Automatic Formation and Analysis of Virtual Organization

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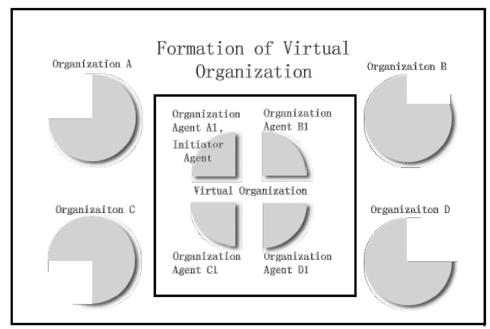
Outline

- Background
  - What is VO?
  - Why use MAS to study VO
- Formation process
- Operation phase - individual decision making
- A statistical model for predication
- Simulation and experiments
- Conclusion and Future work

Virtual Organization

- A temporary teaming of enterprises.
- Share physical, human and knowledge resources via information technologies.
- A virtual organization enables member enterprises to
  - share skills, costs
  - access to one another's markets
  - decrease the risk of investments.



•Agile Infrastructure for Manufacturing Systems (AIMS)
  • Lockheed, Texas Instruments, and several universities
• Goal of AIMS:
  •to develop mechanisms in both business and technology infrastructures
  •using national information highways
  •allow companies to very rapidly put together partnerships for the development of complex projects. (AIMSNet)

Life Cycle of Virtual Organization

Identification Phase	Description of product or service to be delivered by the virtual organization, which guides the conceptual design of the virtual organization.
Formation Phase	Rational selection of the individual organizations (partners), based in its specific knowledge, skills, resources, costs and availability.
Operation Phase	Control and monitoring of the partner's processes, including resolution of conflicts, and possible virtual organization reconfiguration due to partial failures.
Dissolution	Breaking of the virtual organization, distribution of the obtained profits and storage of relevant information.

Virtual Organization and MAS

- Agent is an appropriate metaphor
- Multiagent system - a set of agents
  - autonomous or semi-autonomous entities
  - perform tasks in complex and dynamically changing environments.
- Many similar aspects between MAS and VO:
  - constructed of intelligent individuals;
  - different relationships among these individuals
  - each individual has only limited knowledge and resource;
  - individuals interact with each other - coordinate, negotiate, share knowledge, transfer information
  - form and dissolve all kinds of organizations and groups.

Project description

- Implement a multiagent system
  - supports the simulation of artificial marketplace
- Develop mechanisms for decision-making
  - in various stages of virtual organization
- Perform experiments
  - evaluate and verify those mechanisms
- Gain a better understanding of the organizational problems.

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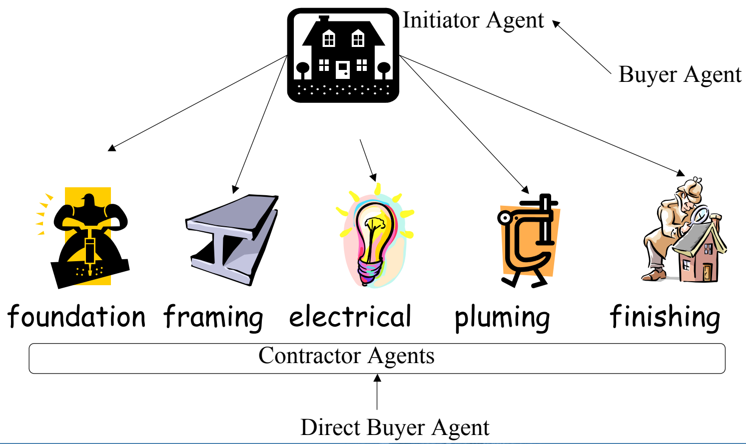
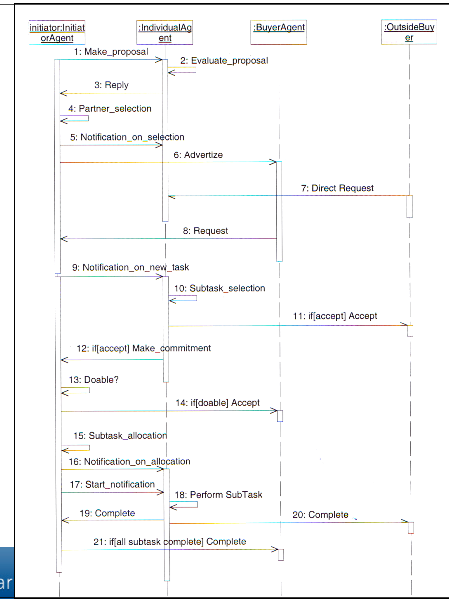
Scenario - Virtual Building Organization





