# Managing Weighted Preferences with Constraints in Interactive Applications

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Abstract: Developing intelligent and interactive systems with visual user interfaces is essential for any website and mobile device. In this study, we propose a new web-based shopping system to elicit buyer's requirements and preferences and to provide a set of suggestions accordingly. This process is achieved by first representing the elicited information through graphical models and then solving the underlying constrained problem. More precisely, we have used the Weighted CP-nets (WCP-net) graphical model to allow the user to express fine-grained preferences on the product attributes and their values in a quantitative or a conditional qualitative form. The latter has been extended in this paper to include constraints between attributes. A backtrack search algorithm is then performed to solve the constrained WCP-net and to return a set of Pareto optimal solutions satisfying all the constraints and maximizing all the preferences.

## 1 INTRODUCTION

Nowadays, client preferences, such as web services (Santhanam et al., 2008; Brafman and Domshlak, 2009a), play a key role in customized artificial intelligence applications. Several online websites include some communication with customers to be able to comprehend and respond to their needs. When a client is enthusiastic about purchasing a new product, he will access the web to search for it. However, existing shopping sites offering clients new goods are still problematic. Clients may not be pleased if these sites are difficult to use as they do not want to deal with complications or spend too much time browsing through the sites. Corporations may not see this as a serious issue when designing shopping websites that are not user friendly. Additionally, the results produced by these websites do not usually meet the specifications of clients. To be successful, these applications should improve the consumer interaction. Increasing the satisfaction of users can be achieved by assist them in eliciting their preferences and requirements as done in matchmaking systems (Jiang and Sadaoui, 2012) and online auctions (Sadaoui and Shil, 2016). Furthermore, several of these websites are available in a restricted environment. While expressing his preferences for a laptop for example, the customer cannot select parts that are not compatible with each other. Hence, we should consider a scenario where both preferences and constraints co-exist together (Sadaoui and Shil, 2016). This has motivated us to develop an interactive shopping application that maximizes the user's desires while satisfying some requirements. This application is based on the Weighted CP-nets (WCP-net) graphical model that we extend to include constraints between attributes. A backtrack search algorithm is then performed to solve the constrained WCP-net and to return a set of Pareto optimal solutions satisfying all the constraints and maximizing all the preferences.

The rest of the paper is structured as follows. The following section provides a brief background about preferences and related graphical models as well as constraint satisfaction. Section 3 presents the extended model Weighted CP-nets. Section 4 describes our interactive shopping system based on Weighted CP-nets. Finally, Section 5 lists concluding remarks and future works.

## 2 BACKGROUND

Preference reasoning is an important subject in the area of artificial intelligence, computer science and finances (Walsh, 2007; Brafman and Domshlak, 2009b;



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Boutilier et al., 1999). Managing preferences is crucial in those applications where customers search for the best outcome meeting their requirements. Therefore, developing an application to manage constraints and preferences is necessary in the decision making process (Walsh, 2007; Chevaleyre et al., 2008; Rossi, 2005). Nevertheless, there are lots of challenges when reasoning is conducted, especially when constraints and preferences co-exit together (Brafman and Domshlak, 2009b; Rossi, 2005). Preferences exist in various forms: qualitative conditional and quantitative. Quantitative preferences are called cardinal or soft constraints while qualitative preferences are called ordinal and often include conditional preferences. Many models have been proposed to handle these types of preferences.

A Constraint Satisfaction Problem (CSP) is a well-known framework for solving constraint problems (Dechter, 2003). The CSP includes a set of variables, each one is defined on a discrete domain of values, and a set of constraints restricting the values that the variables can simultaneously take (Dechter, 2003). A solution to a CSP is a complete assignment of values to variables such that all constraints are satisfied (Dechter, 2003).

A Conditional Preference Network (CP-net) is a graphical model for representing qualitative and conditional preferences (Boutilier et al., 2004; Brafman and Dimopoulos, 2003). Nodes represent variables or attributes, and arcs the conditional preferences (Boutilier et al., 2004; Brafman and Dimopoulos, 2003). The CP-net expresses conditional qualitative statements; for example, I prefer Pepsi more than orange juice when the main dish includes red meat (Boutilier et al., 2004; Brafman and Dimopoulos, 2003).

