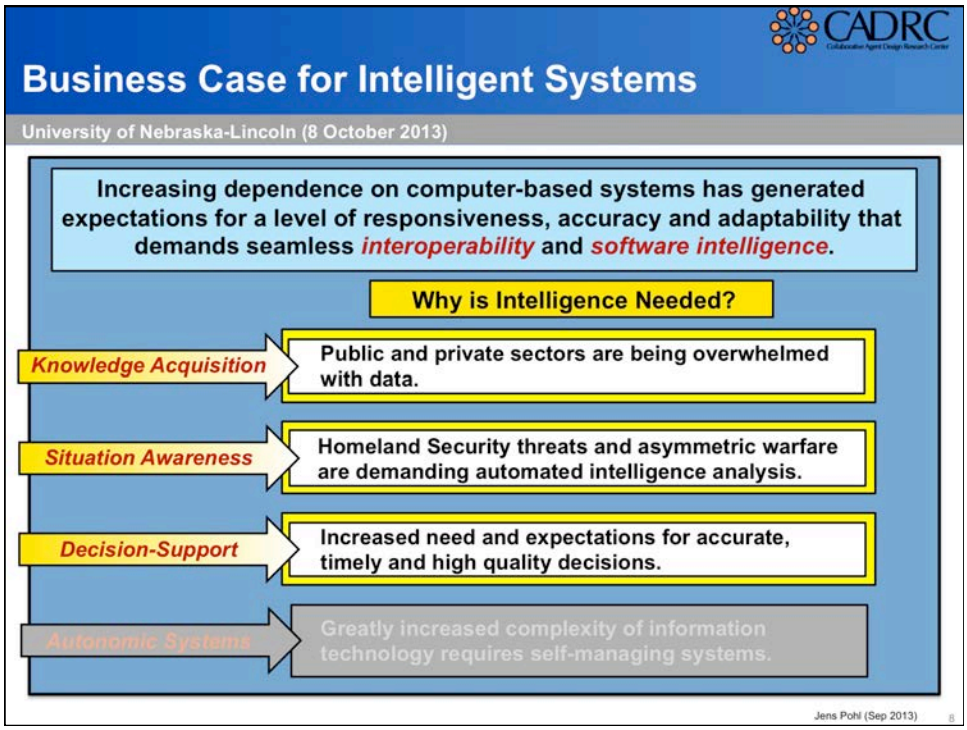
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Business Case for Intelligent Systems
University of Nebraska-Lincoln (8 October 2013)
Increasing dependence on computer-based systems has generated expectations for a level of responsiveness, accuracy and adaptability that demands seamless interoperability and software intelligence.
Why is Intelligence Needed?
Knowledge Acquisition
Public and private sectors are being overwhelmed with data.
Situation Awareness
Homeland Security threats and asymmetric warfare are demanding automated intelligence analysis.
Decision-Support
Increased need and expectations for accurate, timely and high quality decisions.
Autonomic Systems
Greatly increased complexity of information technology requires self-managing systems.
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From Data to Knowledge

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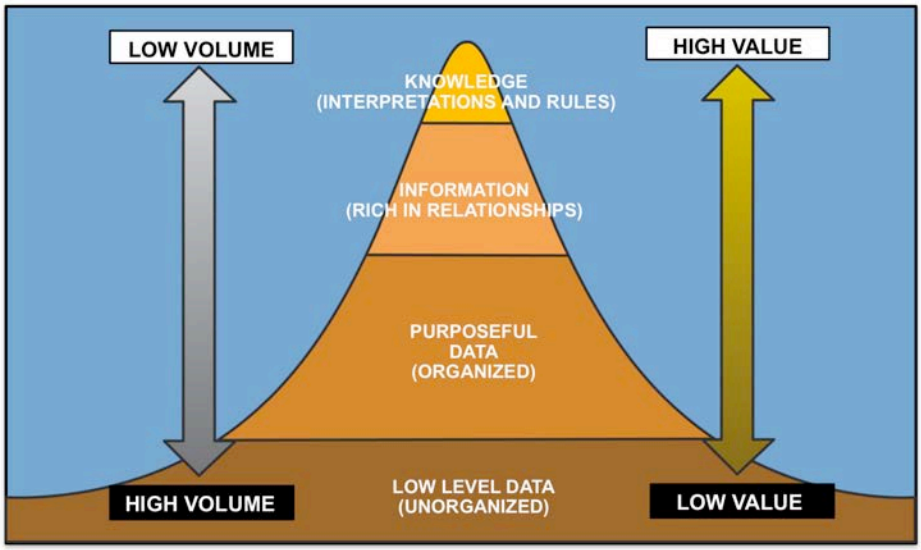

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Fundamental Distinctions

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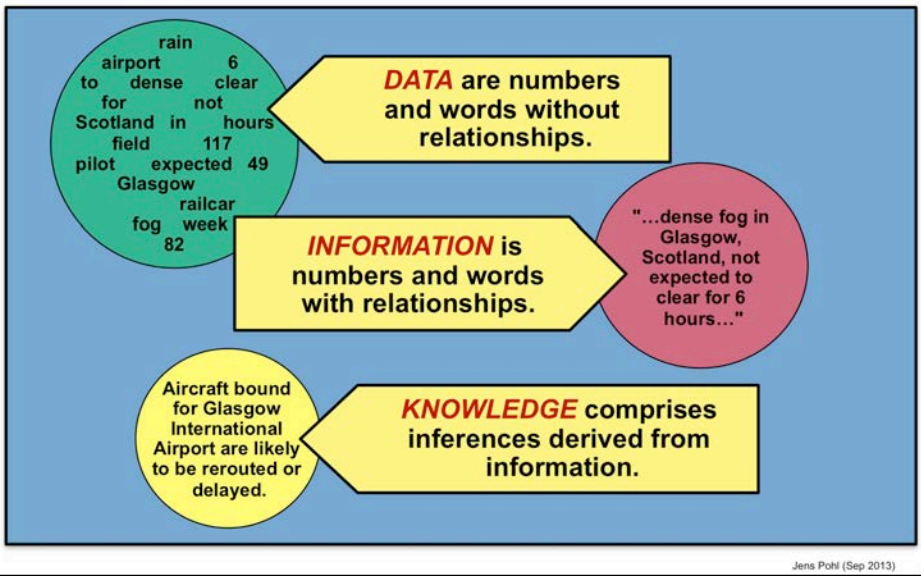