Negotiation protocol

- initiator agent sends proposal for VO
  - type of task needed for the organization
  - estimated work load (*L*)
  - Estimated net profit to the organization (*R*L*)
- bid from the potential participant
  - type of task the agent is capable of (*Tbi*)
  - the number of tasks it will perform (*Lbi*)
  - its profit sharing rate (*Sbi*)

Partner Selection Process

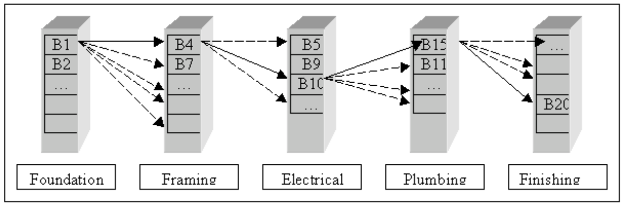
- Criteria - Maximize profit
  - Maximize profit of the VO

$$R*L$$

  - <u>Maximize profit of the initiator</u>,

$$R \cdot L' \cdot (1 - Sum(S_{bi}))$$

L' - actual working load = min(Lbi), $L' <= L$.



Note that this graph does not show all the connectors; in fact each bid in a bin can be linked to any bids in the next bin. Solid arrows represent the final selection and dash arrows show other possibilities.

- Recursive best-first search algorithm (RBFS)
  - group the bids into different bin
  - select the best bid from the first bin which maximize the initiator's profit, but also remembers the second-best choice
  - go to the next bin, find the best of the current bin
  - Compare the expected profit of current choice with the second best choice
    - Not less than: continue to the next bin,
    - Less than: unwind to the previous bin and choose the second best
  - Continue this process unit an optimal solution is found

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Penalties for Lack-of-commitment

- Organization needs the devotion from agents
- Agents are self-interested, aiming to maximize local utility.
- Introduce penalty of lack-of-commitment to encourage agent to fulfill their promises.
- Two possible penalty policies
  - linear penalty policy - a fixed penalty rate for each unfilled commitment.
  - progress-based penalty policy - a decreasing penalty rate as more commitments has been fulfilled

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How important a task is?

- An agent
  - belong to multiple virtual organizations
  - different goals and objectives.
- Agents are
  - bounded-rationality
  - limited resources
  - imperfect knowledge of its environment.
- How to evaluate and choose from tasks associated with different organizations and goals?
  - Task from one organization
  - Task from another organization
  - Task from direct contacted agents

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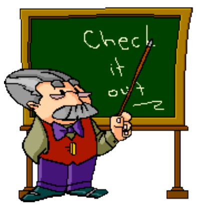
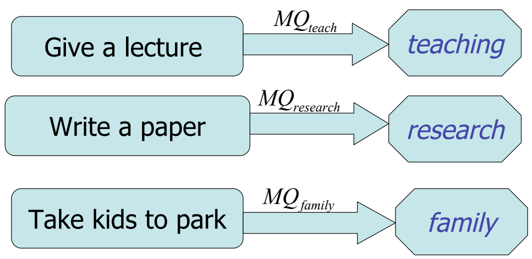
Motivational Quantities

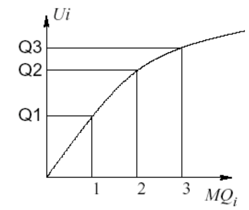
- Agent has multiple roles, multiple goals
- MQ represents progress towards organizational goal
- Preference function F_i: $MQ_i \rightarrow$ utility





Motivational Quantities - more

- Motivational Quantities (*MQ*) represents the progress towards organizational goals quantitatively.
- Each agent has a set of *MQs* which it is interested in and wants to accumulate.
- Each *MQ* is associated with is associated with a preference function (utility curve).
- The evaluation of *MQ* is context-based.



