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

Outline

- Introduction
- Modeling overview
- Mission components
- Organizational structure
- Performance measures
- Illustrative experiment
- Conclusion

Modeling Overview

- **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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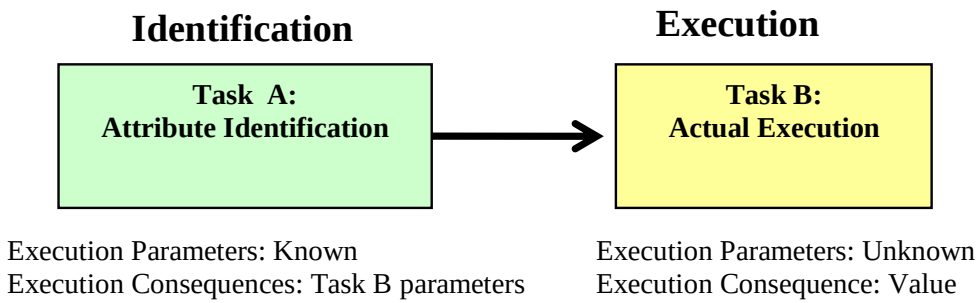
Mission Components - Resources

- **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

Mission Components - Tasks

- **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

Processing parameters
o Required resources o Baseline execution time o Baseline unit workload
Execution Consequence
o Identified processing parameters of some tasks o Resource gain



  - 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 Structure

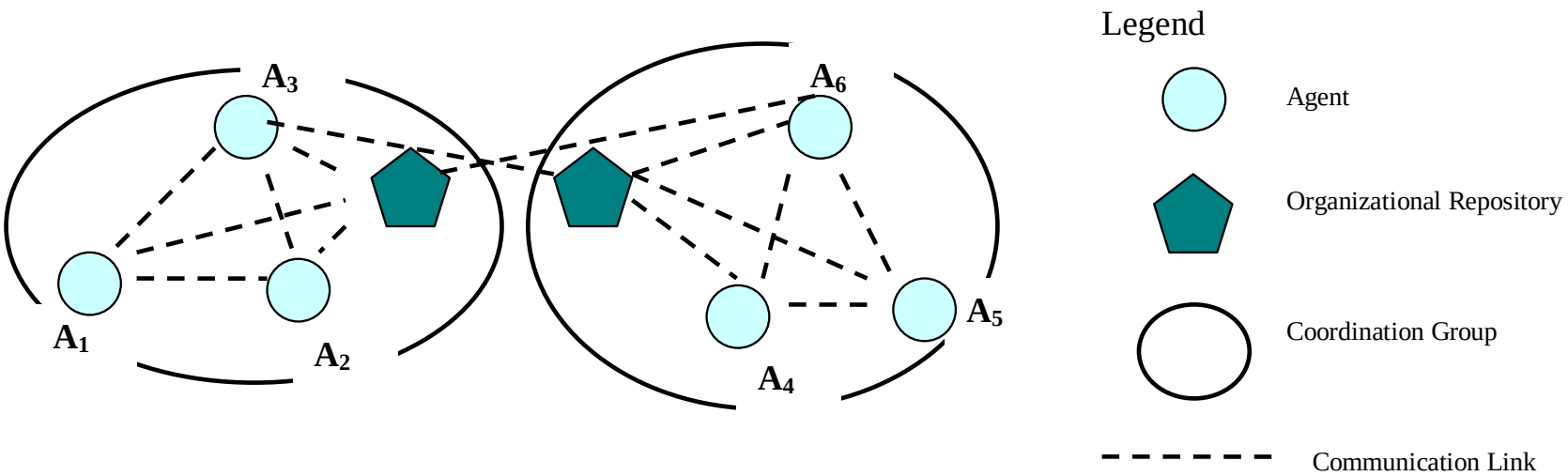
Organizational components

- **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

Organizational Structure (2)

- **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



Organizational Structure (3)

- **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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Performance Measures

- **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

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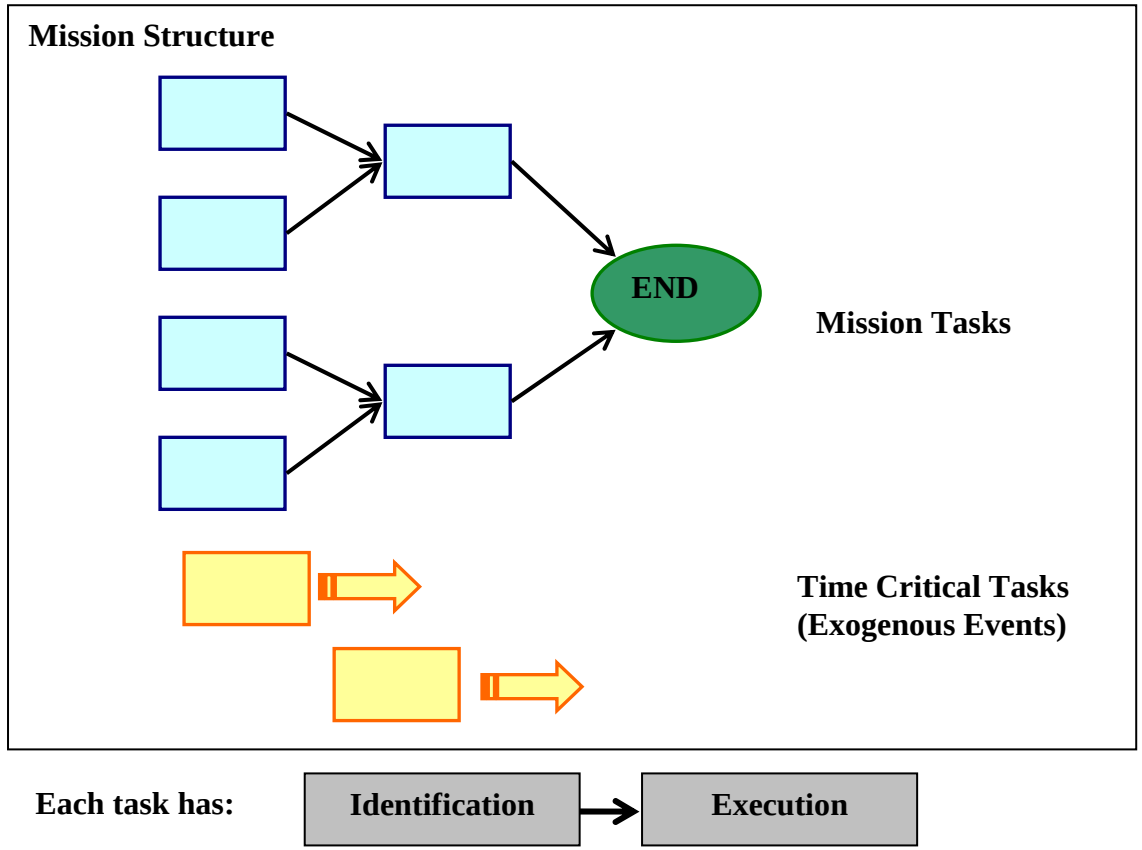
Illustrative Experiment