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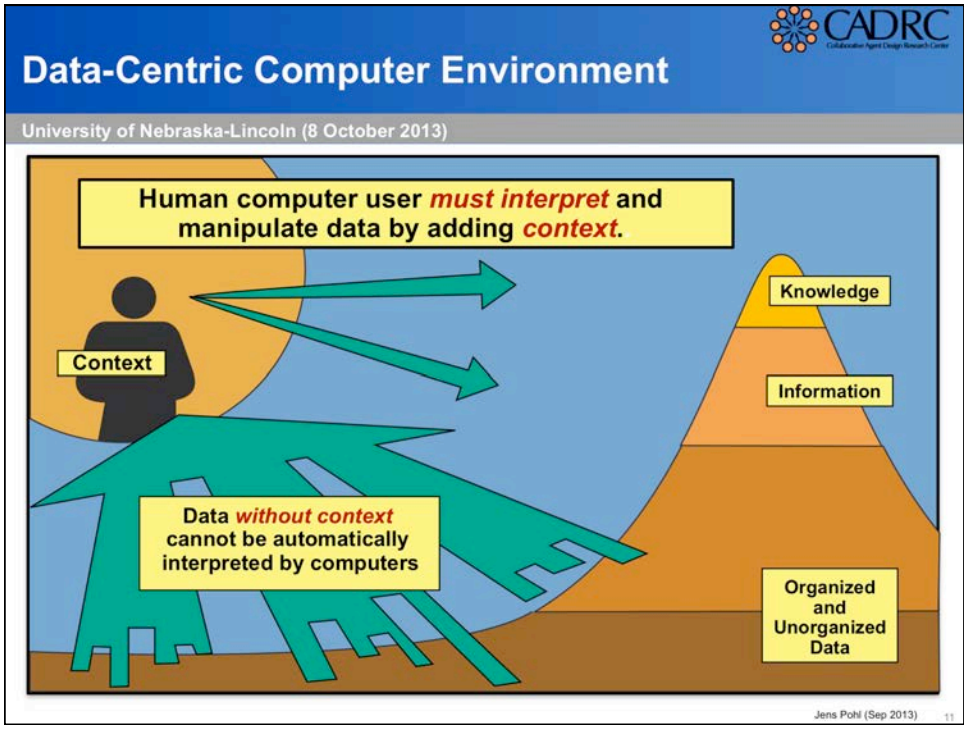
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Data-Centric Computer Environment
University of Nebraska-Lincoln (8 October 2013)
Human computer user must interpret and manipulate data by adding context.
Context
Knowledge
Information
Data without context cannot be automatically interpreted by computers
Organized and Unorganized Data
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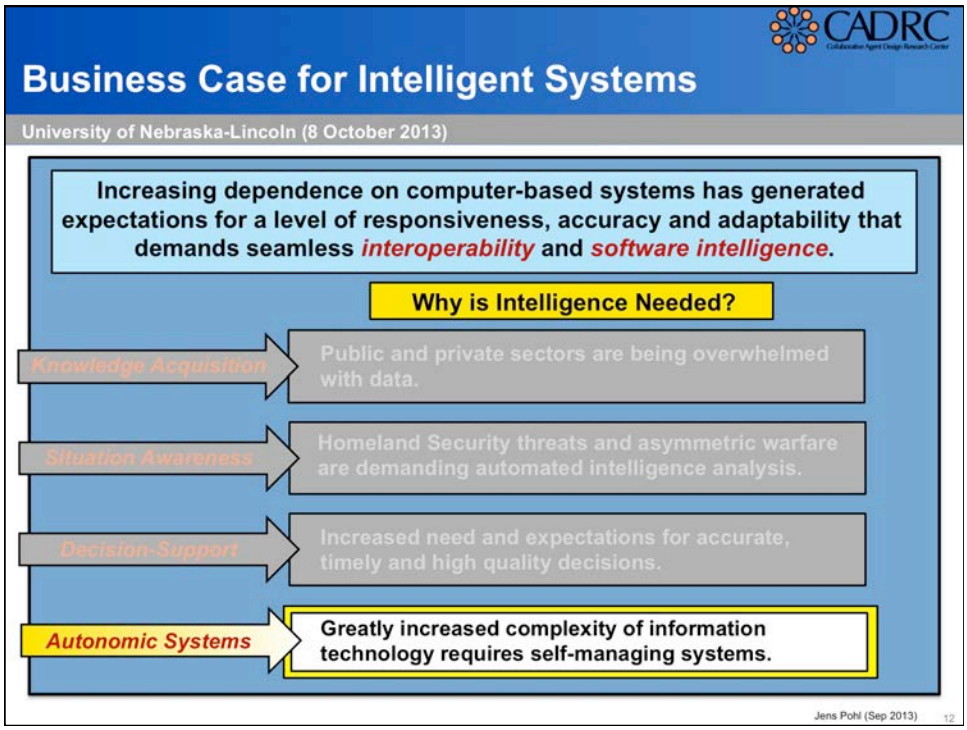
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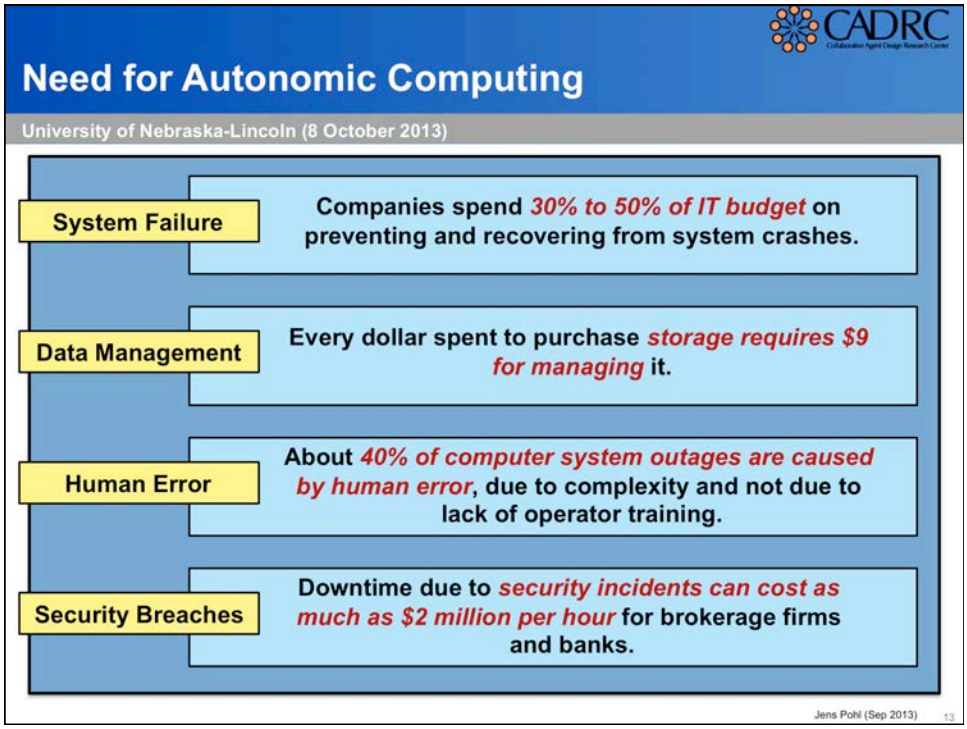
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Need for Autonomic Computing
University of Nebraska-Lincoln (8 October 2013)
System Failure
Companies spend 30% to 50% of IT budget on preventing and recovering from system crashes.
Data Management
Every dollar spent to purchase storage requires $9 for managing it.
Human Error
About 40% of computer system outages are caused by human error, due to complexity and not due to lack of operator training.
Security Breaches
Downtime due to security incidents can cost as much as $2 million per hour for brokerage firms and banks.
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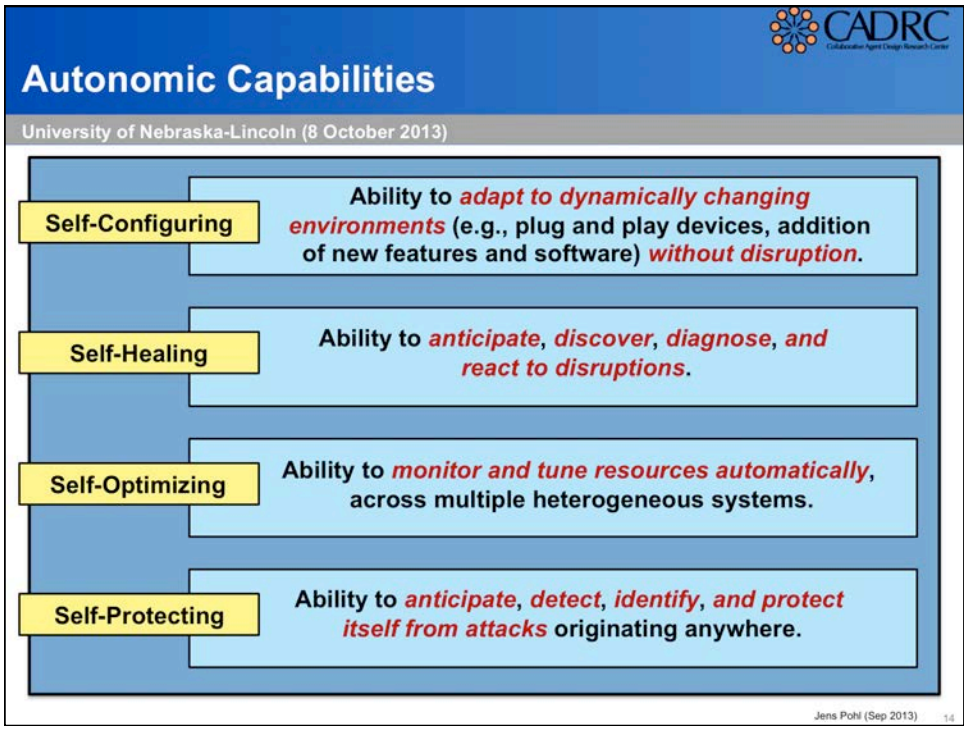
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Autonomic Capabilities
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Self-Configuring
Ability to adapt to dynamically changing environments (e.g., plug and play devices, addition of new features and software) without disruption.
Self-Healing
Ability to anticipate, discover, diagnose, and react to disruptions.
Self-Optimizing
Ability to monitor and tune resources automatically, across multiple heterogeneous systems.
Self-Protecting
Ability to anticipate, detect, identify, and protect itself from attacks originating anywhere.
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Autonomic Self-Healing Requirements

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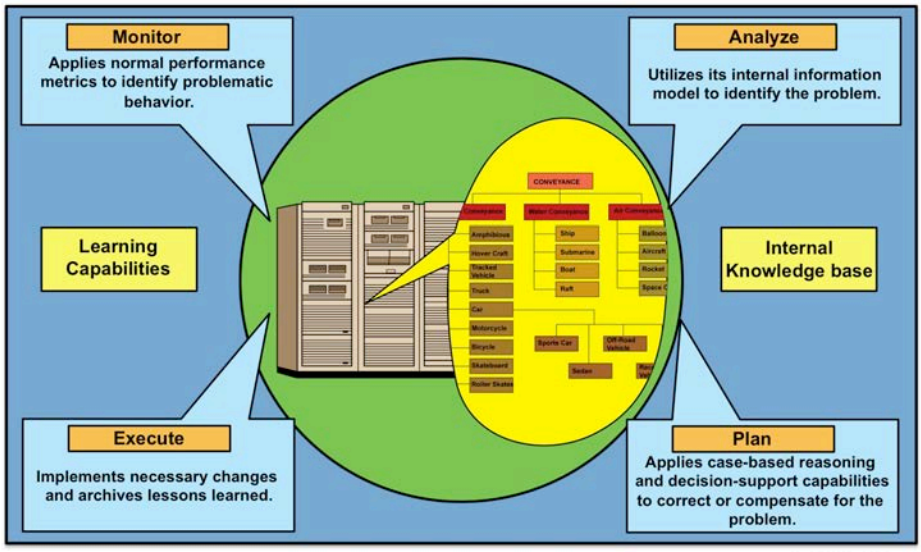

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Approaches to Intelligent Systems

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Context Components

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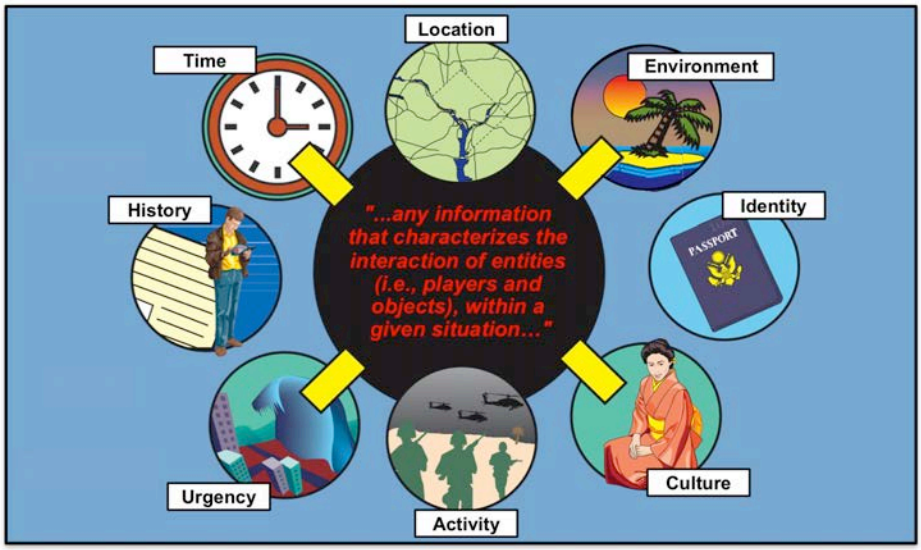

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Context as an Enabler

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Context is a prerequisite for . . .

