Evolutionary Organizational Search (Extended Abstract)

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Introduction

The organization of a multi-agent system specifies:

1) Authorities 2) Roles Assignments 3) Other relationships, e.g. data flow & coordination

The organization of multiagent systems (MAS) may significantly influence the efficiency, adaptability and robustness [2, 3, 6]. In this work, we keep our focus in optimizing *organizational control* rather than operational control. In other words, we are interested in long-term guidelines such as authorities, role assignments and responsibilities rather than exact algorithmic instructions for specific tasks like communication protocols.

Stochastic, Less Prone to Stalling

In this paper, we propose Evolutionary Organizational Search (EOS), an optimization method based on strongly typed genetic programming (STGP) [4]. EOS optimizes tree-shaped organizations and is well suited for hierarchical organizations as well as other tree-like organizational forms such as holarchies and federations.

EOS is designed to take into account special constraints and needs of real-world MASs. Due to its stochastic nature, It is potentially more efficient than exact searches and less prone to stalling at local optima than greedy methods.

Related Works

Directive Qualitative Frameworks

- Example: Omni [1]
- Cover the entire design process, including both organizational control and operational control,
- Only qualitative analysis and require human judgments.

In contrast, with a focus on organizational control, EOS performs automated quantitative analysis, which may produce convincingly justified results and ease the manual burden.

Automatic Quantitative Optimization Methods

Method	Algorithm Type	Domain Knowledge
So and Durfee [6]		Holistic, implicit
Horling [2]	Exact Search	Holistic, as explicit templates
KB-ORG [5]		As multiple small fragments
EOS	Meta-heuristic	Discovered during the search

These quantitaive search techniques mainly differ in the utilization of domain knowledge and search method. In [5], knowledge about MAS is broken into small fragments to make individual design choices. In [2], the Organizational Design Modeling Language (ODML) is proposed to model multi-agent systems with holistic templates and system-level performance models. EOS allows translation from ODML templates to EOS specifications.

In [2], exact global searches are performed, employing techniques such as backtracking and equivalence class. In [5], design choices are selected in the order of their values, computed according to the knowledge fragments provided.

As the optimization complexity is NEXP-complete [2], it is generally infeasible to apply exact search methods. Therefore, it is necessary to develop a heuristic global search method for organization optimization. In addition, it is also desirable to let the algorithm to learn about and adapt to the search space, rather than relying completely on the knowledge supplied by human designers.

EOS provides a stochastic, meta-heuristic approach for organizational optimization of MAS. It is capable of discovering knowledge during the search process and utilizing it to bias the search direction towards promising areas.

E O S

Evolutionary Computation imitates evolution, the optimization method of nature. The selection pressure pushes the population towards desirable regions and optimal solutions.

Genetic Programming

- Solution Representation: Parse Trees
- Mutation: Re-grow Subtrees (Point Mutation)
- Crossover: Swapping Subtrees

Strongly Typed Approach [4]

- Each node has a returned type
- Functions specify returned types of arguments

Evolutionary Organizational Search (EOS)

- Extends from the strongly typed approach
- Semantics: GroupNode, AgentNode, ResourceNode, RoleNode
- GroupNode: Represents a grouping of agents and agents
- RoleNode: Used for role mulitplexing
- Allows for separate optimization of each element

Other Constraints includes:

- Maximum tree depth
- Maximum & minimum number of resources utilized by the system

Significance of Evolutionary Organizational Search

- Applicable to a range of tree-shaped organizational forms
- Due to its stochastic nature, less prone to stalling at local optima than greedy methods or local searches
- Exploiting knowledge obtained during the search and adapting dynamically
- Being population-based, EOS can be easily implemented as a distributed algorithm
- Anytime algorithm. Suitable for dynamic organizational re-design

Distributed, Anytime Algorithm

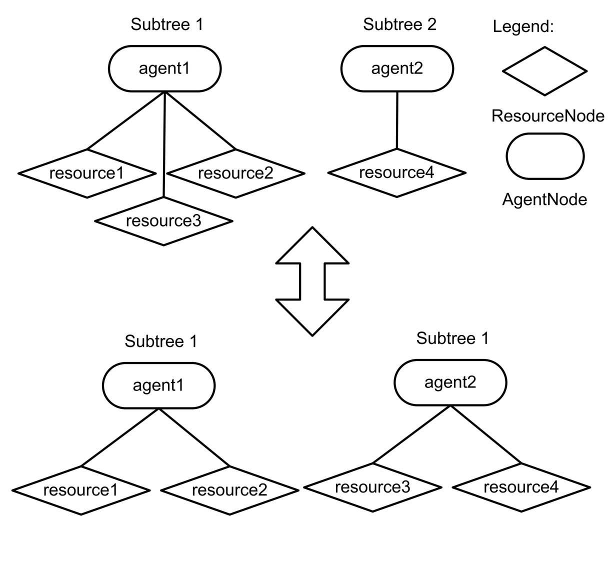
Algorithm

Tree Growth:

