Organizational self-design in semi-dynamic environments

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Motivation

What do we want to do?

To organize agents and address the following issues:

- The number of agents needed to solve the problem
- Allocation of subtasks and resources to the agents
- Coordination of inter-agent activities

So what's the problem?

- There is no best way of organizing and all ways of organizing are not equally effective:
  - The optimal organizational structure depends on the underlying problem being solved and the environmental conditions.
- Environmental conditions or problem structure may change.
  - Precludes the use of a static (compile-time) organization.
- All problem instances and environmental conditions are not unique.
  - Precludes the use of a new, bespoke organizational structure for every problem instance.

Our Answer:

We propose a dynamic run-time approach to organization based on Organizational-Self Design (OSD)

Our Contributions:

- Extend existing OSD work (2) to use TÆMS as its underlying problem representation, which allows us to:
  - Perform quantitative reasoning over the task structure
  - Represent cost/quality tradeoffs
  - Soft relationships like facilitates and hinders
- Incorporate coordination mechanisms into OSD

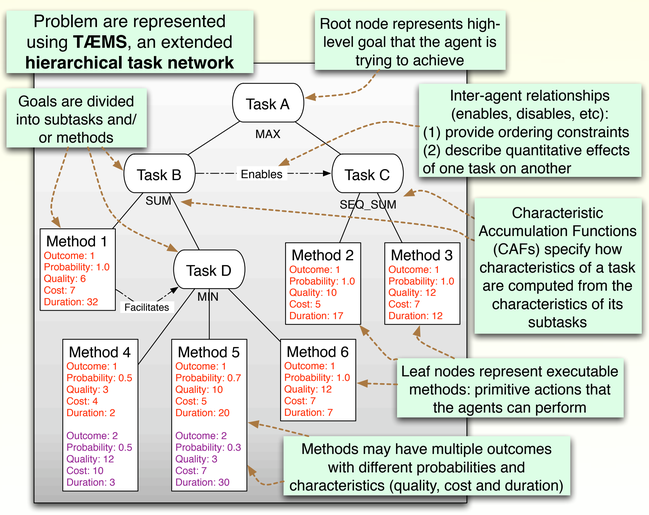
Basic Premise

- Problem solving requests arrive continuously at varying rates and with varying deadlines

Approach

- Start off with an initial organization
  - consisting of a single agent, solely responsible for all activities
- Each agent in the organization checks to see if:
  - It is overloaded:
    - It spawns off a new agent to handle part of its load
  - It is free (underloaded):
    - It combines with another agent to save resources

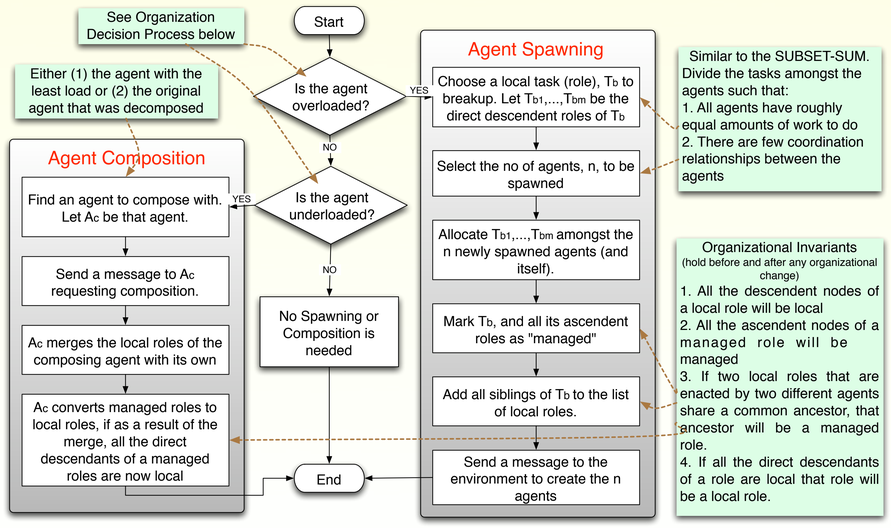
Problem Representation



Organizational Structure: Roles and Relationships

- Organizations are characterized by an organizational structure, which
  - consist of roles and relationships between the roles
  - is contingent on the TÆMS task structure
- A role is defined as a TÆMS subtree rooted at a particular node
  - By definition, a role may consist of one or more sub-roles
  - A role may be enacted by one or more agents and one or more roles may be enacted by every agent
- Relationships constrain the communication between the agents

