Planning and Procurement in Multi-agent Systems

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Abstract. When undertaking a large task such as planning a vacation or building a custom car, many interactions with other people are bound to occur. With the large volume of e-commerce being witnessed today, automation of the planning and purchasing tasks required in large jobs is possible. To do so, new technology, where many software agents must work cooperatively and competitively alongside each other to create efficient plans, is necessary.

This paper will propose a strategy for the automation of procurement of goods and services required in plans created by a society of agents. This strategy focuses on synchronizing future price quotes from suppliers, and attempts to predict, based on statistical data, when there may be a better time in the future to purchase goods and services required by a plan.

1 Introduction

1.1 Planning

Planning is the problem domain of artificial intelligence that involves finding a sequence of actions, called a plan, that will solve a set of goals. The problem solving system that is used to find these plans is known as a planner. The planning process typically begins with providing the planner with some representation of the initial state of the world, the set of actions that can be performed in this world, and a set of goals. The task of the planner is to determine a sequence of actions that will transform the world from the initial state to a state in which all goals have been met.

1.2 Multi-agent Systems

There is no real consensus in the agent community as to what constitutes an agent. For the purposes of this paper, the following definition from [PMG98] shall be adopted: An agent is a computer software entity that is capable of autonomously perceiving, reasoning about, and acting upon its environment. A computing system that consists of more than one working agent is known as a multi-agent system (MAS). [DL89] defines a MAS as a loosely coupled network of problem solvers (agents) that interact to solve problems that are beyond the individual capabilities or knowledge of each problem solver.

1.3 Multi-agent Planning

When presenting their research in multi-agent planning, many authors seem to disagree on the exact meaning of multi-agent planning. Is the MAS creating the plans or executing the plans? Or both? Do the agents in the MAS work cooperatively or competitively when creating or executing the plans? If the more interesting cases are considered, where multi-agent systems are used for both creating and executing plans, we have the following four scenarios:

Many competitive agents planning for many competitive agents
Many competitive agents planning for many cooperative agents
Many cooperative agents planning for many competitive agents
Many cooperative agents planning for many cooperative agents

It becomes even more interesting to consider MAS's in which more than one, or even all, of these scenarios are involved. One way to envision such a system is to consider an MAS consisting of a number of teams. Agents on the same team work together to create plans, while competing against other teams (for resources, quality of plans, speed in creating plans, etc.). Customer agents, some of whom cooperate with each other while others compete, request plans from plan creators and execute them. For example, consider a customer wishing to plan a vacation trip. The customer has a choice of many travel agencies (teams), each consisting of a number of travel agents who work together. The customer will be presented with a plan of when to leave, where to stay, what to do, when to come home, etc., with an associated cost. The customer can then choose to buy, ask for a different plan, or decline altogether and choose a different travel agency.

1.4 Procurement

All plans created need to be assessed a cost, so that an educated decision on which plan to choose can be made. In order to assess the cost of a plan, the costs of the resources required in the plan must be obtained, negotiated, or predicted by the planning agents. There are many different ways in which resource suppliers may choose to deal with their customers. Consider four possible methods of resource distribution by the suppliers:

(1) *The supplier may offer a non-negotiable price at which a purchaser has a definite period of time to decide to take-it-or-leave-it.*

(2) *The supplier may offer a negotiable price.*

(3) *If resources are limited, the supplier may choose to open an auction.*

(4) *The supplier may offer a time in the future at which a price quote can be given (e.g. upcoming sale or possible market value change).*

Automating the procurement of goods available by means similar to distribution method (4) is the topic of discussion in this paper.

