Autonomous Situation Awareness and Autonomous Logistics

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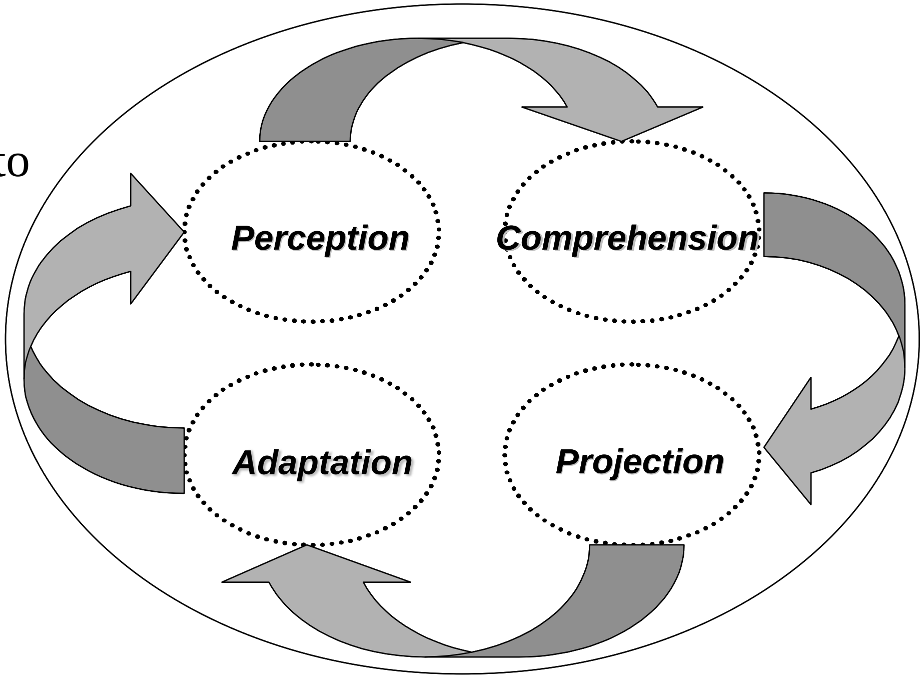
Autonomous Logistics Situation Awareness

Four parallel closely interacting processes:

- *Perception*
  - Data acquisition and mapping into object attributes and dynamics
- *Comprehension*
  - The integration, interpretation, and storage of information
  - The initial assessment of emerging needs, events and risks
- *Projection*
  - The anticipation of future events
  - The full assessment of risks
- *Process Adaptation*
  - Adaptation of sensing and communications to unfolding event dynamics.



Autonomy and Logistics

- A key aspect of autonomous intelligence is the ability to execute plans adaptively in dynamic environments
  - Understanding near-term needs for reacting to changes in the environment;
  - Flexible sequencing of plan components subject to demands and operational constraints.
- Adaptive logistic plan execution in dynamic environments is a critical promise of the future generation of logistic architectures
  - **Architectures that include mobile logistic sites between the top level planner-scheduler and lower level distribution systems.**
- Army TACOM and MDA have funded embedded instrumentation with a flexible Artificial Intelligence framework that could fulfill this promise in a cost-effective, affordable way.
  - *Providing reactive goal-seeking behavior, plan monitoring, and plan repair through a fully integrated knowledge based approach.*

Timeline sketch of programs for performance based precision logistics

- 1996 Boeing introduces on-board performance monitoring for airlines
- 1997 Joint Strike Fighter program office funded DARPA program to develop key components for "pull" logistics where the force assets report performance to logistics centers and factories.
- 2000 US Marine Corps funds the Autonomic Logistics System project to provide centralized precision logistics using web-centric support for "good enough – soon enough" logistics with hard deadlines to support marine expeditionary forces.
- 2003 US Army funds the Common Logistics Operating Environment (CLOE) for vehicle centric situation aware 3-day STRYKER FORCE

Funding Timeline

- 1996 - ONR - Miniature Sentient Instrumentation Controller (SIC)
- 1997 – JSF - Research for in-flight electrical fault isolation
- 1998 - DARPA - Bayesian dynamic resource management
- 1999 - FLC - "Smart Wiring" laboratory demonstration
- 2000 – NAVAIR - "Smart Connectors" for plug-n-play applique
- 2001 – DARPA - "Autonomous Negotiating Teams" autonomic logistics
- 2002 – ONR - "Real time logic switched inferential reasoning
- 2003 - NAVAIR - D3 in-flight inferential processing
- 2004 - MDA - Real-time data driven diagnostics and prognostics
- 2005 – ONR - Sentient Reasoning for equipment life extension
- 2006 – JSF - Application Specific Integrated Circuit (ASIC) module
- 2006 - Army - Technology demonstration program