1. Automated *interpretation* of data.
2. Automated *filtering* of data.
3. Automated *retrieval* of useful data.
4. Intelligent collaborative decision *tools*.
5. *Self-healing* and *secure* information networks.
6. Responsive human-computer *interfaces*.

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Ontology Representation of Context

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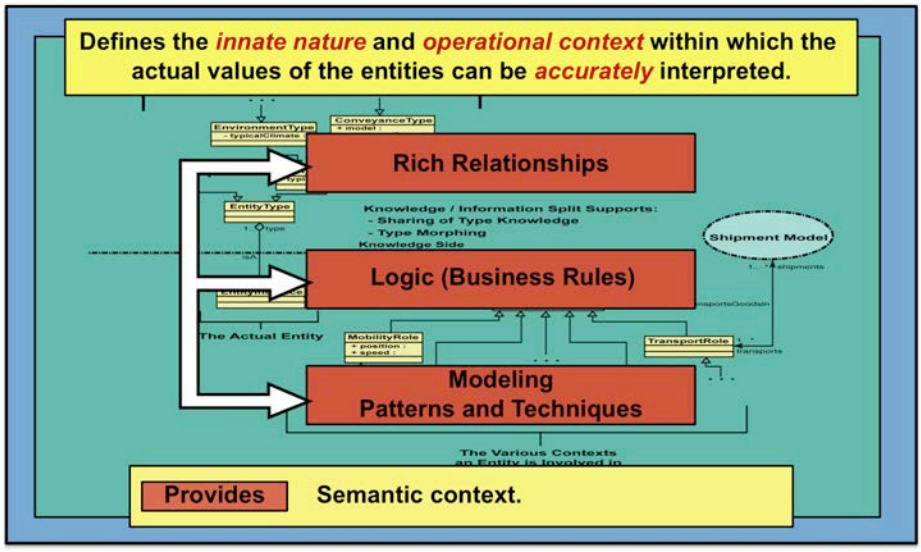

Ontology is Machine Processable

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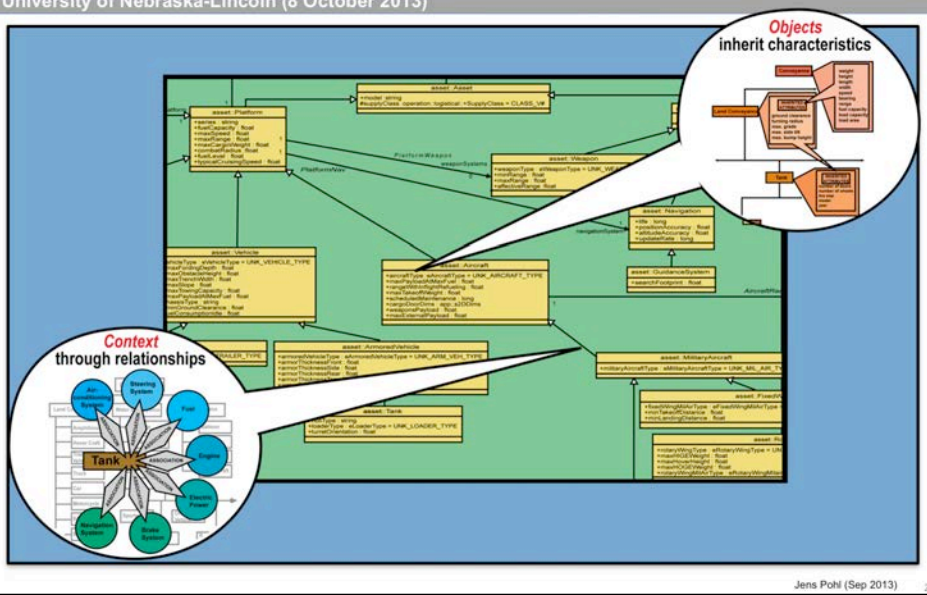

Typical Modeling Pattern

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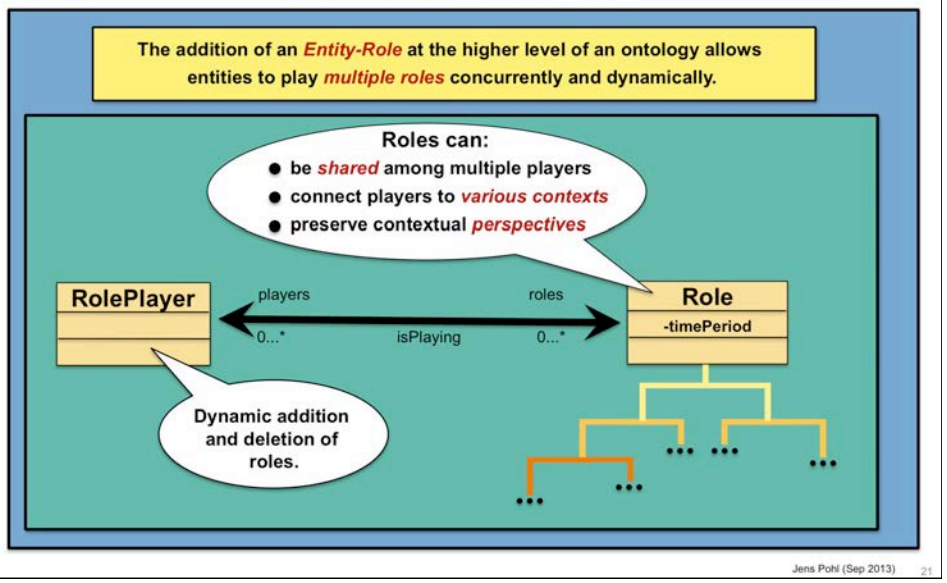

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Entities Can Play Multiple Roles

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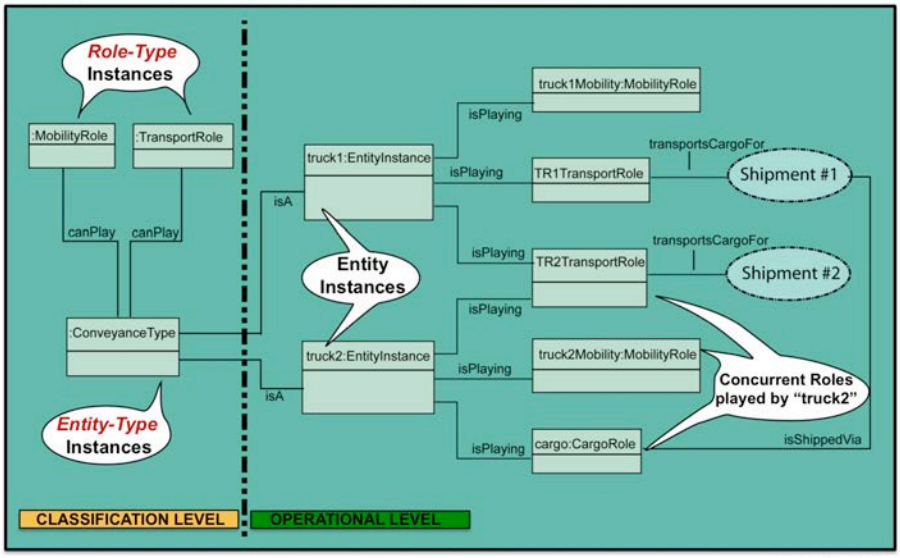

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Multi-Layered Context Representation

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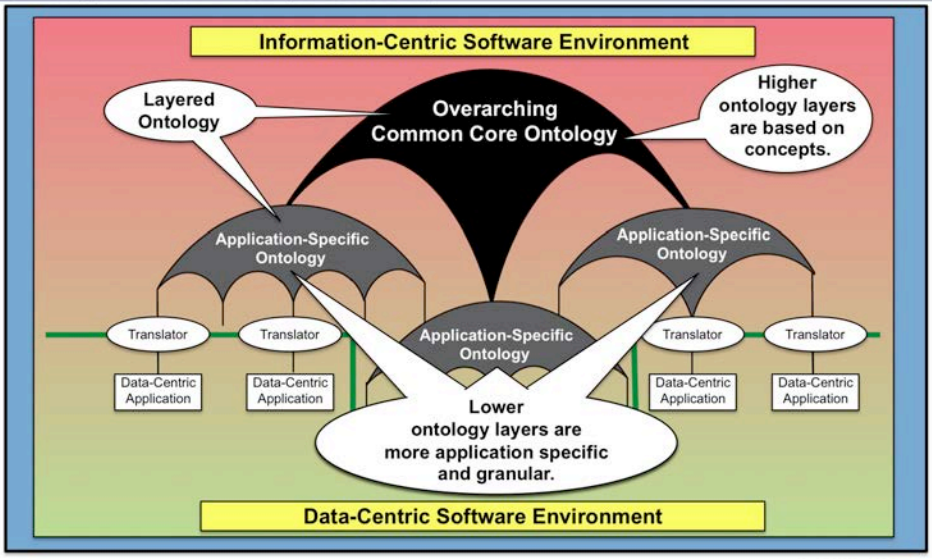

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Computer-Based Agents

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What is a computer-based agent?

"Software code that is capable of *communicating* with other agents (including human agents) *to facilitate some action*"

What is an intelligent agent?

1. Communicates using an *expressive language*.
2. Has knowledge (*context*) and acts on its own initiative.
3. Collaborates with other agents to *accomplish goals*.
4. Uses *local information* to manage local resources.

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Human Reasoning

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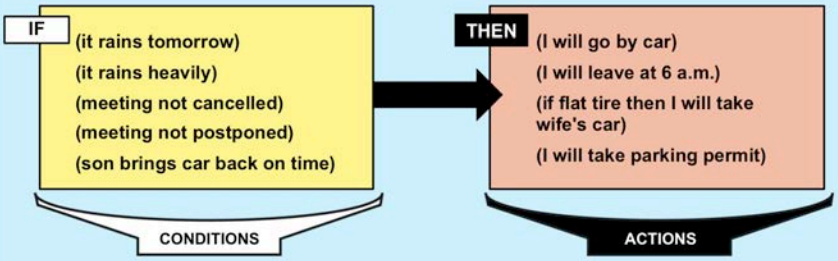
The human reasoning process can be described as a *production system* in which conclusions are drawn based on the existence of certain conditions.

