

# Scalable Complex Contract Negotiation With Structured Search and Agenda Management

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## Abstract

A large number of interdependent issues in complex contract negotiation poses a significant challenge for current approaches, which becomes even more apparent when negotiation problems scale up. To address this challenge, we present a structured anytime search process with an agenda management mechanism using a hierarchical negotiation model, where agents search at various levels during the negotiation with the guidance of a mediator. This structured negotiation process increases computational efficiency, making negotiations scalable for large number of interdependent issues. To validate the contributions of our approach, 1) we developed our proposed negotiation model using a hierarchical problem structure and a constraint-based preference model for real-world applications; 2) we defined a scenario matrix to capture various characteristics of negotiation scenarios and developed a scenario generator that produces test cases according to this matrix; and 3) we performed an extensive set of experiments to study the performance of this structured negotiation protocol and the influence of different scenario parameters, and investigated the Pareto efficiency and social welfare optimality of the negotiation outcomes. The experimental result supports the hypothesis that this hierarchical negotiation approach greatly improves scalability with the complexity of the negotiation scenarios.

## Introduction

When groups need to decide, for example, on the design of a car or an air traffic control system, on the elements of a peace treaty or a piece of legislation, or on the management of a transportation network or electric grid, they typically need to bring hundreds of agents to agreements concerning thousands of interdependent issues. In such scenarios, the presence of self-interested elements makes centralized optimization approaches or distributed optimization approaches

such as DCOP inapplicable, because participants would deviate from any optimal solution in which they have not taken part of. Negotiation is for self-interested entities to reach agreement. However, such real-world negotiations must deal with huge contract spaces and highly complex utility functions with multiple local optima (Bar-Yam 1997). This poses a significant challenge over most existing negotiation techniques, which are focused on simple problems involving relatively small number of agents and a few independent issues, usually assuming linear utility functions.

To meet this challenge, we present a scalable approach for complex contract negotiation using structured anytime search and agenda management. By “agenda management” we mean a process by which agents decide which issues to negotiate about and in what order. By “structured”, we mean that we rely on a hierarchical decomposition of the negotiation problem to perform this agenda management. By “anytime”, we mean that the agents can keep looking for better agreements after reaching an agreement if time allows.

Hierarchical structure, including multiple-level decomposition, is commonly used in human-design systems to reduce system management complexity. We adopt a hierarchical model for negotiation problems proposed in (Zhang and Klein 2012). In this model, the system/problem in negotiation is represented as a decomposition of a set of sub-systems, which reflects the interdependency relationships among negotiation *attributes* (hereinafter, used interchangeably as *issues*): the attributes that belong to the same sub-system are highly interdependent, while the interdependency level across different sub-systems is much weaker.

Our structured search with agenda management approach can be summarized as follows. The mediator first collects meta-level information about the interdependency of all attributes at the top level from each agent. Using this information, the attributes on the same level are clustered in different groups (highly interdependent issues are grouped together). The agenda-based mechanism then guides the agents to negotiate agreements for each cluster. These sub-agreements can then be combined into a single provisional high-level

contract and refined by further negotiations to take into account whatever weak inter-cluster dependencies may exist. The result of this process is a top-level agreement, which sets the context for negotiations over the remaining levels. For example, given a constraint *if  $x > 5$  then  $y < 4$* , a higher-level agreement with  $x = 6$  then constrains the lower level searching for  $y$  to values less than 4. This process is repeated until all issues have been considered and a fully-specified agreement is reached. The anytime search continues looking for better agreements when resource is available.

This hierarchical search process reduces the computational effort significantly. By dividing the search into multiple levels and also clustering attributes into smaller groups, the combinatorics involved in making complex contracts is radically reduced. Additionally, each high-level agreement defines the context for further search and eliminates a large part of the remaining search space. This hierarchical approach may potentially find better negotiation outcomes, if the system decomposition is done in a way that the higher-level attributes constrain the search space the most, and the search is effectively directed to the most promising area.