1.5 Automating Procurement

When automating the process of purchasing goods and services to complete a project, it is wise to have a strategy that can be planned ahead of time, before the automated purchasing process begins. This way, the system can handle all of the details without requiring any human interactivity. This paper presents one possible approach. Consider a human buyer, working on a project that can be built in one of two ways: either by acquiring goods A and B or by acquiring goods C and D. First the buyer obtains a price quote on good A. The buyer, no matter how low the price of A might be, is not likely to commit to purchasing A until he/she knows the price of B. If B's price is unreasonable or over budget, then A becomes useless to the buyer, especially since the buyer still has the option of obtaining goods C and D instead.

Quite often, a supplier may not be able to give a quote on a price at shopping time, but might instead be able to guarantee that a price can be quoted at some definite point in the future. Or in some cases, even though a supplier may be able to give a quote at shopping time, it might also know of some definite point in the future when a better price may be available (e.g. an upcoming sale). So, looking at future quotes is not only advantageous in some cases, but also sometimes required.

The strategy presented in this paper focuses on synchronizing the quote intervals of all purchases required in the project. A quote interval is the period of time that the quote is available to the purchaser for acceptance. The system can then evaluate the feasibility of buying all of the goods and services for a project, based on pre-existing preferences and parameters, before ever committing to a single purchase. Furthermore, it attempts to synchronize quote intervals of supplies residing in different plans. Consider the buyer's advantage in the above example if he/she could examine the quoted prices of all goods A, B, C, and D simultaneously. The buyer could then make an informed decision of whether to go for goods A and B or C and D, and make purchases accordingly. It would certainly be advantageous to have an automated system that could make its own decisions based on this much information.

1.6 Temporal Intervals

Before the process can be described, a few definitions on temporal interval terminology are presented. The first three come from [All83]. Consider the notation X_s and X_f to be the times that an interval X starts and finishes, respectively.

Definition 1 (Before) An interval X is *before* an interval Y iff $X_f < Y_s$.

Definition 2 (Overlap) An interval X *overlaps* an interval Y iff $X_s < Y_s < X_f < Y_f$.

Definition 3 (During) An interval X is *during* an interval Y iff $X_s > Y_s$ and $X_f < Y_f$.

Definition 4 (Intersect) An interval X and an interval Y *intersect* iff one of the following is true: X overlaps Y, Y overlaps X, X is during Y, or Y is during X.

2 Devising a Procurement Plan

The process of devising a plan for the procurement of goods works in the following five stages: (1) Plan construction (2) Validation (3) Comparison set placement (4) Cost assessment (5) Purchase time selection.

2.1 Plan Construction

Problem instances are coded using the STRIPS [FN71] representation, and all possible plans are produced using the STRIPS planner. The set of goods and services that need to be purchased during execution of a plan is known as the *purchase package* for that plan.

2.2 Validating the Purchase Packages

Every purchase package will undergo a validation attempt. A valid purchase package is described by the following definitions:

Definition 5 (plan deadline) The *plan deadline* is the point in time where the customer needs all supplies to be purchased.

Definition 6 (contract period) The *contract period* is the interval of time beginning with the plan request and ending with the plan deadline.

Definition 7 (quote interval) The *quote interval* for an item I is the interval in time beginning with the time a price quote is given for I and ending with the time a decision of whether or not to buy I at that price must be made.

Definition 8 (valid) A purchase package P is considered to be *valid* iff there exists an interval t in the contract period such that t is during a quote interval for every item in P and t is during the contract period.

Definition 9 (purchase interval and active quote interval) The *purchase interval* PI of a valid purchase package P is the longest interval that is during a quote interval of every item in P. For each item I in P, the quote interval Q_I for I such that PI is during Q_I (there will be exactly one such Q_I) is known as the *active quote interval* for I in P.

Negotiation with suppliers of items required in each purchase package will be performed with the goal of validating the purchase packages. Only valid packages are useful, since a quote interval for each item in a valid package intersect, giving the purchaser the ability to assess the terms of all items before actually committing to purchasing any of them. Packages that cannot be validated are discarded. All packages that are found to be valid are placed in *comparison sets*.