The typical representation of a production system is a set of *IF ... THEN* statements or *rules.*



When all of the *conditions* are satisfied the *actions* of the production are executed.

What Software Agents *Can* Do!

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Computer-Based Agents Can:

- *Communicate* with other agents and users.
- *Monitor* events.
- *Reason* about available information
- Retrieve *information* from external sources.
- Hold deep *knowledge* in narrow domains.
- Request and provide *expert services*.
- Pursue interests and *objectives*.
- Accomplish low level *learning* tasks.

SOA-Based Infrastructure Components

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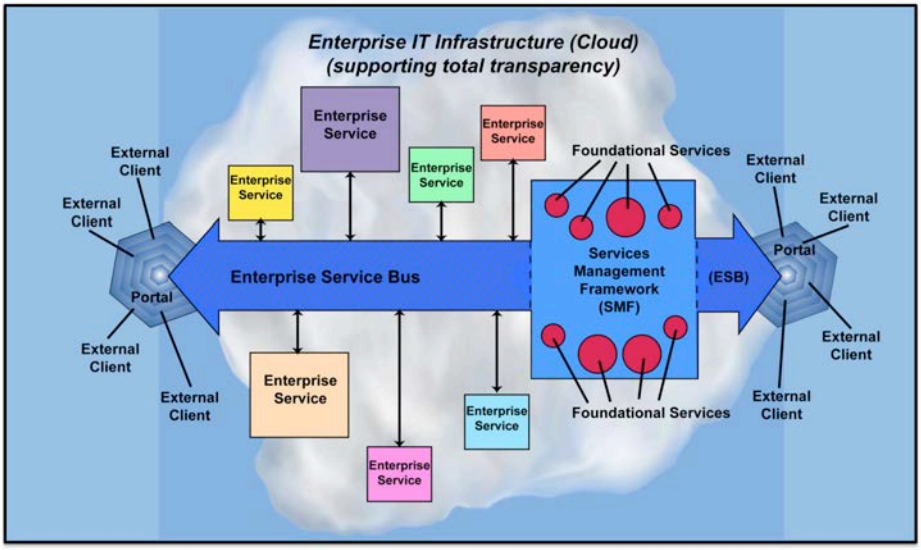

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An Intelligent Supply Chain IT Environment

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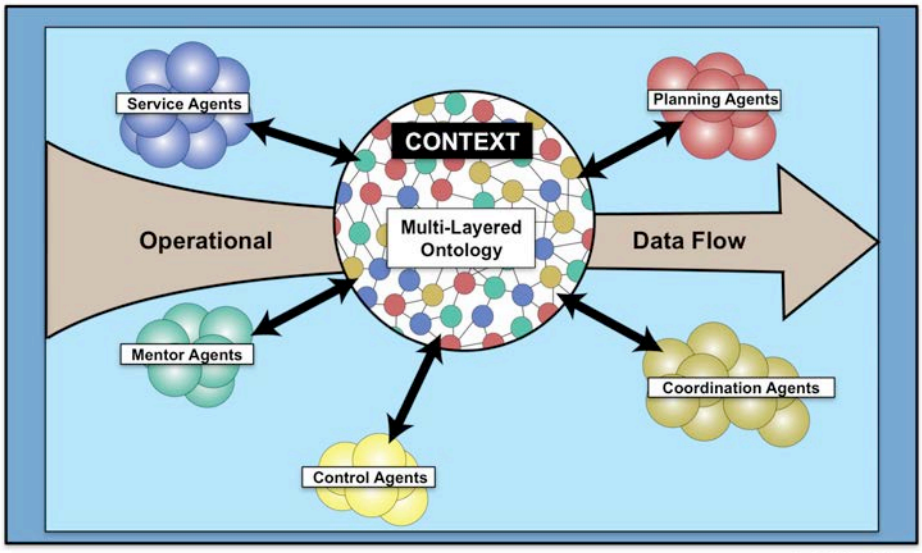

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Typical Service Agents

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Ability to *interpret raw weather data* into a weather report that has *meaning* to both the *human operator* and the *machine*.

Ability to *monitor* the fuel consumption of conveyances during movements (sensor data), *project* fuel requirements, *locate* refueling nodes, and *assess* fuel capacities at nodes.

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Typical Planning Agents

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Ability to *plan* and *re-plan multi-modal routing* alternatives under time critical conditions taking into account route conditions, efficiency, cost, and risk.

Ability to rapidly *estimate* the *cost of alternative movement plans* during both strategic planning and execution.

Ability to *assess* the *risks* associated with *alternative movement plans* based on past performance, current threat conditions, weather forecasts, and political factors.

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Rapid Re-Planning Capabilities

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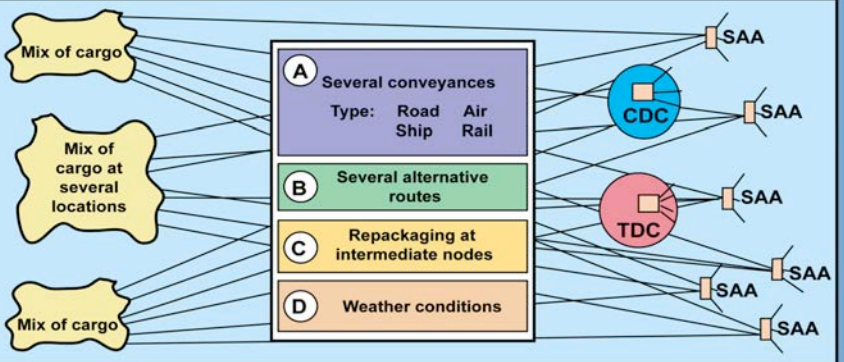
Intelligent re-planning tools will be available to assist operators in the analysis, evaluation and generation of alternative shipment plans.



Re-planning tools will *scale* to problems of increasing complexity.

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Monitoring a 'Container'

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Mentor Agents represent the *interests* of a *particular object* (e.g., *container*, pallet, individual cargo item, conveyance, etc) subject to the *current state* and *role played by that object*.

As soon as the container was loaded the interests of the container were automatically represented by a *Mentor Agent*.

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Typical Coordination Agents

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Conflict Agent

Ability to *detect conflicts* among agents and within the transportation network, and *identify the likely cause(s)*.


Collaboration Agent

Ability to *facilitate collaboration* by *activating agents* and *alerting human operators* of the need for interaction.


Threat Agent

Ability to *assess threat conditions* based on intelligence sources and relate these to *individual shipments*, as well as the *global transportation network*.


Convoy Domain Agent


Ship Domain Agent


Air Domain Agent


Rail Domain Agent

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Typical Governance Agents

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Governance Agents are responsible for ensuring that individual movement plans are in *compliance* with *Commander's Intent*, established *priorities*, applicable *ROEs*, *security* regulations, and *performance* expectations.


Commander's Intent

Ability to *abstract* the principal features of a movement plan *to a conceptual level* for the generation of Commander's Critical Information Requirements (CCIR).


Performance Agent

Ability to *apply metrics and assess* not only the *goodness* of an individual movement plan but also its impact on the *overall operational efficiency*.


Priority Agent


Security Agent


ROE Agent

Governance Agent

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Intelligent SOA-Based Environment

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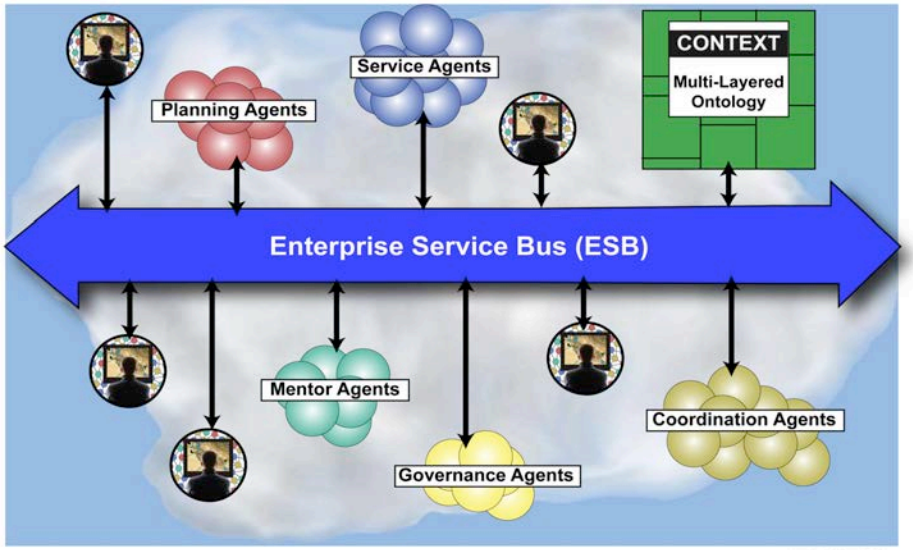

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Intelligent LogC2 Environment

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Typical Military Scenario

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High priority Requisition for add-on-armor (AOA) supplies received by DLA (Defense Logistics Agency) from the Iraq theater.

One of *hundreds* of requisitions received daily.

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Are the requested supplies in inventory?

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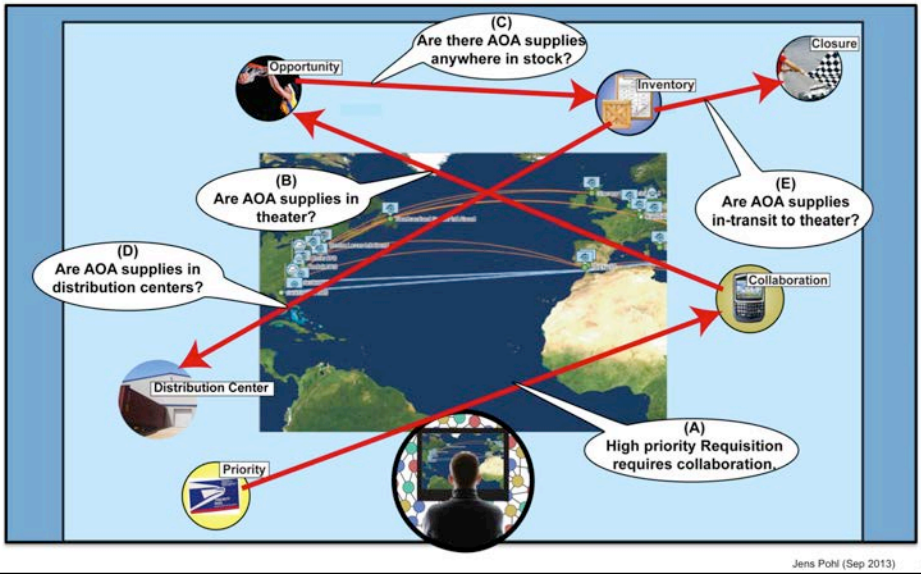

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Supplies must be outsourced.