Our hierarchical search and agenda management approaches opens a new avenue of research in multi-attribute negotiation. In most research work so far, negotiation is considered as a “package deal”: a fully-specified contract is proposed, modified, accepted or rejected (Klein et al. 2003; Zheng et al. 2013). Combinatorial auctions (Nisan et al. 2007) is another “package deal” approach for negotiation with large number of issues. This type of negotiation can be seen as a flat plane search, since it relies on finding a point in the solution space (a fully specified contract) to maximize a predefined utility function. The biggest concern of such flat-plane search models is the *computational scalability*. Several approaches have been proposed in the literature to deal with this scalability concern. In (Ito, Hattori, and Klein 2007; Marsa-Maestre et al. 2009), agents approach agreements by posting increasingly narrow constraints (regions on the space of possible agreements), over multiple rounds. Computational complexity is reduced, but they were only able to handle negotiations of *moderate* scales.

There are some works dealing with separate issue negotiation, where each issue is negotiated either sequentially or in parallel (Fatima, Wooldridge, and Jennings 2004; Inderst 2000). Sequential negotiation agenda management (Pendergast 1990) has been studied for simple contracts (Fatima, Wooldridge, and Jennings 2004) where independence is assumed among multiple issues or where negotiation problems are restricted (e.g. resource allocation (Fatima and Wooldridge 2013) or service-level agreements (Abedin et al. 2009)). Research work also has been performed on managing concurrent one-to-many negotiations, which also may improve scalability by parallelization (Mansour, Kowalczyk, and Wosko 2012; Sim and Shi 2010). In this context, (Abedin et al. 2009; Luncean 2011; Zhang and Lesser 2007) exchange meta-level information to arrange the negotiation agenda. (Dang and Huhns 2006) and (An, Lesser, and Sim 2011) each proposes a multi-round negotiation protocol for concurrent negotiations, (Aknine 2011) proposes a control model to manage overlapping negotia-

tions. However, all these works assume the negotiation issues are on the same information detail level, which does not allow for the significant reduction of the search space that hierarchical structured agendas provide. Hierarchical negotiation is proposed in (Bruns and Cortes 2011) and (Karaenke and Kirn 2010), but agenda management in this context is not explored. The study the management of hierarchically structured multiple interrelated negotiation issues with dynamic negotiation agenda, as presented in this paper, is in great need of research attention (Hujala and Kurttila 2010).

In the rest of this paper, we first review the hierarchical model proposed in (Zhang and Klein 2012). We then present a mediator-facilitated anytime search process using this model. We will also describe the scenario matrix used to model the problem structure, present the experiment setting and discuss the results obtained. Finally, we conclude and outline future lines of research.

## Hierarchical System Representation

In most complex negotiation scenarios, whether the problem under negotiation is a process, a system, or a component, it can be decomposed into a hierarchical structure using domain knowledge abstractions. A hierarchical representation for negotiation problems presented in (Zhang and Klein 2012) is summarized here. A complex negotiation system/problem  $S$  can be further decomposed as a set of sub-systems (components)  $\{S_1, S_2, \dots, S_n\}$ , and each sub-system  $S_i$  can be further decomposed as  $\{S_{i_1}, S_{i_2}, \dots, S_{i_n}\}$ . There are a set of attributes (issues) associated with each system  $S$  and sub-system.

User preference profiles are represented as sets of constraints. Each constraint represents a goal of the agent, and a *rank* (or *weight*) value associated with it represents the relative importance of this goal. When a constraint is satisfied, its weight is added to the overall contract utility. This *qualitative* preference model has been widely used in the literature to represent multi-attribute preferences (Hindriks, Jonker, and Visser 2009; Marsa-Maestre et al. 2009), and has the advantage of removing the need to acquire a utility function specifying a numeric value for each possible outcome (Hindriks, Jonker, and Visser 2009). A constraint is in fact a hyper-volume that describes compatible issue values, and thus a high-utility portion of the contract space.