2.3 Comparison Sets

Definition 10 (comparison set) A *comparison set* is a set of valid purchase packages in which the purchase interval of each package in the set intersect.

Definition 11 (action interval) The *action interval* of a comparison set C is the longest interval that is during the purchase interval of every purchase package in C.

All valid plans are placed in comparison sets. Comparison sets are built such that for any comparison set C with an action interval A, and for every purchase package P with purchase interval PI, if PI and A intersect, then P is placed in C. Note that a purchase package can be placed in more than one comparison set. Comparison sets are useful since the quote interval for all items in every purchase package in a comparison set intersect, giving the purchaser the ability to assess the terms of all items in many packages at one time, before being required to committing to buying any of them. Next, each comparison set is assigned a cost.

2.4 Cost Assessment

In this paper, statistics use a normal distribution to predict the costs of items and purchase packages. Other distributions can easily be substituted if found to be more appropriate.

Definition 12 (item cost) An *item cost* is a random variable with an expected value E and a variance V.

Definition 13 (purchase package cost) A *purchase package cost* is a random variable A with an expected value E equal to the sum of the expected values of items in the package, and a variance V equal to the sum of the variances of items in the package.

Definition 14 (comparison set cost) For n independent purchase packages in a comparison set CS, the cost of CS is the lowest dollar amount c such that:

$$\left(\prod_{i=1}^{n} Prob(A_i > c)\right) < 0.5$$

where A_i is the actual cost of purchase package i.

This is the point where it becomes unlikely that all actual costs will be higher than c (and therefore likely that one cost will be less than or equal to c). This is considered to be the likely lowest purchase package cost in the comparison set. For example, consider a comparison set consisting of three purchase packages with the following expected values and variances:

Package 1: $E = 100, V = 90$
Package 2: $E = 97, V = 50$
Package 3: $E = 101, V = 87$

In this case $c = 93$, since

$$P(A1 > 93) \times P(A2 > 93) \times P(A3 > 93) = 0.7704 \times 0.7157 \times 0.7967 = 0.44$$

and also since $c = 92$ would not satisfy the condition, giving a likelihood of about 0.51, making 93 the lowest integer that satisfies the condition. This means that it is 44% likely that all actual costs in the comparison set will be higher than 93 and therefore the likelihood of getting a cost less than or equal to 93 is 56%.

2.5 Purchase Time Selection

Purchasing should take place during the action interval of the comparison set with the lowest cost. This should be the best time to buy.

3 An Example

Consider the following planning task: A customer needs a vacation. The task is to plan a method of travel to the vacation spot, and to find a place to stay. The two methods of travel are: (1) plane (which requires a shuttle pass from the airport into town) and (2) train. The two types of accommodations are (1) motel and (2) hotel.

The problem is encoded using STRIPS representation, giving several options of flights, hotels, etc., and several plans with their corresponding purchase packages are found by the STRIPS planner. After the validation stage, we are left with the following valid purchase packages. All items in the purchase package are listed by their active quote interval in the plan. Times are represented by the integers from 0 to 30. Syntax for the *quote* predicate: quote(Item, QuoteStartTime, QuoteEndTime, ExpectedPrice, Variance)

Purchase Package 1
quote(hotel, 0, 10, 100, 100)
quote(flight, 0, 10, 500, 600)
quote(shuttle, 0, 20, 10, 10)
Purchase Interval: 0,10
Expected Cost: 610
Variance: 710

Purchase Package 2
quote(motel, 20, 30, 100, 40)
quote(flight, 20, 30, 340, 380)
quote(shuttle, 15, 30, 10, 10)
Purchase Interval: 20,30
Expected Cost: 450
Variance: 430

Purchase Package 3
quote(hotel, 15, 30, 100, 100)
quote(flight, 15, 20, 600, 600)
quote(shuttle, 0, 20, 10, 10)
Purchase Interval: 15,20
Expected Cost: 710
Variance: 710