WCP-nets is a weighted extension to CP-nets allowing users to state their preferences in a fine-grained way (Wang et al., 2012). More precisely, user's preferences can be defined at different scales (Wang et al., 2012; Xu et al., 2009). Here, the significance relation (weight) among attributes can be expressed by showing the range in which an attribute is more significant than another (Wang et al., 2012; Xu et al., 2009).

# 3 MANAGING WEIGHTED PREFERENCES WITH CONSTRAINTS

## 3.1 Problem Statement

We consider the problem where the qualitative preferences come with weights corresponding to their degree of importance. More precisely, the problem is defined as follows: a multivalued domain over a set of $n$ variables $V = \{V_1, V_2, \ldots, V_n\}$. Each variable $V_i$ is associated with a set of possible values $dom(V_i) = \{v^i_1, v^i_2, \ldots, v^i_{m_i}\}$. The set of variables $V$ is the result of combining two disjoint sets $V = V_{Qual} \cup V_{Quan}$. $V_{Qual}$ is the set of variables that represent the Weighted CP-net while $V_{Quan}$ is the set where each variable $V_i \in V_{Quan}$ has a utility function $\mu(V_i)$ associated to it. A utility function for variable $V_i$ is a mapping from $dom(V_i)$ to $[1, 10]$. We also consider the presence of a set of constraints $\mathcal{C}$ over the variables in $V$. Consequently, a solution (i.e. mapping from $V$ to its domain) is feasible if and only if it satisfies all the constraints in $\mathcal{C}$. Thus, the problem can be viewed as a triple $\varphi = \langle \mathcal{N}, \mathcal{U}, \mathcal{C} \rangle$ where:

- $\mathcal{N}$ is a Weighted CP-net over a subset of variables $V_{Qual} \subset V$
- $\mathcal{U}$ is a set of utility functions over $V_{Quan} \subset V$
- and $\mathcal{C}$ is a set of constraints over $V$

Given $\varphi$, the aim is to find a set of solutions that are feasible according to $\mathcal{C}$ and optimized according to both $\mathcal{N}$ and $\mathcal{U}$. In other words, the goal is to look for the Pareto set of optimal solutions. A feasible solution is Pareto if it is not dominated by any other feasible solutions. The Pareto set is the set of all Pareto optimal solutions.

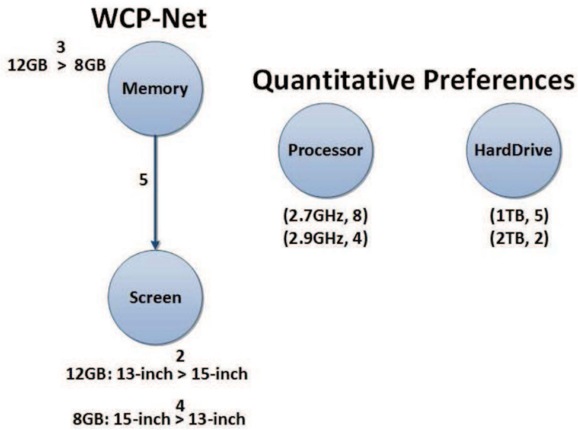


Figure 1: An Example of a WCP-net and Quantitative Preferences.

### 3.2 Solving Method

The proposed solving method is shown in Algorithms 1, 2 and 3. Algorithm 1 returns the Pareto set according to the CP-net (qualitative preferences) and the set of constraints. This is basically a backtrack search algorithm assigning variables sorted in a topological order. Once the Pareto set is obtained, 2 and 3 are then applied to determine weights to each optimal solution (based on the quantitative preferences) and to return an ordering of these solutions.

To better describe the solving method, let us consider the example depicted in Figure 1. The WCP-net is defined as a set of two variables (Memory and Screen), each with its own preference table. For the variable Memory, the client prefers 12 GB of memory three times more than 8 GB. For the screen variable, when the memory value is 12 GB, the client prefers a 13-inch screen two times more than a 15-inch. For a memory of 8 GB, the client prefers a 15-inch screen four times more than a 13-inch. The relation and level among attributes can be clearly defined as well. For instance, the variable memory (parent) is preferred five times more than the variable screen (child). Quantitative preferences are defined as a set of two variables (Processor and HardDrive), each one with its preference table. For the variable Processor, the client has a preference for a 2.7 GHz processing speed at a value level of 8 and a 2.9 GHz speed at a value level of 4. For the HardDrive variable, the client shows a value level of 5 for a 1TB and a value level of 2 for a 2TB. We will show through the following equations how to compute the weighted values of the qualitative data represented as a WCP-net for the two variables Memory and Screen in order to sum those weights with the values level of the quantitative preferences. WM and WS represent the weights for variables Memory and Screen respectively.