Constraints are placed into different levels according to where its involved attributes belong. If a constraint’s involved attributes belong to different levels, the constraint is placed at the highest level. During hierarchal negotiation, agents only consider constraints placed at the current level. The choice of the attribute values at a higher level further restrains the domain of lower-level attributes involved in the same constraints. Hence the lower-level search is performed only within the *context* imposed by the decisions made at higher-levels in the hierarchy. Next, we will present more details about this hierarchical negotiation search process.

## Hierarchal Negotiation Search Process

The hierarchal negotiation search process involves a mediator and a set of agents. Each agent represents a user (a stake-

holder in the system) and negotiates on behalf of this user. The preference information provided by the user is kept private by the agent. The system decomposition knowledge is public to all agents and to the mediator. The negotiation process is conducted in a top-to-bottom order (i.e. starting with the highest level). At each level, there is a meta-negotiation session to determine the negotiation agenda followed by a regular negotiation session to select the preferred *common choices* (CC) based on agents' bids.

### Meta-negotiation: determining negotiation agenda

A *decision group* contains a number of (highly) interdependent issues, and a negotiation agenda is a partial ordering of a set of decision groups  $\{DG_i\}$ . An agenda is represented as a directed acyclic graph. A link from  $DG_i$  to  $DG_j$  specifies that the negotiation of  $DG_i$  should be performed before the negotiation of  $DG_j$ . Having such an agenda allows negotiation to be conducted for each DG separately, and reduces the search space for bidding generation and evaluation, since each DG only encompasses a subset of the issues.

The agenda selection process works as follows. First, each agent submits meta-level information about the dependency relationships among all the attributes  $\{X_i\}$  at the current level  $l$ . The agent infers the dependency relationships from the constraints provided by the user. Attributes involved in the same constraint are considered dependent. The more constraints these attributes share, and the more important these constraints are, the stronger the dependency is. The dependency relationship is computed based on the rank/weight information of the constraints, and is classified as *strong*, *weak* or *none*. More specifically, each agent  $A_m$  submits a  $n$  by  $n$  matrix  $D_m$ , where  $n$  is the number of attributes at the current level,  $D_m[i, j]$  represents the dependency relationship between attributes  $X_i$  and  $X_j$  for agent  $A_m$ . The mediator then creates a global dependency matrix  $GD$  based on the matrix  $D_m$  submitted by all agents:

$$GD[i, j] = \max_{1 \leq m \leq \text{agentNum}} D_m[i, j]$$

According to  $GD$ , the mediator then clusters all attributes into three types of groups: strongly dependent groups (all attributes inside are strongly dependent); weakly dependent groups (all attributes inside are weakly dependent) and independent attributes. The clustering mechanism is a graph traversal process using depth-first search with  $GD$  as the graph adjacent matrix. A *preferred group size limit* parameter can be used to influence group formation.

The mediator then sends the group divisions to all agents, and each agent submits its preferences about the ordering of these decision groups in negotiation (*agenda*). Since the latter issues will be negotiated in the context of the previous negotiation results, the agenda actually affects the negotiation process and thus potentially impacts the negotiation outcome. The decision groups with the biggest potential impact on the outcome utility should be negotiate earlier.

An agent evaluates the impact of group  $DG_i$  as:

$$\text{utilityImpact}(DG_i) = \sum_{\gamma \in \Delta_i} \text{weight}(\gamma),$$

where  $\Delta_i$  is the set all constraints over  $DG_i$ . All decision groups are sorted based on their utility impact in decreasing

order (i.e. highest impact group first). A numeric *precedence value* is assigned to each decision group corresponding to its utility impact with normalization. This ordered decision group list is returned to the mediator. Each agent may (very likely) have different views of the importance of those DGs. Though agents could lie about the dependency relationships among attributes and/or their true preferences, it may not be computationally feasible to lie efficiently (Bartholdi, Tovey, and Trick 1989). It is our future work to study how agents can lie to guarantee benefit in such a multi-level clustered negotiation setting, and how to discourage such lying.