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MQ Scheduler

- Input: a set of potential tasks
- Each task has a set of attributes:
  - Earliest start time (est)
  - Deadline (dl)
  - MQ produced (MQPS)
  - MQ consumed (MQCS)
  - Process time needed (d)
- Output: a set of tasks selected to perform and how to perform them

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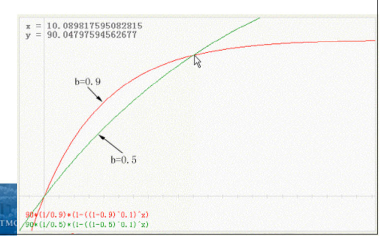
MQ mapping function

- Direct task - assume monetary value
  - using a linear mapping function f(x) = x
- Organizational task - has a special MQ for each organization it belongs
  - A: expected utility from/of the virtual organization
  - B: control parameter, 0 < b < 1, bigger b make the first several tasks more important.
  - C: number of commitments the agent has made towards this organization.

$$f(x) = a \cdot \frac{1}{b} \cdot (1 - ((1-b)^{\frac{1}{c}})^x)$$



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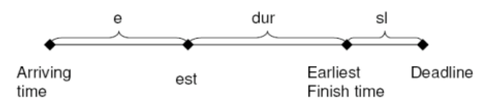
A statistical model

- To analyze and predict the behavior of agents and organization, a formalized model is needed [AAMAS04: Shen]

- r_i : Task *Ti* arrives at an agent at time t with a probability of $1/r_i$.
- e_i : The difference between the arrival time of a task *Ti* and its earliest start time est_i.
- dur_i : The duration of the task *Ti*.
- sl_i : The different between the earliest possible finish time of a task and the deadline dl_i.
- R_i: The reward of a task *Ti* if it's finished.



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Probability of conflict

- Task i has a conflict with task j when:

$$dl_i - est_j <= dur_i + dur_j,$$
$$dl_j - est_i <= dur_i + dur_j$$
$$sl_i - dur_j \le est_j - est_i \le dur_i - sl_j$$

- Probability of conflict:

$$Pc_{ij} = P(sli - durj <= estj - esti <= duri - slj)$$
$$Pc_{ij} = \sum_{z=-\infty}^{+\infty} \sum_{y=z}^{+\infty} [\sum_{x=z}^{y} Pest_j - est_i(x)] * Pdur_i - sl_j(y) Psl_i - dur_j(z)$$

$$Pdur_i - sl_j(y) = \sum_{x=-\infty}^{+\infty} Pdur_i(y) = \begin{cases} \frac{b_i^d - a_j^s - y}{(b_i^d - a_i^d)(b_j^s - b_j^s)}, & \max(a_i^d - a_j^s, b_i^d - b_j^s) < y < b_i^d - a_j^s; \\ \frac{1}{b_i^d - a_i^d}, & a_i^d - a_j^s \le y \le b_i^d - b_j^s; \\ \frac{1}{b_j^s - a_j^s}, & b_i^d - b_j^s \le y \le a_i^d - a_j^s; \\ 0, & otherwise \end{cases}$$

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Expected reward

- When a direct task Ti arrives, the agent accumulates reward if:
  1. There is a conflict between Ti and one organization task Tj, The reward of Ti is higher than that of Tj, no conflict with other direct task.

$$ER_i^{(1)} = Pc_{i,j} \cdot (1 - Pc_{ii}) \cdot E(R_i \mid R_i > R_j)$$

  2. The only conflict caused by Ti is with another direct task Ti'. The reward of Ti is higher than that of Ti'
  3. There is a conflict with both another direct task and an organization task. In addition, the reward of Ti is the highest
  4. There is no conflict caused by Ti
- When an organization task arrives, the agent collects reward only if itself and all other involved agents commit to this task

$$ER_i = \frac{1}{r_i}(ER_i^{(1)} + ER_i^{(2)} + ER_i^{(3)} + ER_i^{(4)}) + \frac{1}{r_i} ER_i^{(5)}$$

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Modified Statistical Model

- Instead of have the reward of task randomly distributed in a range, the reward of the task also depends on the current progress (time t)
- Introduce a look-up table