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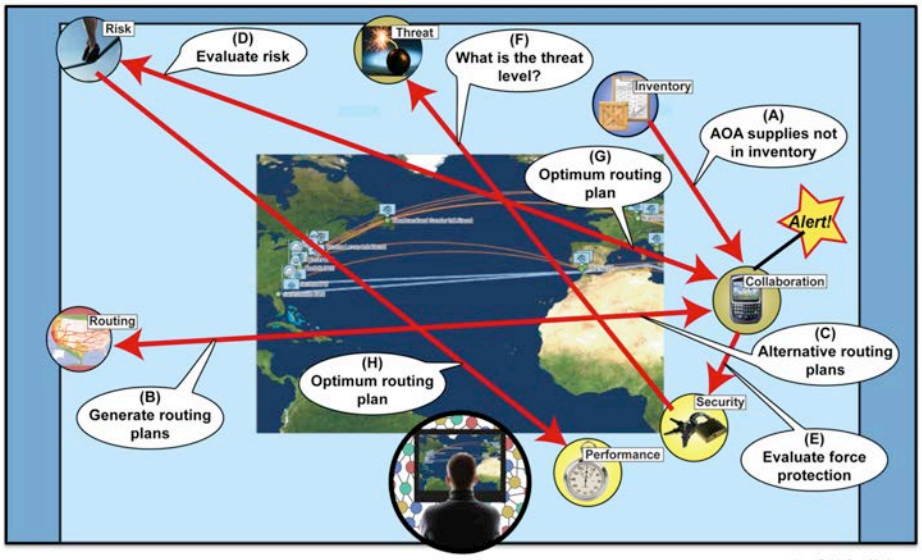

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Mentor Agent is assigned to Requisition

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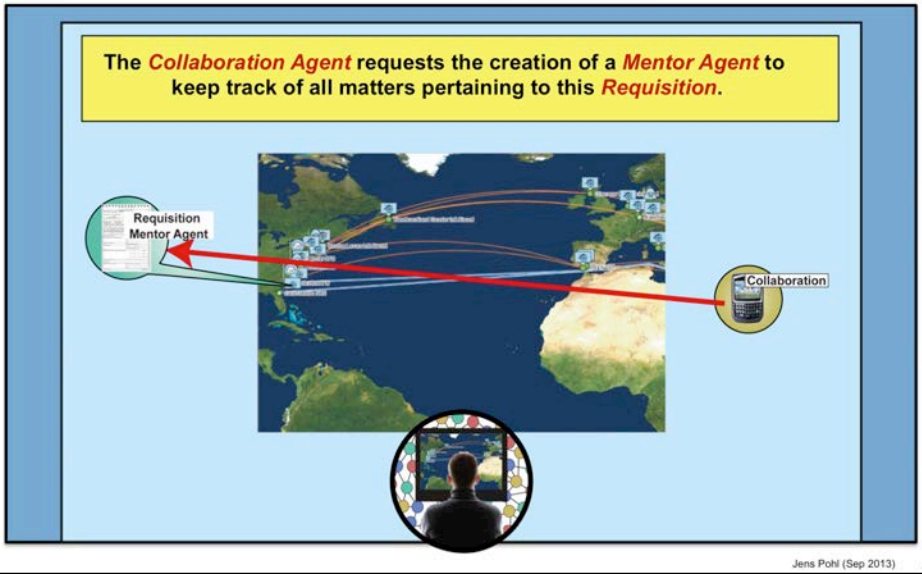

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Potential Thanksgiving event.

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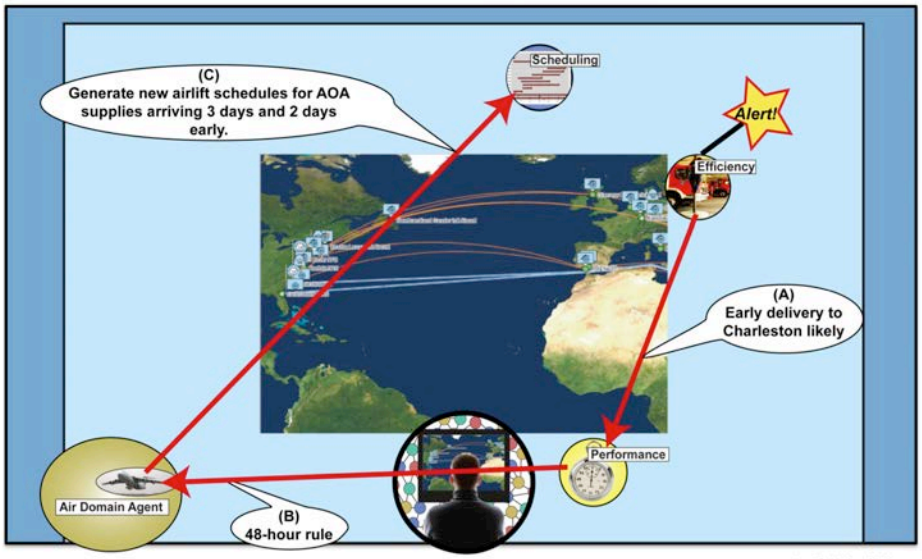

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Decision on commercial airlift.

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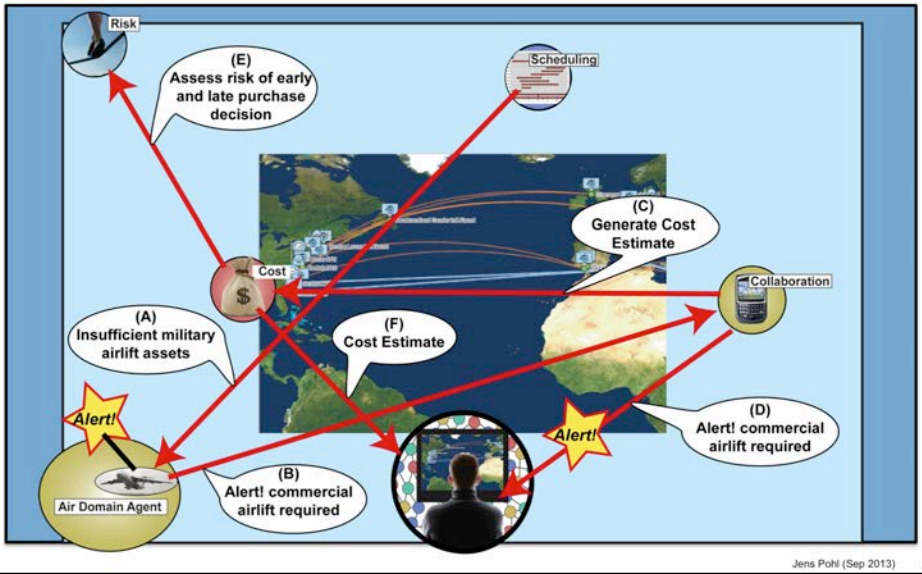

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Decision made in minutes, not days.

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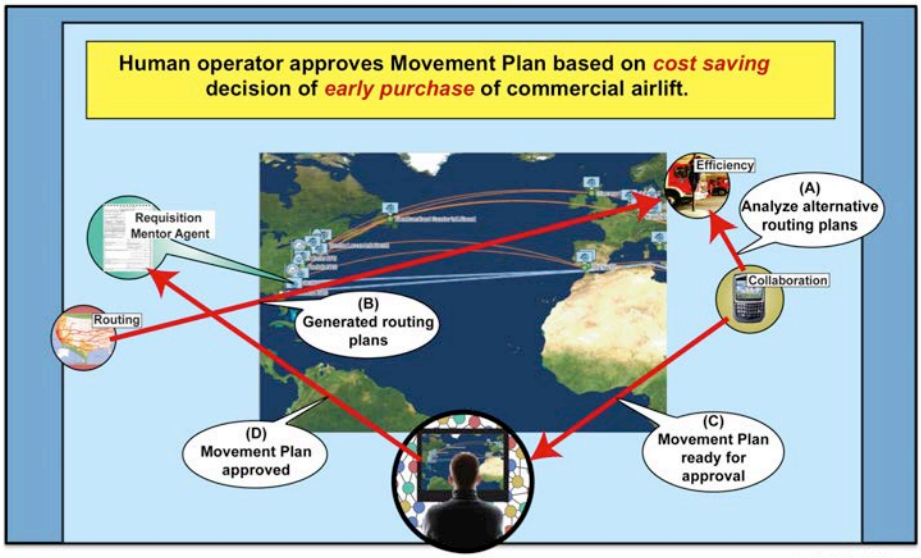

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Typical Execution Events.

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Glasgow Airport is fogged in.