Finally, the mediator computes an impact value for each decision group by summing the agent precedence values for each group. A global directed acyclic graph is generated based on both the dependent relationships and the impact values of all decision groups. This is the negotiation agenda for the current level.

### Negotiation as a tree search process

With the negotiation agenda available at each level, the mediator conducts a tree search process in the structured agenda space. As illustrated in Figure 1, each node represents a partially specified *state* (partial contract). To expand a node  $n$  at depth  $l$ , the mediator executes the negotiation agenda at the next level  $l + 1$ , by requesting bids for each DG according to the specified order in the agenda. The request is accompanied by the bidding context information  $\Gamma$ , as recorded in node  $n$ , which describes the attributes in previous decision groups (on the path from the root to node  $n$ ) with assigned value ranges ( $r$ ). This represents the restrictions that previous higher-level agreements impose in the current-level negotiation. The mediator also informs the agent the limit of number of bids to submit,  $BL$ .

Upon receiving a bidding request for the decision group  $DG_i$  and the given context  $\Gamma$ , each agent submits its most preferred  $BL$  bids (choices) for all attributes in  $DG_i$ . Each bid has an associated preference value, which is the sum of the weights of all constraints satisfied by this bid. Agents use the following *iterative search* procedure to generate bids:

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 $\Delta \leftarrow$  all constraints over  $DG_i \cup \Gamma$ ;
bid set  $\Theta \leftarrow \emptyset$ ;
 $BL \leftarrow$  bids limit provided by the mediator;
while  $\Delta \neq \emptyset \wedge |\Theta| < BL$  do
  newBids = findBids( $\Delta$ );
  for all  $B \in$  newBids do
     $\text{preference}(B) = \sum_{\gamma \in \Delta \wedge \text{Sat.}(B, \gamma)} \text{weight}(\gamma)$ ;
  end for
   $\Theta \leftarrow$  newBids  $\cup \Theta$ ;
   $\gamma_{\min} \leftarrow \arg \min_{\gamma \in \Delta} \text{weight}(\gamma)$ 
  remove  $\gamma_{\min}$  from  $\Delta$ ;
end while

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The *findBids*( $\Delta$ ) currently adopts the max-product algorithm (Marsa-Maestre et al. 2009), using message-passing to solve the constraint satisfaction problem formulated as a maximum weight independent set (MWIS) problem.

The mediator selects the  $\tau$  top preferred *common choices* (CC) by finding the intersections among the bids submitted by all agents. A valid common choice of bid  $B_m = \{X_i = r_{m_i} : 1 \leq i \leq k\}$  and  $B_n = \{X_i = r_{n_i} : 1 \leq i \leq k\}$  is