$$\mathrm{WM} + \mathrm{WS} = 1 \tag{1}$$

$$\mathrm{WM} + \mathrm{WS} = 5\mathrm{WS} + \mathrm{WS} = 6\mathrm{WS} = 1 \tag{2}$$

$$\mathrm{WS} = 0.16 \tag{3}$$

$$\mathrm{WM} = 0.84 \tag{4}$$

$$(12GB, 13-inch) = (0 \times 0.84) + (0 \times 0.16) = 0 \tag{5}$$

$$(12GB, 15-inch) = (0 \times 0.84) + (2 \times 0.16) = 0.32 \tag{6}$$

$$(8GB, 13-inch) = (3 \times 0.84) + (4 \times 0.16) = 3.16 \tag{7}$$

$$(8GB, 15-inch) = (3 \times 0.84) + (0 \times 0.16) = 2.52 \tag{8}$$

The best outcome has less weight according to the WCP-net and the quantitative preferences (12 GB, 13-inch, 2.9 GHz, 2 TB) = (0+4+2) = 6. The worst outcome has a high weight (8 GB, 13-inch, 2.7 GHz, 1 TB) = (3.16 + 8 + 5) =16.16. It is assumed that there are two hard constraints, a global constraint being the client's budget, and a local constraint being the available attributes such as speed, screen size and hard drive capacity. The maximum price and local constraints can be expressed as incompatible tuples among different components of the product such as laptop. As an example, the two component (12 GB, 15-inch) and (2.7 GHz, 2 TB) are incompatible. Therefore any tuple in the optimal solution with those components will not be listed as a set of optimal solutions because they do not satisfy the local constraints. Once the set of qualitative data with a weighted extension to CP-nets along with quantitative preferences is obtained, the list of optimal solutions has to satisfy the hard constraints. For example, tuple (12 GB, 13-inch, 2.9 GHz, 2 TB) satisfies the local constraints.

Algorithm 1: WPrefC method - finding Pareto set.

**Input**: CP-net $\mathcal{N}$ and a set of constraints $\mathcal{C}$
**Output**: The Pareto Set $\mathcal{S}$ (initially empty)
1. let $>$ be topological ordering over $\mathcal{N}$
2. let $T$ be a stack
3. push $\{\}$ into $T$
4. while (T is not empty)
5. $n \leftarrow$ pop first element
6. if ($n$ is complete assignment)
7. if ($n$ is not dominated by any element in $\mathcal{S}$)
8. add $n$ to $\mathcal{S}$
9. else
10. for every value $v_i$ of next variable $V_i$ w. r. t. $>$
11. if ($n \cup (V_i, v_i)$ is consistent with $\mathcal{C}$)
12. push $n \cup (V_i, v_i)$ into $T$
13. Return $\mathcal{S}$

## 4 SYSTEM DESCRIPTION

Our online shopping system has been developed using the following software:

1. Programming environment: Microsoft Visual Studio 2013 (ASP.NET - C Sharp).
2. Programming languages: Visual C Sharp 2012/2013 (ASP.NET MVC 5 Web Application), HTML and JavaScript.

Algorithm 2: WPrefC method - assigning weights to all tuples of the CP-Net.

**Input**: Pareto Solutions $\mathcal{S}$
**Output**: Ordering and assigning weights to CP-Net tuples $>_{WPrefC}$ over $\mathcal{S}$
1. let $>_{WPrefC} \leftarrow \{\}$
2. for every two elements $s_i, s_j \in \mathcal{S}$
3. for $k = 1$ to $|V|$
4. if $V_k(s_i)$ is equally preferred to $V_k(s_j)$
5. $(s_i, s_j) = 1$ and add $(s_i, s_j)$ to $>_{WPrefC}$
6. else
7. if $V_k(s_i)$ is mildly preferred to $V_k(s_j)$
7. $(s_i, s_j) = 2$ and add $(s_i, s_j)$ to $>_{WPrefC}$
8. else
8. if $V_k(s_i)$ is strongly preferred to $V_k(s_j)$
9. $(s_i, s_j) = 3$ and add $(s_i, s_j)$ to $>_{WPrefC}$
10. else
8. if $V_k(s_i)$ is very strongly preferred to $V_k(s_j)$
11. $(s_i, s_j) = 4$ and add $(s_i, s_j)$ to $>_{WPrefC}$
12. else
8. $V_k(s_i)$ is extremely preferred to $V_k(s_j)$
13. $(s_i, s_j) = 5$ and add $(s_i, s_j)$ to $>_{WPrefC}$
14. if $V_k(s_i) \neq V_k(s_j)$
15. if $V_k(s_i)$ is better than $V_k(s_j)$
16. add $(s_i, s_j)$ to $>_{WPrefC}$
17. else
18. add $(s_j, s_i)$ to $>_{WPrefC}$
19. Return $>_{WPrefC}$