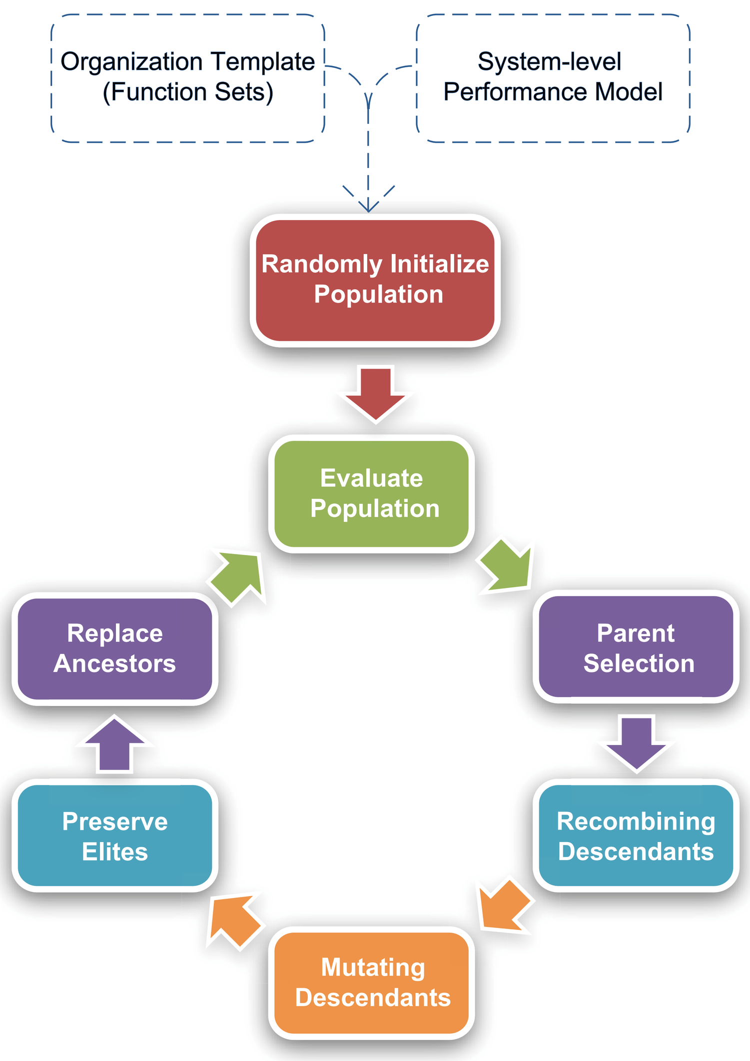
Taken into account depth and resource constraints to ensure all trees and subtrees generated are valid.

Recombination Operator:

1) Swapping subtrees only when they contain equal number of resources and the swapping will not violate the depth constraint.
2) Automatic routine learning: learn useful structures and adapt the symbol sets to cater to different problems.



Redistribution Mutation: Redistribute resources among agents and agents among groups



Outline of Evolutionary Organizational Search

Experiments

We optimize the organization of an hierarchical information retrieval (IR) system. Agents include those which control databases, aggregators which collect data from lower agents and route messages, and mediators which accept user queries and decide which portion of the system to search. A group of mediators, in charge of aggregators and databases below it, sit at the topmost layer of the system and cooperate to answer user queries.

The system performance is affected by two factors: recall rate ($\in[0, 1]$) and response time (in milliseconds). The recall rate is determined by the relevant data being searched compared to total relevant data in the system. The utility value to be optimized is computed as follows.

$$\text{utility} = \text{recall\_rate} \times 1000 - \text{response\_time} / 10$$

Three sets of experiments with different environmental variables were repeated for 50 times. Fifty individuals were evolved for 20 generations. The table below shows how the organizational structure of a system managing 15 databases adapted under different environment. Among various organizational features, we are mainly interested in the number of mediators. The results suggest a trade-off between recall rate and response time. When the system was not queried very often (0.05), a single mediator that administered all databases could cope well, but when the query rate was increased to 0.10, multiple mediators that share the workload became necessary. In the third setting, when the system searched only databases under a single mediator, the number of mediators was decreased so as to maintain a good recall rate.

Empirical Results: Different Organizations under Different Environments

Query Rate	Max Search Set Size	Number of Mediators		Utility	
		Average	Standard Dev.	Average	Standard Dev.
0.05	4	1.00	0.00	851.22	1.47
0.10	4	4.74	0.44	468.17	13.84
0.10	1	2.00	0.00	346.52	4.91

Conclusions

In this paper we proposed a novel framework of evolutionary optimization for multi-agent organizations, which we name Evolutionary Organizational Search, based on strongly typed genetic programming. It fills the gap between existing quantitative optimization frameworks by adding a stochastic, meta-heuristic global optimization technique to the existing armory. EOS considers special constraints and requirements of MASs, such as limits on resources, and can be applied to a wide range of tree-shaped organizational forms. Our experiments generated differently structured organizations under different environmental settings for an information retrieval system, illustrating the power of EOS to adapt to changing environments.

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References

[1] Dignum, V., Vazquez-Salceda, J. and Dignum, F. Omni: Introducing social structure, norms and ontologies into agent organizations. *Proceedings of the Third International Joint Conference on Autonomous Agents and Multi-Agent Systems(New York, NY, 2004)*, 91-102.

[2] Horling, B. *Quantitative Organizational Modeling and Design for Multi-Agent Systems*. PhD Thesis, University of Massachusetts at Amherst, 2006.

[3] Horling, B. and Lesser, V. A survey of multi-agent organizational paradigms. *Knowl. Eng. Rev.*, 19, 4 (Dec.2004), 281-316.

[4] Montana, D. J. Strongly typed genetic programming. *Evol. Comput.*, 3, 2 (Summer 1995), 199-230.

[5] Sims, M., Corkill, D. and Lesser, V. *Knowledgeable Automated Organization Design for Multi-Agent Systems*. Technical Report 07-43, University of Massachusetts, Amherst, MA, 2007.

[6] So, Y.-p. and Durfee, E. H. Designing organizations for computational agents. In *Simulating Organizations*. AAAI Press/ MIT Press, 47-64, 1998.

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