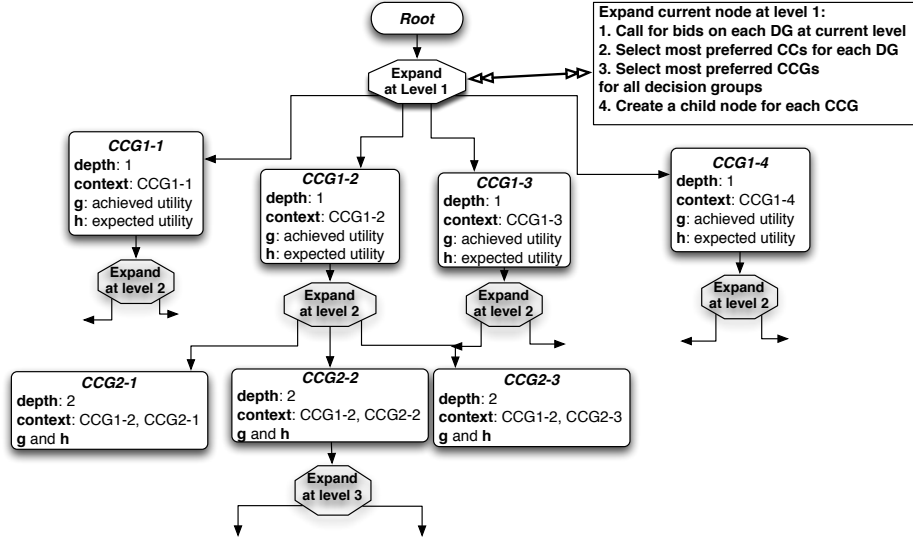


Figure 1: Negotiation Search Tree

the non-empty intersection of these bids, and its preference value is the sum of the preference values of different agents:  $CC_{mn} = B_m \cap B_n = \{X_i = r_{m_i} \cap r_{n_i} \neq \emptyset : 1 \leq i \leq k\}$ , and its preference value is the sum of the preference values of different agents. A complete search of all possible combinations takes  $O(BL^n)$  time for  $n$  agents, which is not computationally feasible for large  $BL$  and  $n$ . To increase the possibility of finding valid combined bids with limited computational cost, the value for the bid limit  $BL$  is chosen based on  $|DG|$ . In the current implementation,  $L$  is set as  $2^{|DG|}$ , bounded by two constant parameters  $[minBidsNum, maxBidsNum]$ . When no valid bid combination is found, the mediator will double the value of  $BL$  and repeat the bid requesting process until  $BL$  reaches  $maxBidsLimit$  (a constant parameter, value 20 is used currently for hierarchical negotiation).

After the negotiation for all decision groups has been finished, the mediator has a set of ordered preferred common choices  $\{CC_{j_1}, CC_{j_2}, \dots, CC_{j_r}\}$  for each decision group  $DG_i$ . A *common choice group*  $CCG_l$  is a group of common choices  $\{CC_{1l}, CC_{2l}, \dots, CC_{gl}\}$ , each for one decision group at the current level  $l$ . The preference of a  $CCG$  is the sum of preference values for all common choices included in this group:  $preference(CCG_l) = \sum_{CC_{i_l} \in CCG_l} preference(CC_{i_l})$ . The mediator then selects the most preferred  $\chi$  common choice groups and create a new node for each CCG, and this CCG is the state of the corresponding node and then becomes part of the context of any further search continuing from this node. These new nodes are inserted into the open list.

As the next step, the best node is selected from the open list and examined; if it is not a complete solution (i.e. a solution found at the bottom level where all attributed have been negotiated and decided upon) then the node is expanded. This process is repeated until a complete solution is found. Evaluation function  $f(n) = w * g(n) + (1 - w) * h(n)$  is used to evaluate each node  $n$ , where  $w$  is a parameter with a

value between 0 and 1 and  $g(n)$  represents the achieved utility of node  $n$ . In our negotiation search, it is the preference value of the current context of node  $n$ , which measures the sum of weights of all constraints all already considered and satisfied by the context.  $h(n)$  is the heuristic function to estimate the expect utility that may be achieved with the current context. It is a challenge to develop a good  $h$  function. We have considered the following two approaches:

- $h_a(n)$  is the sum of weights of all un-evaluated constraints that potentially can be satisfied when extends the context  $CCG$  in node  $n$ . It requires additional computational cost to evaluate all constraints below current level.
- $h_b(n)$  is the sum of weights of all un-evaluated constraints. It's easy to obtain but not very informative.

Using the aforementioned function, we implement an anytime search procedure for the mediator, as follows:

1. Using  $w = 1$ , meaning  $f(n) = w * g(n)$ , the mediator conducts a greedy search until a first solution  $S_1$  is found.
2. Update  $w$ ,  $w = 0.5$ .
3. Using the solution quality of  $S_1$ ,  $g(S_1)$ , to prune the open list, removing all nodes with  $f^*(n) = 0.5 * g(n) + 0.5 * h(n)$  less than  $g(S_1)$ .
4. Continue search until the termination condition is met. Adjust  $w$  depending on the size of open list and the search progress to direct the search in either deepening direction (finding a solution quicker) or broadening direction (find a better solution).