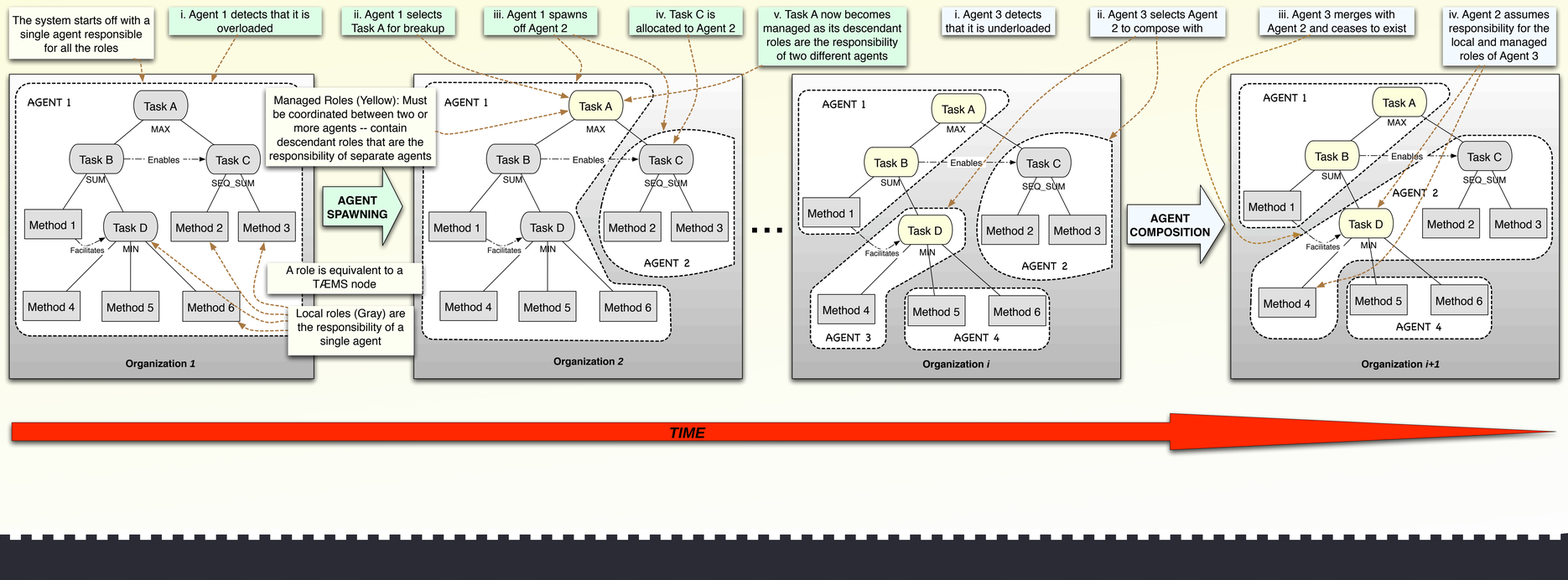
Organization Formation/Adaptation Process



Organization Decision Process

- Probability of organizational change should be inversely proportional to time since last organizational change
  - We use simulated annealing to vary this probability.
  - $p = e^{-\frac{\Delta E}{kT}}$, where
    - p = probability of keeping an existing organizational structure
    - T = time since the last organizational change
    - ΔE = amount of overload/underload
  - p is capped at $p_{threshold}$ to prevent the agents from being unresponsive to environmental change
- Computation of ΔE:
  - Agent Spawning
    - Sort the outstanding tasks by their deadlines
    - Iterate over the sorted tasks and compute:
      - min = absolute minimum time needed to have a non-zero probability of task completion
      - expt = expected time needed to complete the task
      - g_min = minimum time needed to guarantee task completion in the absence of failures
      - if sum(min) > Deadline
        p = 0, breakup the agent immediately
        else
        $\Delta E = \frac{1}{\alpha(Deadline - Current\_Time - \sum expt) + (1-\alpha)(\sum g\_min - \sum min)]}$
  - Agent Composition
    - If the agent, is idle, compute p using the simulated annealing equation with
      $\Delta E = \beta * Idle\_Time$