IEI Field Demonstrations -Summer 2007

- **Weight off wheels (No weight added)**
- **Affordability – no change in vehicle wiring/connectors**
- **Sensing, data collection and recording**
- **Cognitive fusion (level 3 AI fusion)**
  - Environment factors
  - Activity monitoring
  - Condition diagnostics
- **Stressor control actions**
- **Self and mission goal prognostics**
- **Information for aggressive optimal goal seeking**
- **Low bandwidth communications**

Benefits for Pull-Mode Logistics (Precision Performance Based Logistics)

Army TACOM demonstration will show

- Demonstrated probabilistic demand
- Logistics pull from self aware equipment
- Life extension for reduced logistics footprint
- No weight penalty for PPBL – no added fuel impact
- Increased operational availability with less maintenance logistics
- Statistically accurate time-domain prognostic alerts
- Sensor based inventory -health, consumables, ammo, etc.
- Agent based autonomous logistics negotiation
- Low bandwidth logistics communications
- Aggressive autonomous collaborative logistics goal seeking
- Data sources for command level logistics decision support

PPBL Uses Sentient Reasoning

- *expands Teleo-Reactive* (T-R) robot control programming framework developed by Nils Nilsson (Stanford) in the early 1990s.
- adaptive logic switched Bayesian dynamic (probabilistic) models
- inductive, deductive, and abductive logic inference
- consumeables monitoring
- baseline correlation for equipment health monitoring
- cognitive reasoning for understanding impacts
- aggressive goal seeking with genetic programming

Basic Concepts of Sentient Control

- IEI instrument controllers reason with Bayesian inference
- IEI implement enable adaptive plan execution and robust goal pursuit.
- The program for goal seeking is a sequence of condition-action pairs

$Co \rightarrow a_0$	% *If MissionGoalsAccomplished*
$C_1 \rightarrow a_1$	% *If EnemyObserved then SendLogisticsReport*
…	
$C_n \rightarrow a_{n-2}$	% *If EnginesStarted then PursueNextWaypoint*
$C_n \rightarrow a_{n-1}$	% *If InWater and NotEngineStarted then StartEngines*
$C_n \rightarrow a_n$	% *If MissionAssigned then Prognose and SndLogisticsReport*

- At each cycle, the action associated with the highest true condition executes.
- The program is constructed so that individual actions are expected to make some condition higher in the list true.
- C_o corresponds to top level goal (a_0 is the null action).