This anytime approach allows finding a solution quickly and then continue to find better solutions within available computational resources, which is very helpful for dealing with large-size negotiation problems.

## Problem Structure

The way that this hierarchical negotiation approach works is dependent on the problem structure. To better understand the influence of the input problem structure on the performance of this protocol, we defined five parameters to capture the topological and the interdependent characteristic of

Table 1: Scenario Characteristics

| name                    | min | max |
|-------------------------|-----|-----|
| # levels                | 2   | 8   |
| # attributes            | 50  | 100 |
| # constraints per agent | 250 | 500 |

the problem structure, which is modeled as a tree, where the parent-children relationship represents the decomposition of a component as sub-components:

1. *NumIssues*: number of issues (attributes) in the negotiation. Since all issues have the same domain (integers from 0 to 9), this parameter directly determines problem size. We generated scenarios with 50 and 100 issues.
2. *ShapeBias*: controls the shape of the tree. A bigger value of shape bias produces wider and shallower trees, a small value results in narrower and deeper trees. We generated two different types of trees according to *ShapeBias*, *narrow* (0) and *wide* (10).
3. *WeightBias*: controls how quickly constraint weights decrease with depth. It is assumed that the constraints at each level have different importance, the higher the *WeightBias* is, the more important the higher level constraints are. Two values 0.3 and 0.7 are used.
4. *ScopeProbs*: describes the issue dependency structure. It is expressed as relative frequency of having constraints with different scopes (e.g. involving issues at different levels). Two different settings were used in the current experiments:
  - *tight* = ((Component 80) (Sibling 10) (Child 10)). For all involved attributes of any constraint created, there is 80% probability that these attributes belong to the same component, 10% probability that they belong to sibling components and 10% probability that they belong to one component and its sub-components.
  - *loose* = ((Component 50) (Sibling 25) (Child 25)), where there is a higher chance to find constraints which involve attributes belonging to different components and at different levels.
5. *DimProbs*: describes the order dependency, expressed as the relative frequency of constraints with different number dimensions. Two settings were used in the current experiments:
  - *low* = ((1 50) (2 50)). Half of the constraints involve 1 attribute and the other half involve 1 attributes.
  - *high* = ((1 20) (2 20) (3 20) (4 20) (5 20)). There is equal chance (20% of probability) for a constraint to have 1, 2, 3, 4, or 5 attributes.

The above parameters describe the topological structure of the system tree, the interdependency between attributes, the complexity of the constraints and the relative importance of constraints at different levels. In the next Section, we study the influence of these parameters on the performance of the hierarchical negotiation mechanisms.

## Experimental Studies

Using the five parameters described in previous section with two different categories per parameter, 10 scenarios were generated for each setting, for a total of 320 different testing scenarios, with characteristics measured as in Table 1. For each negotiation scenario, we ran negotiations comparing three different approaches:

1. *Hierarchical Negotiation - Anytime (HNA)*. Negotiation is conducted using our hierarchical structured anytime search with

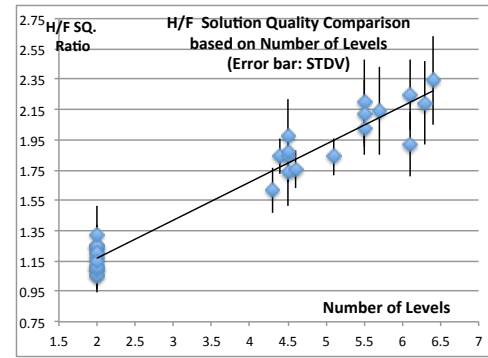


Figure 2: Solution Quality (SQ) Comparison of HNG and Flat based on System Levels;  $H/F\ SQ\ Ratio = HNG-SQ / Flat-SQ$ .