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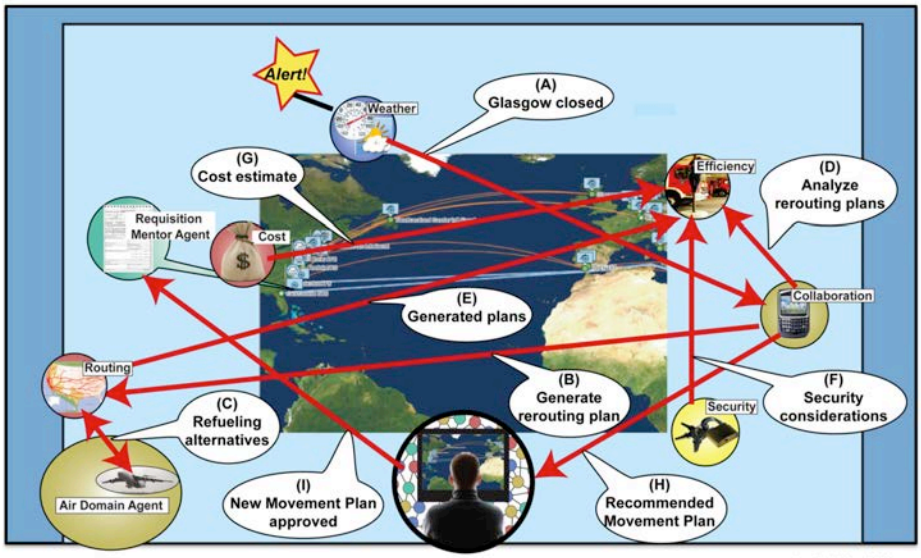

Identification of Opportunities.

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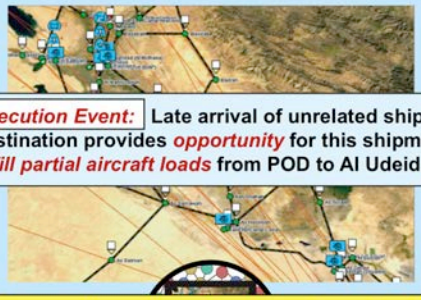
Intelligent *software agents* are continously *monitoring events* and looking for opportunities to *increase efficiency* and *decrease costs*.



Second Execution Event: Late arrival of unrelated shipment to same destination provides *opportunity* for this shipment to *backfill partial aircraft loads* from POD to Al Udeid.

Human operators would easily *overlook* such opportunities due to the large number of transactions.

Cost Savings.

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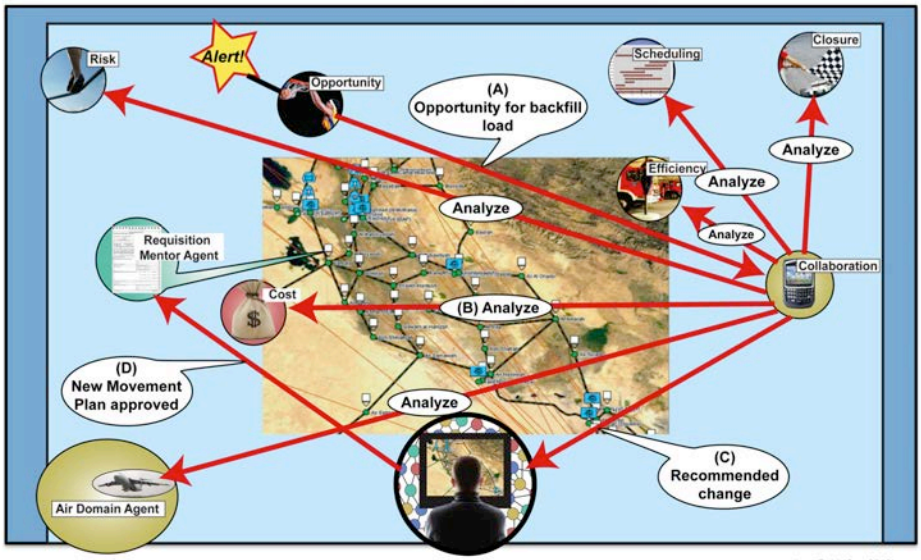

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The Top-Down Symbolic Approach

University of Nebraska-Lincoln (8 October 2013)

Advantages

- Clarity and verifiable precision.
- Availability of mathematical theories and procedures.
- Similarity to the human reasoning process.

Disadvantages

- Must adhere to a largely predefined explicit representation of objects and relationships.
- Cannot easily deal with exceptions and analogies.
- Formal information models are unable to represent the wealth of knowledge that allows humans to exercise common sense.

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Approaches to Intelligent Systems

University of Nebraska-Lincoln (8 October 2013)

1. AI Interests and Approaches.
2. Need for Intelligent Systems.
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4. **Connectionist Approach (Bottom Up).**
5. Subsumption Approach (Bottom Up).
6. Conclusions and Path Ahead.

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Simulation of Human Brain Functions

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The principal capability of the human brain appears to be related to the *processing of patterns*.

Human ***pattern matching*** **applies to:**

- Speech communication.
- Recognition of persons and objects.
- Performing a task such as driving a car.
- Reasoning (i.e., matched conditions that lead to conclusions and actions, as in *productions*).

Simulated ***pattern matching*** **applies to:**

- Reproduce primary brain functions with electronic devices.
- Simulate the two fundamental building blocks of he human brain electronically (i.e., *neuron* and *synapse*).

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The Human Brain

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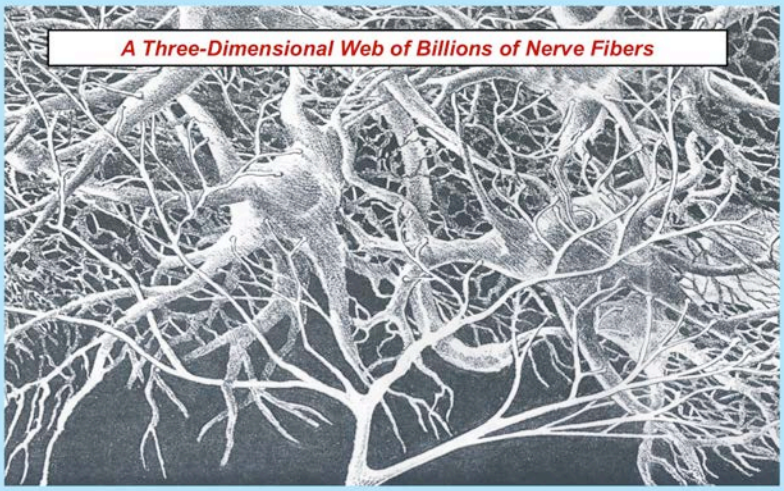

The Simulated Human Brain

University of Nebraska-Lincoln (8 October 2013)

A neural network consists of *multiple connected* layers of artificial neurons, which are referred to as *neurodes.*

- A neurode is a *mathematical function* that can be computed on a digital computer.
- Typically each neurode receives a *large number of input signals.*
- The *input* signals are accumulated by the neurode until they exceed a *threshold value*, and then passed on as *output* to other connected neurodes.

Essentially the neurode computes a *transformation function* that associates a given level of input signals with a particular level of output.

Neurode Operations

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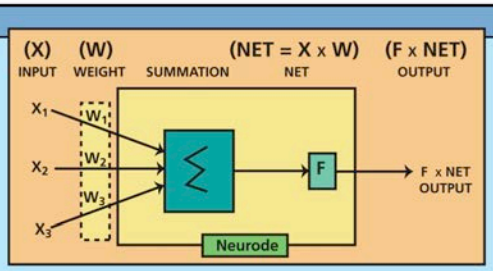

Step 1 Summation of all *individual inputs* (X_1, X_2, X_3, ... X_n) multiplied by the corresponding *weighting factors* (W_1, W_2, W_3, ... W_n). Refinements such as timed input delays and threshold input requirements may be added.

Step 2 Comparison of the net input (NET) with a predetermined *threshold function* (F). Individual input signals are lost at this stage.

Step 3 Generation of an *output signal* if the accumulated input *exceeds the threshold* (F).

Neural Network Architecture

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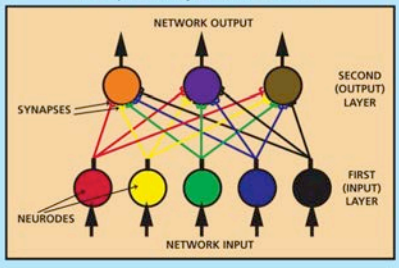
Neurodes are generally interconnected in multiple layers: an *input layer*; one or more *hidden layers*; and, an *output layer*.

A simple two-layer neural network.



- Each input neurode connects to each output neurode.
- Synapses could be *bidirectional*, in which case there would be another 15 (i.e., 3 output neurodes to each of 5 input neurodes) *backward* connections. (The simple neural network shown is a *forward* (only) network.)

Neural Network Operation

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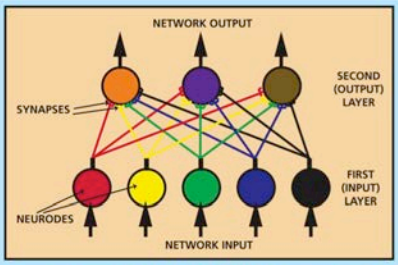

- Each input layer neurode receives a *starting value* between 0.0 and 1.0.
- If the input value (signal) *exceeds the threshold value* then the neurode will *fire* and *send identical output values* (signals) to each second-layer neurode.
- Each second layer neurode multiplies the signal received by a *weighting factor*.
- The signals received from multiple neurodes are *summed*, and if this combined signal *exceeds the threshold* value then the neurode will *fire*.

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The Bottom-Up Connectionist Approach

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Advantages

- Apparently elegant mathematical representation.
- Often performs quite well with incomplete input.
- Can be trained to recognize many kinds of patterns.
- Can recognize conditions that are similar but not identical.

Disadvantages

- Little understanding of mathematical representation.
- Knowledge within internal nodes is not readily accessible.
- Difficult for neural networks to explore alternatives.
- Weighting coefficients at nodes cannot be changed like the memory cells in a digital computer.

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Approaches to Intelligent Systems

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1. AI Interests and Approaches.
2. Need for Intelligent Systems.
3. Logical Reasoning Approach (Top Down).
4. Connectionist Approach (Bottom Up).
5. **Subsumption Approach (Bottom Up).**
6. Conclusions and Path Ahead.