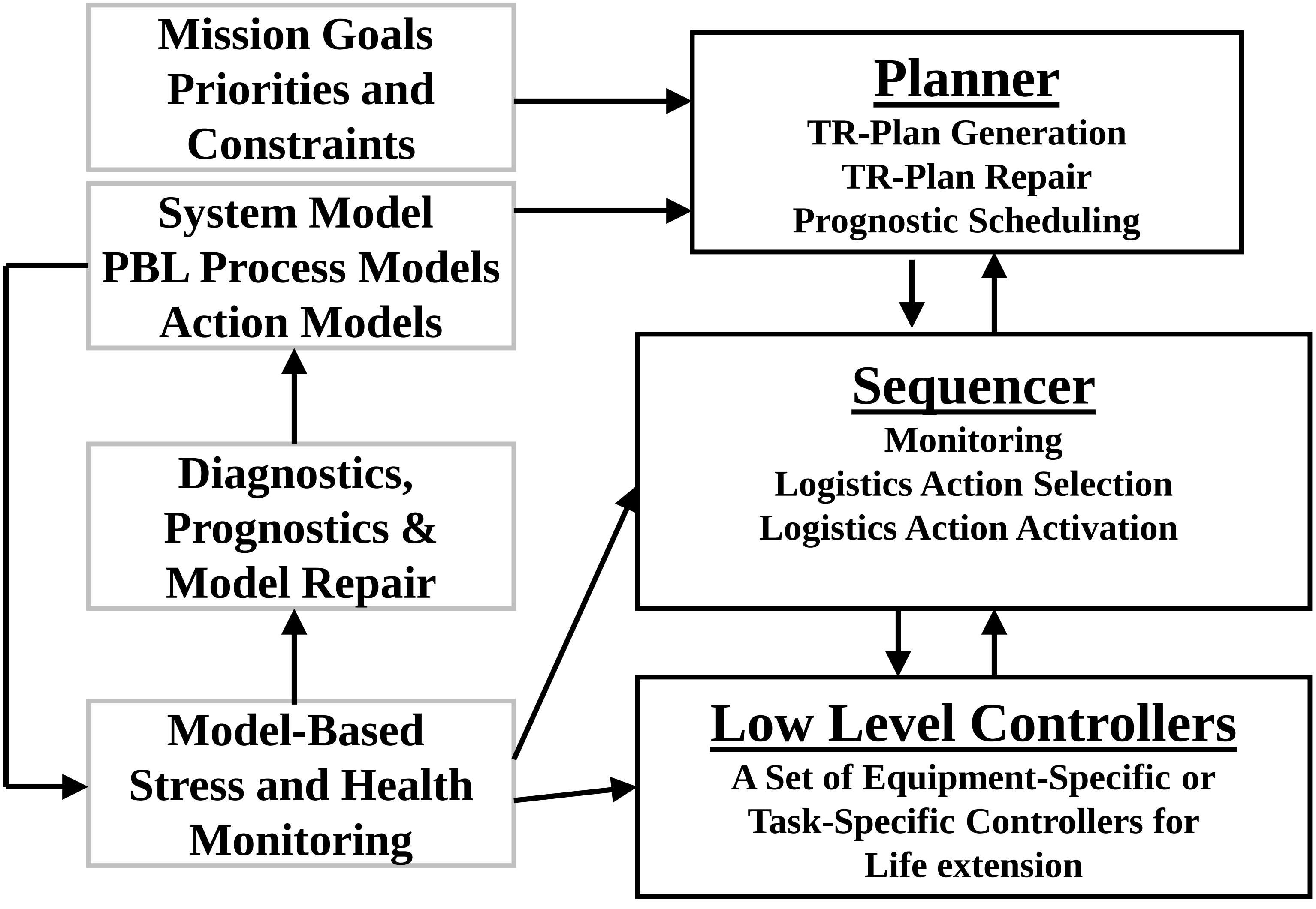
Robust Logistics Pursuit

- Activation tends to move up the tree from lower level goals (chained subgoals) to the top level mission logistics goals.
- The top-down rule selection algorithm insures that top level logistics goals are pursued both adaptively and relentlessly.
- There is a monitoring algorithm for performance risk assessment.
- If an impasse occurs, a diagnostic procedure is invoked to determine the cause. This may be:
  - Need for a high level decision
  - Addition logistics support
  - No rule for handling some unanticipated environmental condition.
- Impasse detection and diagnosis triggers re-invocation of the planner for logistics and mission plan repair.

Sentient Optimal Control (SOC)

- IEI uses a framework for robust reactive goal seeking control for Precision Performance Based Logistics
- It is a three layer framework that includes an extended form of Teleo-Reactive Control as its middle layer.
  - Level 1: The T-R Planner takes mission goals and builds T-R programs.
  - Level 2: The T-R Executive activates lower level control actions.
  - Level 3: Individual low level control algorithms directly control hardware, e.g. pumps, valves, etc. to minimize logistics requirements
  - Performance monitoring & diagnosis supports adaptive plan execution, plan impasse detection, and re-planning.
  - Prognostic Bayesian models support planning into a dynamic future.

The PPBL Architecture



PPBL "Pull" Logistics Benefit Summary

Force / Command

- Reduced manpower requirements through robust decision support
- A robust and inexpensive architecture for robust adaptive logistic plan execution in dynamic environments.
  - A common framework for logistics planning, plan execution, plan monitoring, and model-based diagnostics and prognostics

Battalion

- Potentially quantum improvements in logistics effectiveness

Equipment / Vehicles

- Weight off wheels
- Reduced logistics and operating cost through increased reliability and reduce maintenance through stress management and life extension
- A modular model-based embedded framework supporting automated pull-demand for reducing the logistics footprint and accurate logistics support during operations

Current Status

- The Sentient Instrument Controller is proven and patented
- Bayesian Inference Algorithms for Reasoning are maturing quickly
- Extension to System of Experts models are funded
- Smart Connectors and Smart Wiring have been demonstrated
- An early stage SOC-based prototype, the Sentient Autonomous Maintainer (***SAM***) was demonstrated for the Navy
  - Demonstrating the effectiveness of control for autonomous self-maintenance and logistics situation awareness in small boats.
- Contracts are in place to demonstrate SOC in 2007 on combat vehicles
- Contracts are in place to build the next generation SIC as an ASIC module for deeply embedded in-situ intelligent instrumentation.

Potential SOC Enhancements

- Optimized condition evaluation using focus-of-attention mechanisms to manage the rate of condition evaluation
  - Assigning faster rates for in-focus subfields, slower for out-of-focus;
  - Focus-of-attention provides a key mechanism for reducing computational load and speeding up reaction times.
- Hierarchical behavior abstraction and planning
  - Design of a distributed fully knowledge-based implementation.
  - Implement JAVA and HTML to invoke SOC from a high level program.
  - Use a mechanism for designing programs that explicitly define probabilistic logistic demand triggers during deployment