$T-Test(HNG-SQ, Flat-SQ) = 0.00$

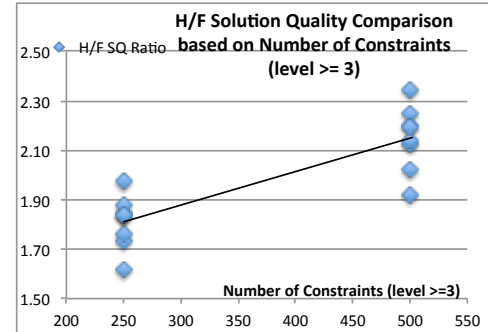


Figure 3: Solution Quality Comparison of HNG and Flat based on #Constraints

agenda management approach. Multiple solutions may be found within the given time limit and the best one is reported.

2. *Hierarchical Negotiation - Greedy (HNG)*. As above, negotiation is conducted taking advantage of the hierarchical structure, but the mediator conducts a greedy search, which terminates after one solution is found or a given search limit is reached.
3. *Flat Negotiation (Flat)*. All attributes and constraints are put into a single decision group for negotiation. The same heuristic bid generation mechanism based on MWIS with a very large bid limit value is used here, hence the Flat approach cannot guarantee finding the optimal solution. The usage of the same basic mechanism allows the focus on studying the impact of the structured negotiation agenda by comparing the hierarchical approach and traditional one-level approach. We have performed other experiments to evaluate the solution optimality.

The data below shows the results from running each of the three algorithms once on each of 320 scenarios. For each scenario, we record the solution found by each approach and the computational time spent on finding that solution. Each data point shows the average value of the results from 10 different scenarios generated with the same five parameter values. We did not perform large number of repetitions over the same scenario because our approach is primarily deterministic, the only randomness happens when choosing from bids or solutions with the exactly same preference values. We did two repetitions over each scenario and the result are very similar, so only one of them is presented here.

**Lesson 1 Learned:** *HNG finds better solutions compared to the Flat approach, and its advantage becomes more significant as #levels increases, supported by Figure 2. This is*

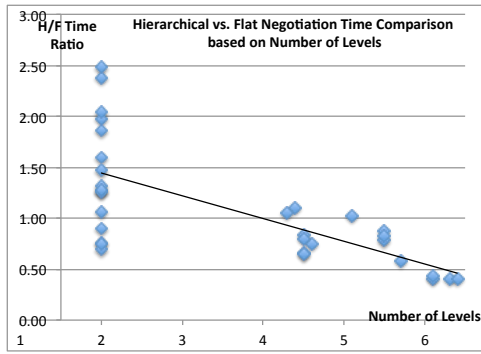


Figure 4: Computation Time Comparison of HNG and Flat

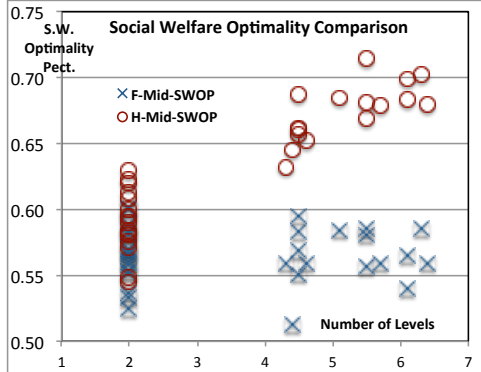


Figure 5: Social Welfare Optimality Percentage Comparison of HNG and Flat (Mid-Point Solution).  $T\text{-Test}(F\text{-Mid-SWOP}, H\text{-Mid-SWOP}) = 0.00$

coherent with our expectations, because the hierarchal approach exploits the system hierarchy structure while the flat approach does not.