Example Illustrating OSD



Evaluation

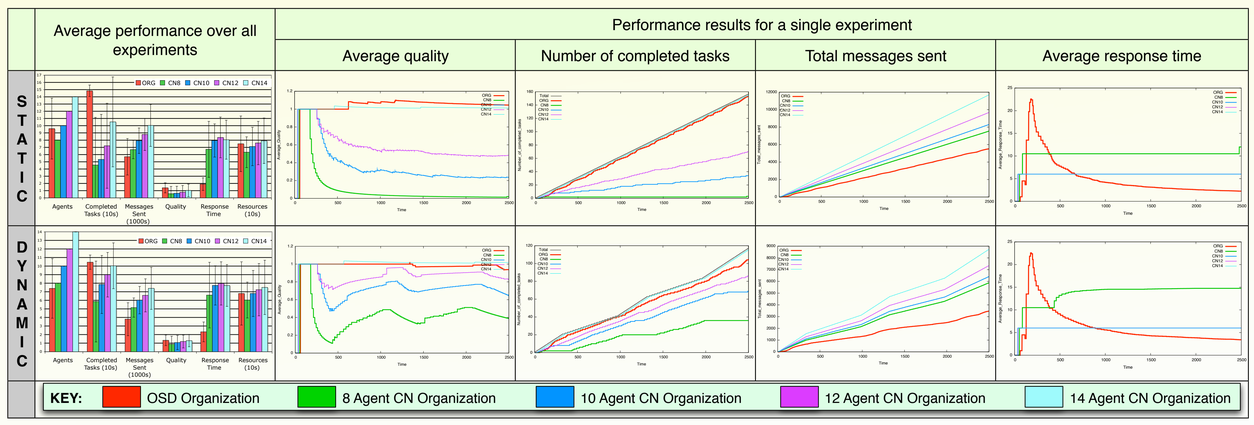
Experimental Setup

- Compared to the Contract Net Protocol (CNP)
- Ran 40 Experiments
  - each experiment was repeated 5 times
    - our OSD approach was used the first time
    - the CNP approach, with 8, 10, 12 and 14 agents, was used in the 4 subsequent runs
  - 20 experiments had a static environment
    - Fixed task arrival rate every 15 cycles
    - Fixed deadline of 20 cycles
  - 20 experiments had a dynamic environment
    - Arrival rate changed from 15 to 30 cycles and back to 15 cycles after every 20 tasks
    - Deadline of 20 cycles
  - Random task structure was generated for each experiment

Hypothesis Tested

Hypotheses Tested using Wilcoxon Matched-Pair Signed-Rank Tests	Static Environments	Dynamic Environments
The OSD organizations require **fewer agents** to **complete an equal or larger number** of tasks when compared to the Contract Net organizations Null Hypothesis: ~~The CN agents complete more tasks than the OSD agents~~ **REJECTED**	$p < 0.0003$	$p < 0.03$
The OSD organizations achieve an **equal or greater average quality** than the Contract Net organizations Null Hypothesis: ~~The CN agents achieve greater quality~~ **REJECTED**	$p < 0.01$	$p < 0.05$
The OSD agents have a **lower average response time** as compared to the Contract Net agents Null Hypothesis: ~~The OSD agents have the same or greater response time compared to the CN agents~~ **REJECTED**	$p < 0.0002$	$p < 0.0004$
The OSD agents **send less messages** than the Contract Net Agents Null Hypothesis: ~~The OSD agents send the same or more messages than the CN agents~~ **REJECTED**	$p < 0.0003$	$p < 0.02$

Performance Graphs



Future Work

- Investigate how changes in the task structure affect the organizational structure
- Incorporate a larger set of non-local effects
- Incorporate robustness into the organization
  - Formalize and evaluate alternative robustness schemes to determine the best one for OSD
- Incorporate communication delays
- Apply OSD to a real-world application

References

1. K. M. Carley and L. Gasser: *Computational organization theory.* In G.Wiess, editor, Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence, pages 299 -- 330, MIT Press, 1999.
2. T. Ishida, L. Gasser, and M. Yokoo: *Organization self-design of distributed production systems.* IEEE Transactions on Knowledge and Data Engineering, 4(2):123--134, April 1992.
3. V. Lesser, K. Decker, T. Wagner, et. al.: *Evolution of the GPGP/TAEMS Domain-Independent Coordination Framework*. AAMAS '02 (Plenary Lecture/Extended Abstract)}, pages 1--2, 2002.