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The Subsumption Architecture

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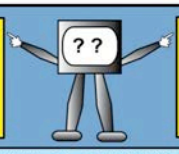
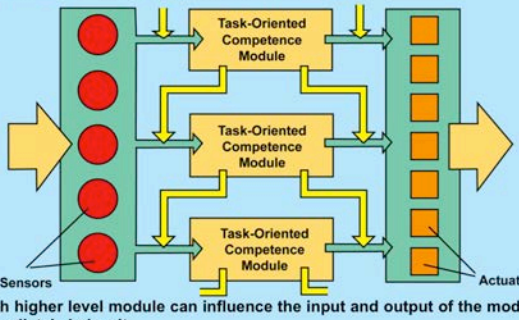
Assumption 1:
Intelligent behavior is possible without explicit knowledge representation and symbolic reasoning capabilities.



Assumption 2:
Intelligence emerges from interaction with the environment.

- The subsumption architecture of a behavior-based agent consists of a hierarchical framework of task-oriented modules.



- Each higher level module can influence the input and output of the module that is immediately below it.

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Key Subsumption Concepts

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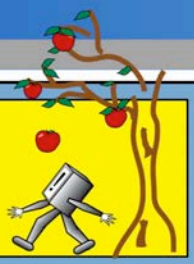

Human-like intelligence emerges from the interaction with an environment. Therefore, an intelligent agent is a robot that is mobile and capable of responding to sensory stimuli.

Intelligent robots are:

- *Situated* in a real world environment to which they respond dynamically.
- *Embodied* to the extent that they have a physical presence and are able to respond to their own sensations.
- *Intelligence* not only due to their computational capabilities, but also through their sensory couplings.
- *Emergent* since their intelligence is derived from their interactions with their components and the environment.

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The Notion of *Situatedness*

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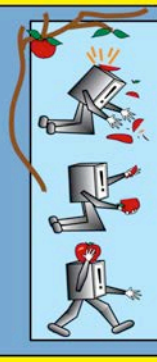
Triggered by its sensors a robot agent dynamically builds a temporal model of the real world that surrounds it. Objects and relationships are primarily relevant as they are sensed and only secondarily important within the larger context of a more complete model of the world.



The robot continuously refers to its *sensors* rather than an internal model of the world.

The robot must *respond quickly* to its sensor inputs.

The robot is forced to build a *temporal model* of its surroundings relative to itself rather than an external framework (e.g.., "...the obstacle that is right now to my left..." rather than "...object-16 which is a chair...".

The robot is required to *learn by interpreting* its real world experiences, with little (if any) initialized knowledge.

This approach is particularly appropriate in a dynamically changing world where the past state of the world provides little reliable information about the current and future states.

The Notion of *Embodiment*

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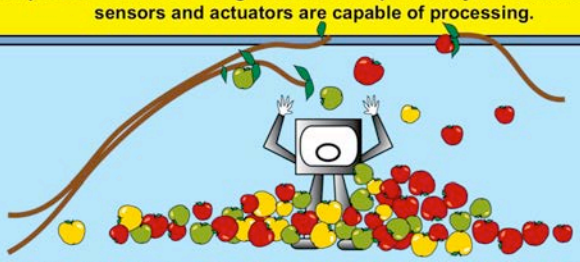
The physical presence of the robot agent forces it to potentially deal with all issues that its sensors and actuators are capable of processing.



- Timely perception and action tend to be the most challenging behavioral capabilities of embodied agents.
- Strategic planning (i.e., problem solving) situations are less likely to be faced by embodied agents.
- Embodied agents are vulnerable to sensor malfunction making some degree of redundancy desirable.

Only an embodied agent can be validated in terms of its autonomous capabilities and its intelligence.

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The Notion of *Intelligence*

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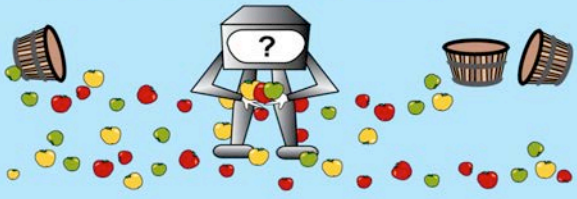
Robot intelligence, like human intelligence, is largely a function of the *degree of complexity of the environment* rather than its own internal complexity.

- In human evolution the development of perception and mobility capabilities took much longer than reasoning capabilities.
- The intelligence of a robot depends more on its dynamic interaction capabilities than its reasoning capabilities.
- It is often difficult and not necessarily useful to draw a distinction between intelligence and environmental interaction.



Intelligence is determined by the dynamics of interaction with the world.

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The Notion of *Emergence*

University of Nebraska-Lincoln (8 October 2013)

Intelligence emerges through the interaction of components. In robots these components are best focused on behavior producing rather than functional information processing tasks.

- The components of behavior-based robots are designed to collectively produce environmental interaction and mobility capabilities (e.g., grasping objects, avoiding obstacles).
- High level intelligent functionality emerges from combinations of lower level behavioral capabilities through a process of repetitive learning.

It is difficult to identify the seat of intelligence since it is the result of the interaction of many contributing capabilities.

Capabilities of the Subsumption Approach

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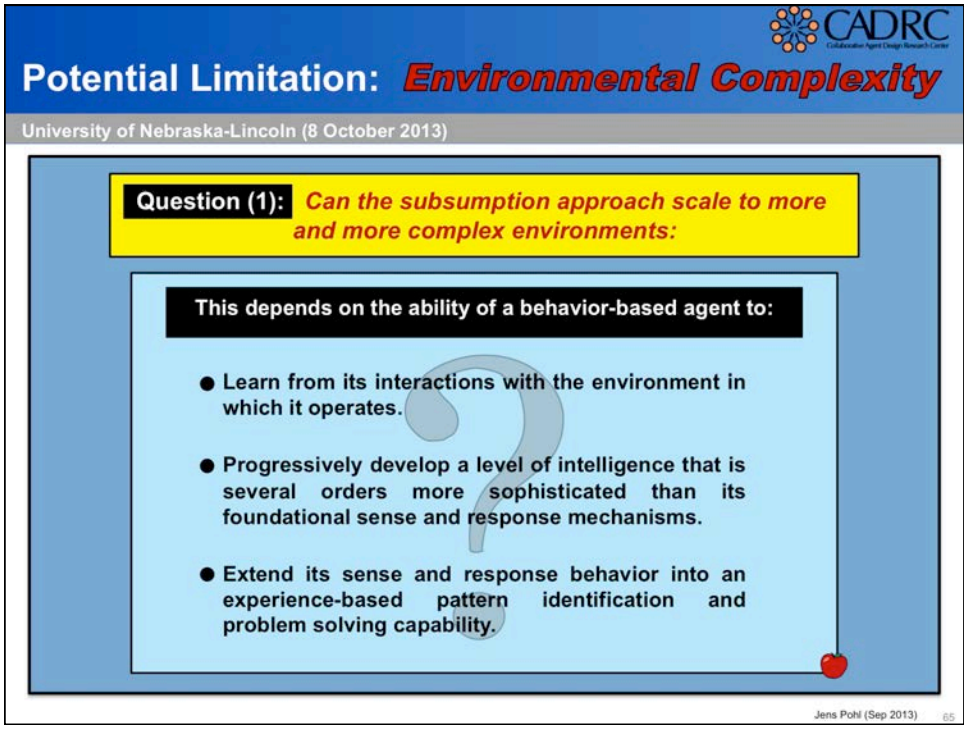
Subsumption or behavior-based systems are *reactive* systems whose planning interests and capabilities are driven largely by extemporaneous needs.

Without resorting to central manipulable or symbolic representations such robots are capable of:

Making predictions and forming expectations about their world.

Developing plans relating to their immediate needs.

Formulating and implementing goals.


CADRC
Potential Limitation: Environmental Complexity
University of Nebraska-Lincoln (8 October 2013)
Question (1): Can the subsumption approach scale to more and more complex environments:
This depends on the ability of a behavior-based agent to:
Learn from its interactions with the environment in which it operates.
Progressively develop a level of intelligence that is several orders more sophisticated than its foundational sense and response mechanisms.
Extend its sense and response behavior into an experience-based pattern identification and problem solving capability.
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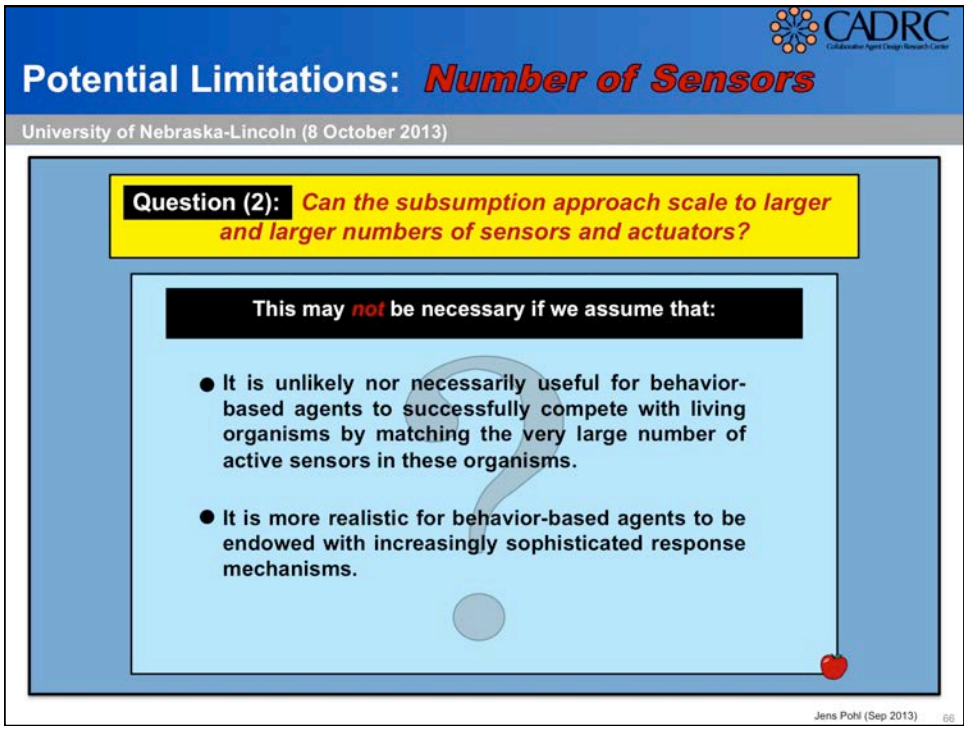
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Potential Limitations: Number of Sensors
University of Nebraska-Lincoln (8 October 2013)
Question (2): Can the subsumption approach scale to larger and larger numbers of sensors and actuators?
This may not be necessary if we assume that:
It is unlikely nor necessarily useful for behavior-based agents to successfully compete with living organisms by matching the very large number of active sensors in these organisms.
It is more realistic for behavior-based agents to be endowed with increasingly sophisticated response mechanisms.
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Potential Limitation: Layers of Behavior

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Question (3): *Can the subsumption approach scale to the addition of more and more layers of behavior?*

Very likely this will prove to be the strength of the subsumption architecture. It should be possible to:

- Reduce the number of layers required to produce the desired level of (intelligent) behavior by both increasing the capabilities of the sensors in the bottom layer and increasing the level of sophistication of the higher level layers.
- In other words, the achievement of higher levels of intelligent behavior may not depend entirely on the addition of more and more layers of behavior.

