Modeling and Agent-based Simulation of Organization In a Stochastic Environment

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Introduction

Motivation
  
  A generic model, and agent-based simulation to analyze
  - Interplay of information collection and decision making processes
  - Agent collaboration and information flow behaviors

  Organizations in stochastic mission environments
  - Stochastic task arrivals
  - Unknown characteristics of tasks, which may be inferred to a certain degree by task identification processes

Our contributions
  
  Depict an organization
  - Consisting of an information processing, communication and coordination structure designed to achieve a specific set of goals
  - Comprised of individuals with different task identification and task execution capabilities, and workload constraints

  Develop a simulation toolkit
  - Discrete event simulator by ANYLOGIC® to quantify the performance of an organization
Introduction

Modeling overview

Mission components

Organizational structure

Performance measures

Illustrative experiment

Conclusion
Mission environment: Set of tasks
- Can be predefined or stochastic and dynamic
  - Predefined – known in advance to the organization
  - Dynamic and stochastic – appearance and disappearance times uncertain
- Require resources and time, and impose workload on agent(s), who will work on it
- Possibly interdependent, with dependencies encoded in a directed acyclic task graph

Organization: Team of agents
- Agents
  - Possess limited resources, and have workload constraints
- Organizational repositories
  - Logical space for agents to share information and transfer resources
- Organizational structure
  - Network of agents and organizational repositories, with communication channels among agents defined in a coordination network
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Resources

- Model physical assets, knowledge, expertise, etc.
- Measurable and can be quantified
- Agents possess resources
- Execution of tasks require resources
- Role in mission and organization modeling
  - Successful completion of a task requires agents working on the task to possess the necessary resources
  - May be gained by agents as a result of task completion, e.g., some knowledge acquisition tasks
  - Some resources may be transferable, i.e., the resource can be transferred from one agent to another through communication
  - Agents can possess resources a priori, or acquire them through the resource transfer process, or as a result of task execution
Tasks

- May pre-exist or appear randomly, can be inter-related
- Can be decomposed
- Lowest level task has:
  - **Processing parameters**: Resources, time and workload, may be unknown a priori
  - **Consequence of task execution**:
    - Identify processing parameters of some tasks
    - Gain resources

<table>
<thead>
<tr>
<th>Processing parameters</th>
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<tbody>
<tr>
<td>Required resources</td>
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<tr>
<td>Baseline execution time</td>
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<tr>
<td>Baseline unit workload</td>
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<table>
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<tr>
<th>Execution Consequence</th>
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<tbody>
<tr>
<td>Identified processing parameters of some tasks</td>
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<tr>
<td>Resource gain</td>
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</table>

Typical lowest level tasks

- **Identification (sub) task**: Apply resources to identify hidden attributes and infer the execution requirements of a task
- **Execution (sub) task**: Apply resources to execute tasks
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Organizational components

**Agent:** Automated system representing human decision makers
- **Ownership of limited resources:**
  - Agent can either own these resources a priori, or can acquire them as a result of task execution
- **Workload constraints:**
  - Workload of an agent cannot exceed its maximum at any time
  - Task identification, execution, communication, and coordination activities contribute to workload

**Organizational repository:** Logical organizational block, models information storage for intra-group and inter-group communication and coordination, it can store:
- **Transferable resources**
- **System configuration information:** Mission task graph, resource capabilities, and workload constraints of agents
- **Run-time information:** e.g., identified task parameters, status of tasks (ready, working, finished, disappeared, etc), and workloads of agents
- **History records:** Resource allocation, communication and coordination records
Organization: A coordination network

- **Agents** and **organizational repositories** as nodes
- **Communication**, links between agents and/or organizational repositories as edges
- **Coordination groups**, subsets of nodes and edges, where agents coordinate their resources to process tasks
Modeling of agent behavior

- **Environment sensing:** Communicate with other directly connected agents and repositories in the organization network, to obtain mission and organizational information.

- **Information processing:** Collecting information to decide which task to execute and when to execute it.

- **Action monitoring:** Supervising activities during task execution.