Algorithm 3: WPrefC method - combining qualitative and quantitative.

**Input**: $f^1$ and $f^2$ mapping functions, constraints $\mathcal{C}$
**Output**: A set of ranked feasible solutions $\mathcal{S}$
1. $\mathcal{S} \leftarrow \emptyset$
2. while $(O_{Qual} \neq \emptyset)$
3. $o_1 \leftarrow \min(f^1(O_{Qual}))$
4. $copy \leftarrow Q_{Quan}$
5. while $(copy \neq \emptyset)$
6. $o_2 \leftarrow \min(f^2(copy))$
7. if $(o_1 \times o_2$ consistent with $\mathcal{C})$
8. add $o_1 \times o_2$ to $\mathcal{S}$
9. remove $o_2$ from $copy$
10. remove $o_1$ from $O_{Qual}$
11. Return $\mathcal{S}$

3. Operating system: Web Hosting under Windows 7 and supporting .NET Runtime Version (ASP.NET 4.5) and PHP Runtime Version (PHP 5.4).
4. Database: SQL Server Database 2012.

The architecture of our e-shopping system follows the 3-layer style as depicted in Figure 2. The graphic user interface allows clients to register and sign in in

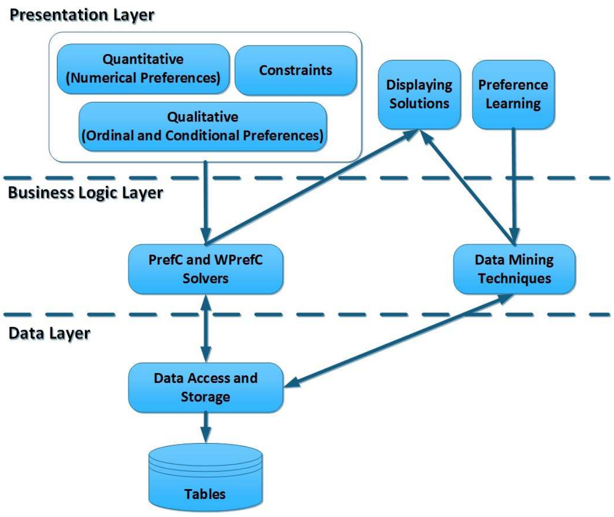


Figure 2: Software Architecture.

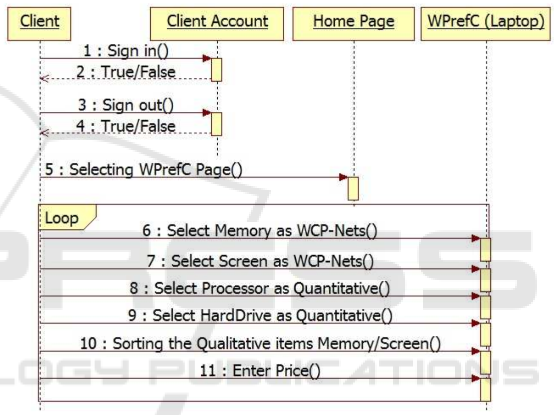


Figure 3: Sequence Diagram.

order to use the system features and also takes care of the constraint and preference elicitation phase. The business logic layer implements the WPrefC solver. The database layer takes care of the information storage and retrieval. Figure 3 illustrates the interactions among the different components of our system when purchasing a laptop. Clients first select the WPrefC page in order to express their quantitative and qualitative preferences for the product.

Figure 4 shows the Graphic user interface of our Online Shopping System.

