Embedded Distributed Real-Time Resource Management

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Challenge: Embedded Real-Time Management of Distributed Resources

- General reoccurring problem; resources may be heterogeneous
- NP Hard: Many possible solutions; most not sufficient

Example Applications
- Mission scheduling, planning, logistics, multi-sortie control of autonomous units, teams of UAV's, UGV's, UWV's, …
- Multi-computer task scheduling, load leveling
- Plant management, power and operations scheduling, and vehicle signature control
- Network load balancing, routing, and wireless spectrum allocation
- Carrier deck operations scheduling
- Traffic flow management, optimization, and intelligent highways

- Management ==> Continuous re-planning
Existing Solutions
• Bin Packing (Coffman 1998, et. al.)
• First-Fit (J. Ullman, 1973)
• Cookie-Cutter (Hoffman 1998)
• HARMONICM (JL Yowell, 1999)
• Multidimensional Bin Packing Algorithms (Kou/Markowsky, 1977)

Tendency: One shot, centralized, static, pre-schedule off-line. Not intended for continuous real-time operations.

Traditional First Fit Scheduling Algorithm

![Diagram of Traditional First Fit Scheduling Algorithm]
Improved Methods

Approach
- Leverage previous methods by distributing and extending them.
  1. Select distribution framework: *Intelligent Agents*
  2. Extend allocation algorithms within agent paradigm

*Intelligent Agent*
- Independent software process with Persistence and Continual operation
- Has perception, goals and logic to achieve goals: *Intent oriented* method
- Serves as proxy for an application stake-holder
- Collectively finds global solution by cooperative negotiations with other agents
- Light weight, embeddable, mobile.

*Agent Method*
Agent and Resource Simulation Environment

• Complex systems: Difficult to understand
• Exploit modeling and simulation for rapid efficient exploration and development
• Must investigate Temporal, Spacial, and Functional aspects
  – Temporal = When resource needed or used
  – Spatial = Where requested/consumed
  – Functional = Express complex agent allocation rules
• Used ATL CSIM
  – http://www.atl.lmco.com/proj/csim
  – Good agent simulator
  – Multi-domains/levels with common simulator
  – Provides mission-level context for engineering models to assess mission success impacts
Experiments

Metrics
- Response Time (min, mean, max, variance)
- Overhead, agent communications (bytes/sec)
- Scalability (growth as function of complexity)

Simulation Approach

Scenario Generator → Agent Models → Resource Models

Reservations

Evaluate
Agent Design

• Tried several approaches

• Key discovery --> Agents with their own internal world models reduce inter-agent negotiations

• World models enable agents to test tentative future actions a priori

• Enables continuous predictive re-planning, --> Anticipatory optimal sequencing
• **Dual mode operation:**
  1. Quick reaction subsystem
  2. Background optimization subsystem

• Agents maintain own world models through observation of environment/past experience

• Agent considers decision alternatives by simulating outcome on internal model

• Requires lightweight, portable, embeddable simulator such as CSIM

• During simulations in CSIM, agents launch their own *mini-simulations* within virtual world
Agents Applied to Real-Time Software Task Scheduler

Agent Based Controller

Application Example 1
Application Example 1

Simulation Process

Physical Network Model

Tasking Load Model

Allocation Time Line Graphs
Application Results

• Combination of advanced algorithms found to enable efficient distributed operation

• Neither agent paradigm by itself, nor advanced algorithms alone could account for improvement individually, but only in combination

• Greater scalability indicated for new approach on applied scenarios
Application Example 2

Next Generation Communications (XG Comms)

- DARPA program to demonstrate 10x > usable wireless spectrum
- Spectrum is presently allocated statically, centrally, but not efficiently
- All spectrum is allocated. Little occupied at any one time or place
- Is multi-dimensional (Time, Freq, Area, Modul) dynamic allocation app.
Application Example 2

Spectrum Management

- CSIM Simulations at multiple simultaneous levels
- Enable agent interaction in realistic mission scenarios
- Multi-view visualizations aid understanding
- Agent models under each vehicle model, contain agent submodels
Application Example 2

Spectrum Management

- World models of agents within each radio view show allocations vs. time (horizontal) and vs. frequency (vertical).

- Multi-dimensional view shows allocations in time duration (right-left) vs. location (depth) vs. frequency (vertical) and vs. priority (color/owner).
General Purpose Distributed Real-time Control Method

Advantages
- Decentralized, continuous operations, real-time
- Embeddable, lightweight
- Minimizes central-dispatch communications
- Improves efficiency, reduces disruptions and response delays
- Greater scalability than centralized solutions

Risks
- New inter-agent communication overhead
- Convergence, solution quality, stability, limit cycles, chaos
- Predictability, ability to set bounds
- The unknown

Lessons Learned
- Modeling and simulation essential for agent deployment