- **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



Illustrative Experiment (2)

- **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

Illustrative Experiment (3)

- **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

Illustrative Experiment (4)

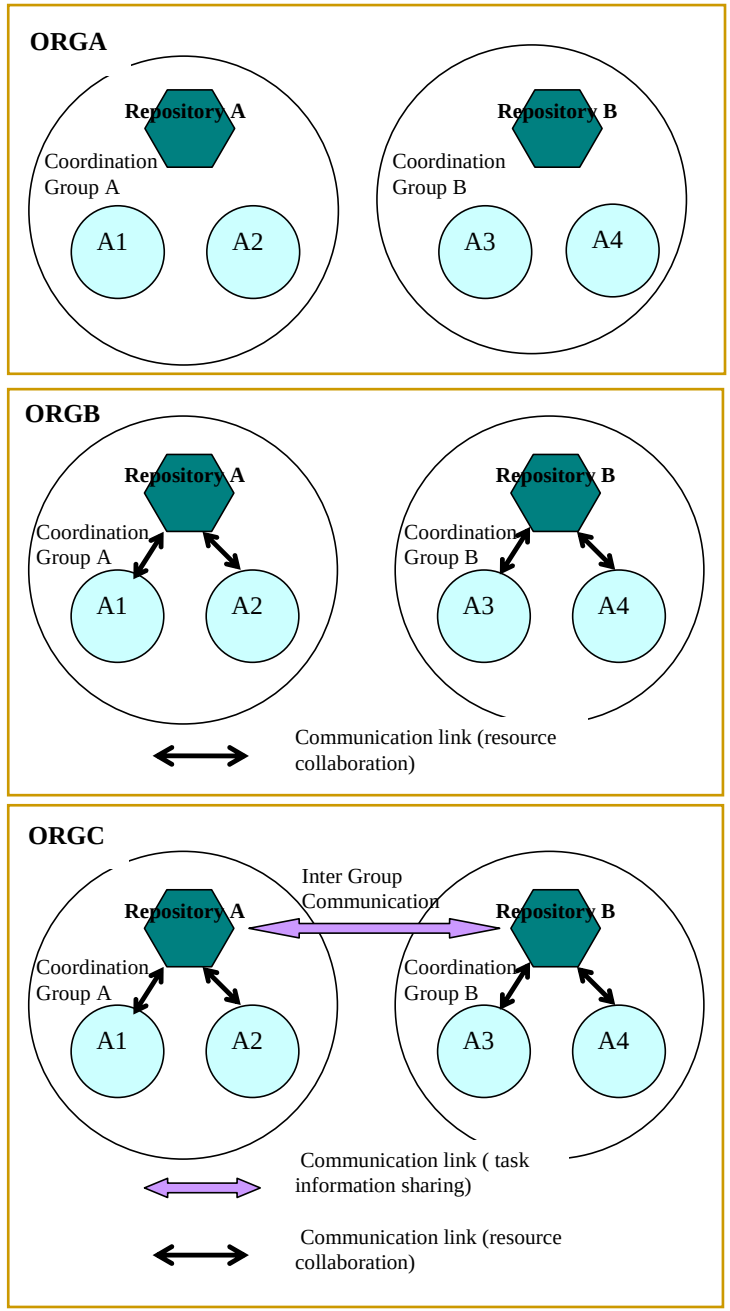
- **Agents:**
  - 5 types of resources, 20 units in total.
  - Maximum workload – 20 time units.
  - Collaboration – workload imposed is proportional to the resources contributed.

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

Illustrative Experiment (5)

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

Performance Metric		ORGA	ORGB	ORGC
Mission completed		NO	YES	YES
Mission completion time		N/A	111	**66**
Percentage of time-critical tasks identified		49.5%	94.6%	88%
Percentage of identified time-critical tasks executed		13.5%	83.8%	71.4%
Percentage of time-critical tasks disappeared w/o processing		39.2%	7.4%	10%
Tasks executed due to information sharing		0%	0%	12.4%
Average time elapsed between appearance and identification of tasks		1.37	4.02	2.9
Average time elapsed between identification and execution of tasks		4.0	6.2	8.2
Avg. agent workload per unit time	A1	0.165	4.33	4.46
	A2	0.09	5.53	6.95
	A3	2.53	7.34	5.14
	A4	0.48	4.04	5.23

Illustrative Experiment - Observations

- **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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Conclusion and Future Research

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 ☺