Parallel and Distributed Simulation of Coalition Structure Generation in Cooperative Multi-agent Systems

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Presentation outline

- Cooperative Multi-agent Systems

- Coalition Structure Generation (CSG)
  - real world examples

- Simulation of CSG
  - ARTÌS / GAIA+ / COALA

- Simplest simulated scenario

- Preliminary experimental evaluation

- Work in progress
Cooperative Multi-Agent Systems

- A **Multi-Agent System** (MAS) is a system composed of multiple interacting intelligent agents.

- Some important characteristics of MAS are: the **autonomy** of agents and their **local view** (limited information sharing). Furthermore, the MAS are **decentralized**: there is any centralized control.

- In this work, we consider **Cooperative Multi-Agent Systems**.

- That is, the agents are inclined to work with each other in order to solve complex problems.
Coalition Structure Generation (CSG)

- Given a set of agents, a **Coalition Structure** is partition of agents.
- That is, a collection of disjoint coalitions or subsets of agents, called blocks, whose union yields the entire population.
- A **Dynamic Characteristic Function** (DCF) or coalitional game, assigns a time-varying *worth* to each coalition.
- The *worth of coalition structures* obtains as the sum of their blocks’ worth.
- Optimality attains where such a global worth is *maximal*.
- Searching for optimal coalition structures is a NP-hard combinatorial optimization problem.
- Therefore, an approach based on *heuristics* is necessary.
Real-world examples

- In general, any optimal partitioning problem with **time-varying** and **imprecise** input (i.e. imprecise worth of blocks)

- For example:
  - what packages to sell in **e-commerce auction** mechanisms.
  - **optimal clustering** with time-varying data sets (i.e. clustering in collaborative tagging systems)
  - coalition (**team**) structure generation in multi-skill organizations
Simulation of CSG

- The modeling and simulation of coalition structure generation in MAS is a complex task due to the intrinsic nature of the systems themselves, which are often:
  - **very volatile** in terms of interactions among agents
  - composed by **very large number** of agents
- The approach based on sequential monolithic simulation is unable to deal with such requirements mainly due to performance and scalability reasons
- Our approach is based on **parallel and distributed simulation**
Simulator design and implementation: logical structure

- Logical structure of the parallel / distributed simulator:

  - Simulation model
    - COALA
  - Adaptive framework
    - GAIA+
  - Runtime middleware
    - ARTÌS
  - Distributed execution architecture
    - CPU 1
    - CPU 2
    - CPU 3

- The **Advanced RTI System (ARTÌS)** is a high performance distributed simulation middleware.
Simulator design and implementation: GAIA+ and COALA

- The **Generic Adaptive Interaction Architecture (GAIA+)** is a load-balancing framework for parallel and distributed simulation that is based on *dynamic reallocation of simulated model entities*. GAIA+ is in charge of the dynamic and adaptive *load-balancing* of computation and communication in the distributed execution architecture.

- **COALA (COAlitions Learn and Adapt)** is a new simulation tool for the study of massively populated MAS, specifically designed for the modeling of coalition structure generation.

- For details: [http://pads.cs.unibo.it](http://pads.cs.unibo.it)
Simplest simulated scenario

The simplest simulated scenario:

- **Merge-and-split heuristic**: constant (random) re-configuration towards coarser and finer partitions

- **Dynamic Characteristic Function (DCF)** varying every 500 simulated time-steps

- **Symmetric DCF**, that is the worth of coalitions depends only on their cardinality (a very simple DCF)

- **Population** of 10,000 simulated agents
Preliminary experimental evaluation

COALA: normalized GW vs. alpha

GW: normalized Global Worth of the coalition structure (higher is better)

Alpha: normalized exploration parameter of the heuristic
More challenging scenarios:

- more complex Dynamic Characteristic Functions (DCF)
- non-symmetric DCFs
- larger populations

Under the simulator point of view:

- exploiting the GAIA+ clustering and load-balancing features to speed-up the simulation runs
- simulation cloning techniques to satisfy the requirement of examining alternative scenarios concurrently
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