Purchase Package 4
quote(motel, 20, 30, 100, 40)
quote(train, 15, 30, 300, 300)
Purchase Interval: 20,30
Expected Cost: 400
Variance: 340

Purchase Package 5	Purchase Package 6
quote(hotel, 15, 30, 100, 100)	quote(hotel, 15, 30, 100, 100)
quote(flight, 15, 20, 600, 600)	quote(flight, 20, 30, 340, 380)
quote(shuttle, 15, 30, 10, 10)	quote(shuttle, 15, 30, 10, 10)
Purchase Interval: 15,20	Purchase Interval: 20,30
Expected Cost: 710	Expected Cost: 450
Variance: 710	Variance: 490

Purchase Package 7
quote(available(louie), 0, 30, 0, 0)
quote(hotel, 15, 30, 100, 100)
quote(train, 15, 30, 300, 300)
Purchase Interval: 15,30
Expected Cost: 400
Variance: 400

Finally, the action intervals are determined and the comparison sets are built:

Comparison Set 1	Comparison Set 2	Comparison Set 3
Action Interval: [0,10]	Action Interval: [15,20]	Action Interval: [20,30]
Packages: {1}	Packages: {3,5,7}	Packages: {2,4,6,7}
Cost: 610	Cost: 400	Cost: 390

The results indicate that during the interval [0, 10] we are over 50% likely to find a purchase package that costs 610 or less, during [15, 20] we are over 50% likely to find a package which costs 400 or less, and during [20, 30] we are over 50% likely find a package which costs 390 or less. Therefore, we can conclude that the best (cheapest) time to buy should be during the interval [20, 30].

4 Conclusions and Future Work

The method for planning purchases presented in this paper is useful in two ways:

1) The high complexity task of finding times in the future when prices can be compared is automated. This task, which is normally done by humans, is time consuming and typically just not done. It is not standard practice since it is too difficult to obtain large masses of information on future quote intervals and synchronize them in such a way as to maximize the ability to comparison-shop.

2) Based on past information and history, the system predicts the best time to buy. The typical practice is to either make purchases based on the best deals available at the time, or to continue shopping until finally a set of prices is found that meets the budget. This system is helpful in that, even though a good deal may have been found, it will indicate that there may be an even better time to shop in the future if one exists.

Currently the system bases its decision of how "good" an action interval is solely on the prices of the purchase packages that can be compared during that time. Clearly, there are other factors that dictate how good a purchase package is, such as:

1) Customer preferences. It may be more preferable to fly rather than to take a train, to stay in a nice hotel rather than a cheap motel, etc.

2) Storage cost. While this may not apply to the travel domain, it may in others that require the purchase of large items that may need to be stored until they are used. This may cause earlier action intervals to cost more since buying at earlier times may give the buyer the need to store items longer.

3) Lateness cost. An action interval that comes late in the contract period may not be preferable, since if good buy cannot be found during that time, it may become impossible to obtain the necessary goods before the contract deadline.

These three ideas would have to be implemented in the system in order to have a useful product. Another idea that might be interesting is to change the expected price probability threshold to something higher than 50%. This would allow the system to be more confident in the price estimates it returns. This may help the buyer who has a firm budget and cannot afford to take chances. However, even without taking these into account, this report has shown not only that procurement of goods and services can be improved, but also that this improvement can be quite effective. It would be interesting to see this technology implemented in an actual Internet "shop-bot". While existing shop-bots have the ability to shop over the Internet for certain goods on behalf of customers, usually returning a few of the best current prices it was able to find, this new technology could allow the shop-bot to establish future quotes with suppliers. Using data from previous transactions, market trends, etc., this shop-bot may be able to give some indication to the customer of a better time to buy in the future. The customer could then check back with the shop-bot at that time to compare the new price quotes offered by the suppliers. If this idea proves to be successful, it could have a great influence on the future of e-commerce.

References

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