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Subsumption Research Goals

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Research principles defined by Brooks for behavior-based agents include:

1. The goal should be to study *complete*, integrated autonomous agents.
2. The agents should be *mobile* robots operating in *unmodified* real world environments.
3. The robots should operate equally well when *unexpected changes* occur in their environment (e.g., dropped objects on the floor, visitors, calibration drift of sensors, etc.).
4. The robots should operate on *time scales* that are very similar to human time scales.

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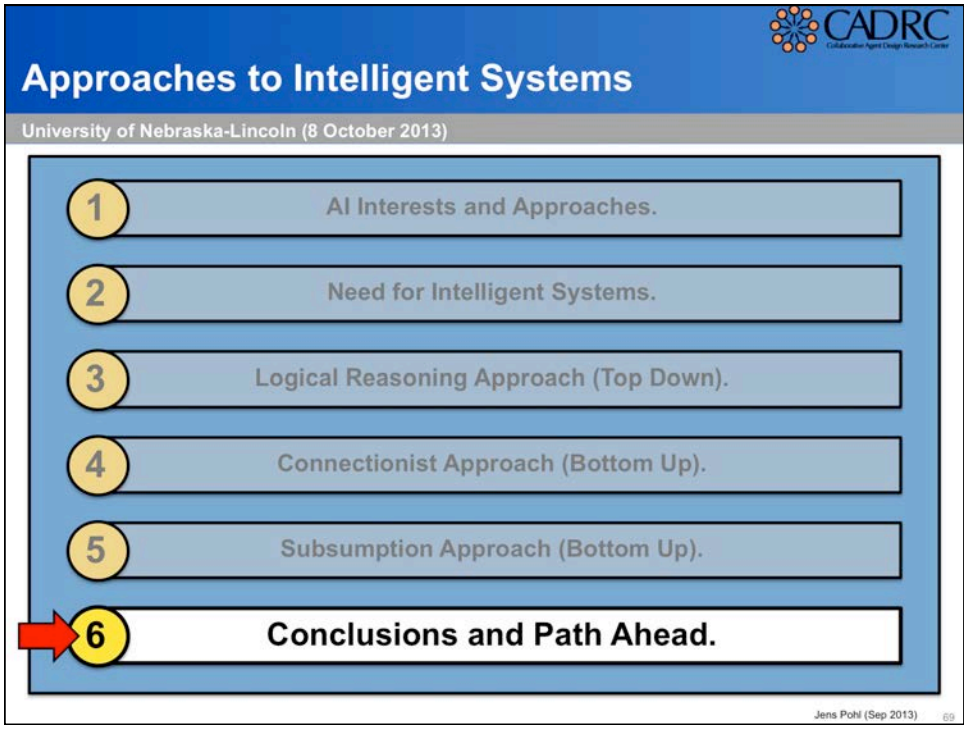
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Approaches to Intelligent Systems
University of Nebraska-Lincoln (8 October 2013)
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6 Conclusions and Path Ahead.
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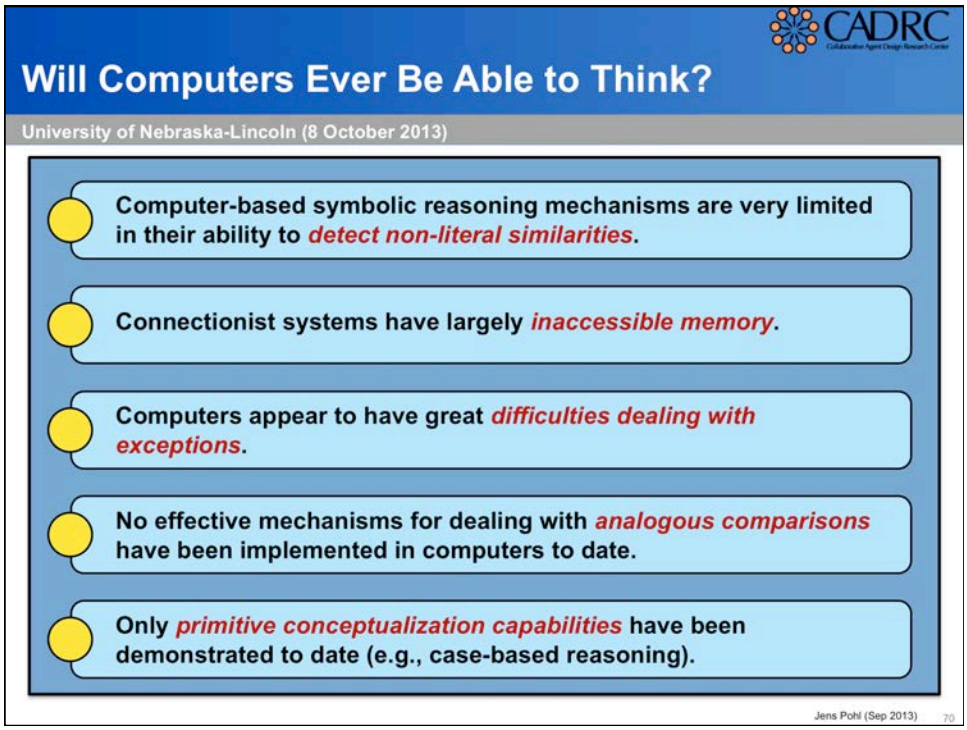
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Will Computers Ever Be Able to Think?
University of Nebraska-Lincoln (8 October 2013)
Computer-based symbolic reasoning mechanisms are very limited in their ability to detect non-literal similarities.
Connectionist systems have largely inaccessible memory.
Computers appear to have great difficulties dealing with exceptions.
No effective mechanisms for dealing with analogous comparisons have been implemented in computers to date.
Only primitive conceptualization capabilities have been demonstrated to date (e.g., case-based reasoning).
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How Well Can People Think?

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- Consistent pursuit of *questionable goals*.
- Limited ability to *focus* and *concentrate*.
- *Faulty generalizations* based on inadequate analysis.
- Obsessive behavior based on *emotional reactions*.
- *Conclusions based on desired outcome* rather than factual reality.
- Defective credit assignment based on *superstition*.
- Inability to separate *personal biases* from value judgments.
- Loss of motivation and *resistance to change*.

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Where Are We Today?

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- Just beginning to understand the importance of *representation*.
- Building systems that do not *scale* well.
- Implementing software agents capable mostly of only *1st and 2nd level reasoning*.
- Little headway in building *hybrid* connectionist and symbolic systems.
- Have not really started to tackle the hard problems of *similarity*, *opacity*, *fragmentation*, *and analogous reasoning*.

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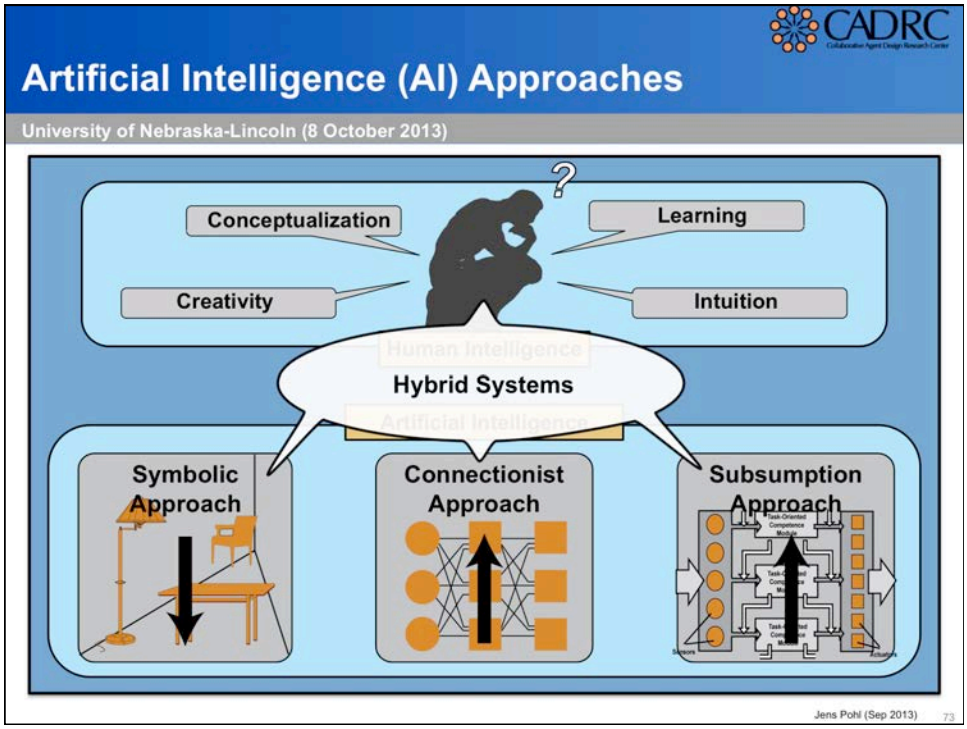
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Artificial Intelligence (AI) Approaches
University of Nebraska-Lincoln (8 October 2013)
Conceptualization
Learning
Creativity
Intuition
Human Intelligence
Hybrid Systems
Artificial Intelligence
Symbolic Approach
Connectionist Approach
Subsumption Approach
Jens Pohl (Sep 2013)
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