- **Agent can play two roles:**
  - **Executor** – Select tasks for execution, and monitor the execution of tasks.
  - **Coordinator** – Coordinates with executors in the same coordination group and directly connected coordinators in other groups for environment sensing and information processing.
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Organizational performance depends on
- Settings and interdependencies among the mission and organizational components, i.e., tasks, agents, organizational structure
- Task scheduling and information exchange of agents

General metrics
- Mission completion:
  - Percentage of tasks completed
  - Percentage of tasks identified
  - Percentage of tasks disappeared before identification, or identified but disappeared before execution
- Workload distribution among agents

Measures on collaboration and information sharing
- Percentage of tasks completed as a result of collaboration and/or information sharing among agents
- Workload imposed on the agents due to collaboration and/or information sharing
**Mission setting**

**Mission tasks:**
- Model pre-defined and briefed jobs
- Interdependent, with dependencies encoded in a task graph

**Time-critical tasks:**
- Model disturbances from the environment
- Mutually independent, dynamic and stochastic time-critical tasks
Resources:
- Eight types of reusable and transferable.
- 4 for identification, 6 for execution, some common

Mission tasks:
- 6 composite tasks (identification, execution phases)
- Consume more resources, take longer, earn more rewards
- Processing times:
  - Identification (10, 20) time units
  - Execution (15, 30) time units
- Resource requirements:
  - Identification – 2 types, 10 units total
  - Execution – 3 types, 30 units total
- Workload imposed:
  - Identification – 5 units/time
  - Execution – 10 units/time
Time critical tasks:

- 10 types.
- One identification, one execution sub-task.
- Average appearance rate – one every 50 time units.
- Life span – (100,200) time units.
- Resource requirements:
  - Identification – 1 type, total 2 units.
  - Execution – 2 types, 4 units total
- Processing times:
  - Identification – (1,5) time units
  - Execution – (5,8) time units
- Workload imposed:
  - Identification – 1 unit/time
  - Execution: 3 units/time
Agents:
- 5 types of resources, 20 units in total.
- Maximum workload – 20 time units.
- Collaboration – workload imposed is proportional to the resources contributed.

Simulation time:
- Mission tasks are completed or maximum of 2000 time units.
Experimental setting

- 4 agents (A1, A2, A3, and A4) with balanced resource capabilities and similar workload constraints, form 2 coordination groups

Organizations of interest for comparison:

- **ORGA** – self-synchronized, no sharing of resources and information among agents
- **ORGB** – intra-group resource sharing
- **ORGC** – intra-group resource sharing and inter-group information sharing
  - A4 synchronizes between repositories A & B.
## Illustrative Experiment - Simulation results

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>ORGA</th>
<th>ORGB</th>
<th>ORGC</th>
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</thead>
<tbody>
<tr>
<td>Mission completed</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Mission completion time</td>
<td>N/A</td>
<td>111</td>
<td>66</td>
</tr>
<tr>
<td>Percentage of time-critical tasks identified</td>
<td>49.5%</td>
<td>94.6%</td>
<td>88%</td>
</tr>
<tr>
<td>Percentage of identified time-critical tasks executed</td>
<td>13.5%</td>
<td>83.8%</td>
<td>71.4%</td>
</tr>
<tr>
<td>Percentage of time-critical tasks disappeared w/o processing</td>
<td>39.2%</td>
<td>7.4%</td>
<td>10%</td>
</tr>
<tr>
<td>Tasks executed due to information sharing</td>
<td>0%</td>
<td>0%</td>
<td>12.4%</td>
</tr>
<tr>
<td>Average time elapsed between appearance and identification of tasks</td>
<td>1.37</td>
<td>4.02</td>
<td>2.9</td>
</tr>
<tr>
<td>Average time elapsed between identification and execution of tasks</td>
<td>4.0</td>
<td>6.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Avg. agent workload per unit time</td>
<td>A1</td>
<td>0.165</td>
<td>4.33</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>0.09</td>
<td>5.53</td>
</tr>
<tr>
<td></td>
<td>A3</td>
<td>2.53</td>
<td>7.34</td>
</tr>
<tr>
<td></td>
<td>A4</td>
<td>0.48</td>
<td>4.04</td>
</tr>
</tbody>
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Observations and inferences:

- **Collaboration**: task identification and execution by multiple agents facilitates:
  - Expeditious mission completion
  - Better handling capabilities, by allowing an agent to contribute and complete tasks, which may be impossible for an agent to finish alone

- **Information sharing**: exchange of task identification results between the two groups facilitates
  - Better focus on mission tasks, by giving them higher priority
  - Balanced workload distribution
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Summary

- Proposed a modeling and simulation methodology for organizations involved in stochastic mission environments
- Stochastic task arrivals, task characteristics not known a priori, but maybe inferred to a certain degree through the task identification processes
- Organizational model implemented using the ANYLOGIC® simulation package

Future work

- Full range of task interrelationships, e.g., conditional task branches
- Information integration and dissemination mechanism
Thank you 😊