Arrival#	Current accepted	P (accepted)	Utility Gain
1	0	0.74	1,159.79
2	0.74	0.74	1,092.74
3	1.48	0.74	1,029.57
4	2.22	0.74	970.0469
5	2.96	0.74	913.9677
6	3.7	0.74	861.1305
7	4.44	0.74	811.3478
8	5.18	0.7082	764.4431
9	5.8882	0.6703	722.0952
10	6.5585	0.6364	684.1748
11	7.195	0.6059	650.017
12	7.8009	0.5782	619.0842
13	8.3791	0.5531	590.9373
14	8.9322	0.5301	565.2137
15	9.4622	0.509	541.6114

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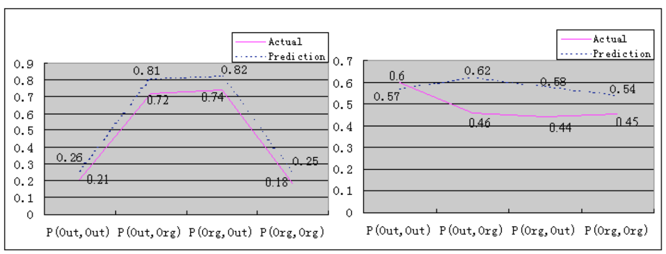
Experiments (1) - Verification of Statistical Model

Outside task: $(freq, (a_i^d, b_i^d], (a_i^s, b_i^s], (a_i^r, b_i^r])$ $(40, (25,30], (0,10], (750,1500])$

Organization task: $(35, (20,30], (0,10], a \cdot \frac{1}{b} \cdot (1-((1-b)^{\frac{1}{c}})^x))$

a=30000, b=0.9, c=20



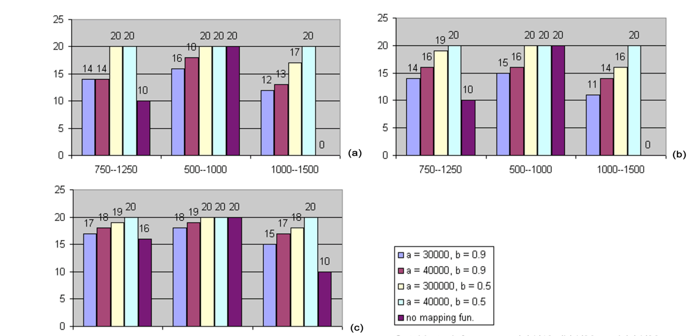
P(Out, Out): conflict probability between outside tasks

P(Out, Org): conflict probability between an outside task and an organization task.

Experiments (2) - **Effects of MQ Mapping Function**

- Bigger a - more commitment
- Smaller b - more commitment

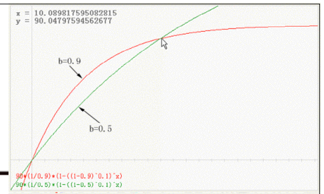
$(40, (20,30], (0,10], a \cdot \frac{1}{b} \cdot (1-((1-b)^{\frac{1}{c}})^x))$



Outside task frequency: (a)1/40, (b)1/20, and (c)1/80.

Linear penalty policy

- Smaller b is better



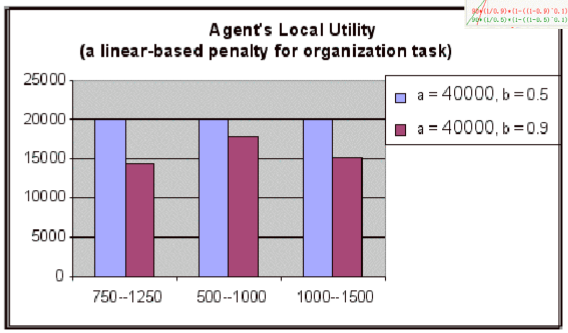
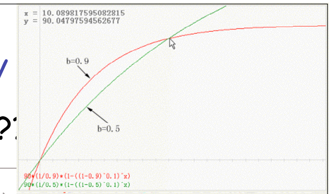


Figure 8: Agent's local utility under a linear penalty policy

Progress-based penalty policy

- Bigger b *should* be better ??