## 5 CONCLUSION

We proposed in this paper an online shopping system based on WPrefC technique - Weighted Preferences with Constraints for interactive applications that lets the clients elicit their requirements when buying a product online. WPrefC technique was introduced in order to resolve the issues of CP-nets and to al-

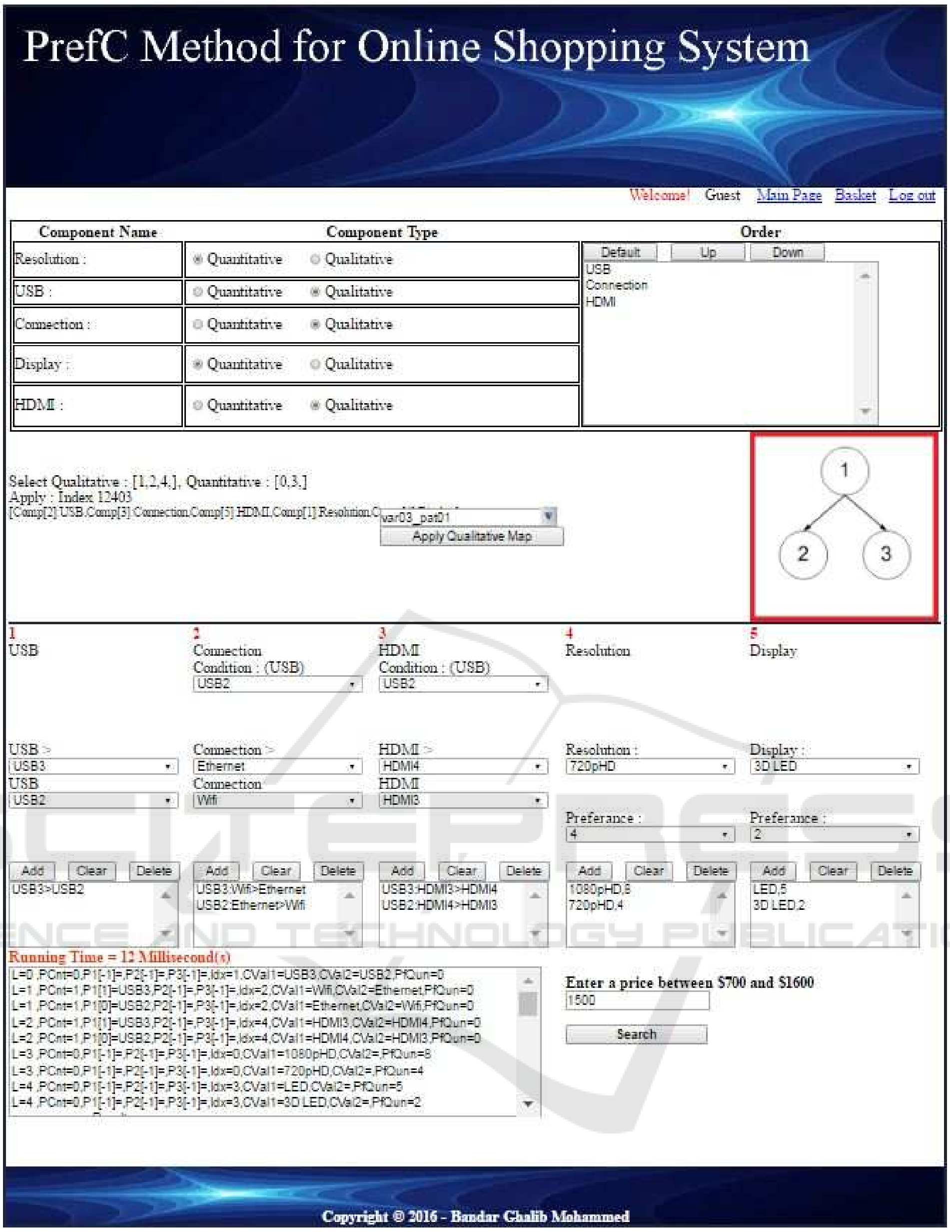


Figure 4: GUI of our Online Shopping System.



low users to state their preferences in a fine-grained way (Wang et al., 2012). Clients are able to express their preferences either numerically (quantitative) or ordinaly (qualitative), and then the system will display a list of optimal solutions by meeting the clients' needs and satisfying the constraints.

For future work, we would like to manage preferences along with dynamic hard constraints where the client is able either to add or delete some hard constraints and notice the influence of those changes on the outcomes. Another research direction is to combine quantitative preferences and qualitative preferences into one solver/algorithm rather than solving quantitative preferences and qualitative preferences separately along with hard constraints.

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