**Lesson 2 Learned:** *HNG's advantage over Flat becomes considerably noteworthy as #constraints increases, considering scenarios with more than two levels, supported by Figure 3. WeightBias has much less impact over the algorithms' relative performances than #levels or #constraints. Data is not shown here due to space limitation.*

**Lesson 3 Learned:** *HNG is more efficient, it spends much less time than Flat negotiation as # levels increases, supported by Figure 4. These results show that our hierarchical negotiation approach greatly improves scalability with #levels and #constraints.*

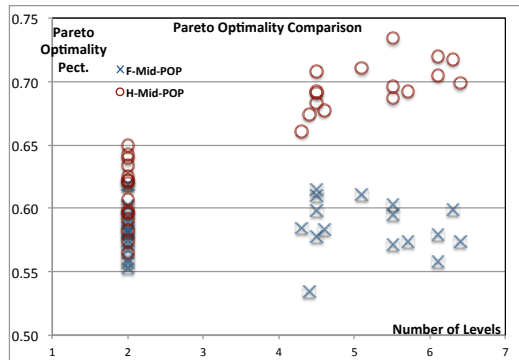


Figure 6: Pareto Optimality Percentage Comparison of HNG and Flat (Mid-Point Solution)  $T\text{-Test}(F\text{-Mid-POP}, H\text{-Mid-POP}) = 0.00$

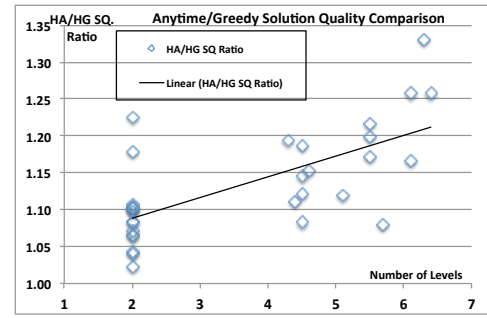


Figure 7: Solution Quality Comparison of HNA and HNG

To investigate the social welfare and Pareto optimality of this hierarchical approach, we used the benchmarking tools provided at Negowiki (Marsa-Maestre et al. 2011) to find the social welfare maximum and the Pareto front for each scenario we tested. We consider these findings are quite reliable because they have been cross verified by different non-linear negotiation mechanisms, and there is no computational limitation applied. Using these findings as benchmark, for each solution found by HNG or Flat approach, we compute its social welfare optimality percentage (SWOP) and Pareto optimality percentage (POP). In order to compute the SWOP and POP, the original range solutions found by HNG and Flat is converted to point solutions by selecting a middle value from each range (referred as mid-point solution).

**Lesson 4 Learned:** *The solutions found by HNG are superior than Flat both in social welfare optimality and Pareto optimality, and the advantage of HNG becomes more evident as #levels increases, supported by Figures 5 and 6.*

Finally, we compare the HNA approach and the HNG approach. HNA spends much more time (10 times on average) than HNG. Figure 7 shows that HNA (with the quicker heuristic function  $h_b(n)$ ) does find better solutions (by design), and the margin of gain seems also to increase as the number of levels increase. However, this margin of gain is not very significant, thus hardly justifying the remarkable extra time spend by HNA. We tested both  $h_a(n)$  and  $h_b(n)$  described in Section , neither one seems to be very effective.

**Lesson 5 Learned:** *In order to improve the performance of HNA, we need to develop more informative heuristics functions that can better predict the expected final quality of a partial solution. This is a very interesting direction for future research.*

## Conclusion and Future Work

In this paper we present a hierarchically structured negotiation search process with agenda management based on meta-negotiation. Different subsets of issues are negotiated at each level and the agreements made on the higher levels prunes the search space that has to be considered at lower levels. This approach shows promising results, significantly reducing the computational effort and the potential of finding better negotiation outcomes for complex problems with large number of interdependent attributes. We formally defined a set of parameters to capture the topological and the inter-dependent characteristic of the problem structure. We have

conducted extensive experimental work to study the impact of different scenario parameters on the performance of various negotiation algorithms, and investigated the Pareto efficiency and social welfare optimality using benchmark functions from Negowiki. There are a lot of important and interesting issues that need to be studied in the future, including: investigating the impact of negotiation agenda on negotiation performance, intelligently navigating in the hierarchical search space with better-informed and more efficient heuristic functions, improving the Pareto efficiency, fairness and incentive compatibility of this negotiation protocol, and exploring the possibilities for automatic system decomposition into a hierarchical structure.

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