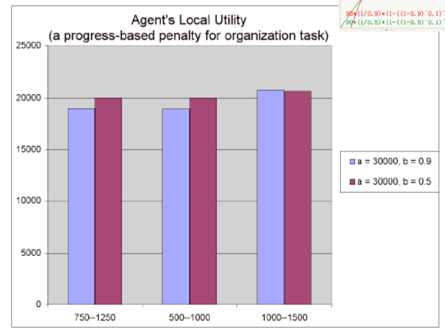


Figure 9: Agent's local utility under a progress-based penalty policy

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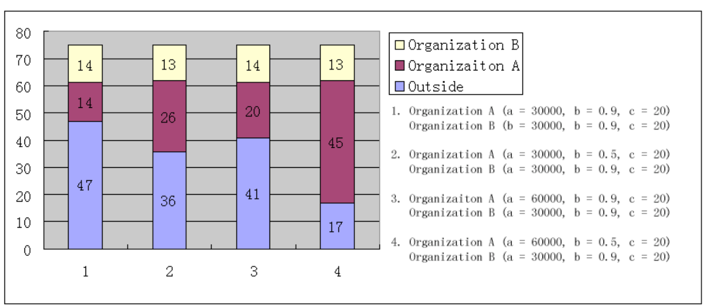
Experiment (3)
Multiple Organization Memberships

- Bigger a, smaller b - more commitment



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Conclusion

- MAS is a useful tool to study virtual organization
- Autonomous agent technology helps to optimize the formation and operation of virtual organization
- MQ framework is useful for addressing sophisticated organization concern
- Formalized statistical model is feasible to predict and analyze the behavior of agent and VO

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Future Work

- Introduce more heuristics in RBFS to reduce the complexity for practical use
- Study how to set parameter in the mapping function in order to best reflect the goal of organization and policy
- Extend the model for multiple organization and possible decommitment
- Develop policy to optimize the performance of the VO

Reference

1. Fischer, K., Muller, J., Hemig, I. and Sheer, A-W, “Intelligent Agents in Virtual Enterprises”, *Proceedings of the First International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology*, (1996).
2. Daniel E. O’Leary, “Virtual Organizations: Two Choice Problems”. In *Proceedings of the Nineteenth International Conference on Information Systems,* pp.145-154. December 1998.
3. Eugénio Oliveira and Ana Paula Rocha, “Agents advanced features for negotiation in Electronic Commerce and Virtual Organisations formation process”. In *Agent Mediated Electronic Commerce: the European AgentLink Perspective*, LNAI 1991, pp.78-97, Springer Verlag, 2000
4. Shen, Jiaying; Zhang, Xiaoqin; and Lesser, Victor. “Degree of Local Cooperation and its Implication on Global Utility”. In *Proceedings of Third International Joint Conference on Autonomous Agents and MultiAgent Systems (AAMAS 2004)*. July, 2004.
5. Wagner, Thomas and Lesser, Victor. “Relating Quantified Motivations for Organizationally Situated Agents”. In *Intelligent Agents VI --- Proceedings of the Sixth International Workshop on Agent Theories, Architectures, and Languages, Lecture Notes in Artificial Intelligence*, pp. 334-348. April, 1999.
6. O'Leary, D. E. , Kuokka, D. and Plant, R. "Artificial Intelligence and Virtual Organizations”. Communications of the ACM. (40:1) 1997. pp. 52-59.
7. Nayak, N., Bhaskaran, K., and Das, R. “Virtual Enterprises—Building Blocks for Dynamic e-Business”. *Proceedings of the workshop on Information technology for virtual enterprises* 2002. pp. 80 - 87 .

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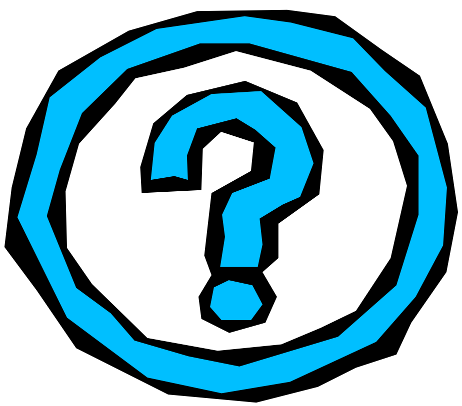
Thank you!



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