An Intuitive and Formal Description of Preferences for Semantic Web Service Discovery and Ranking

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Abstract
Preference modeling constitutes an essential component for the execution of Semantic Web Service (SWS) discovery and, especially, ranking processes, providing facilities to define user requests and preferences. In this technical report we describe our proposed preference model, introducing in Section 1 the existing challenges on this topic that motivates our research work. Section 2 presents an abstract upper ontology to define both services and user requests, that serves as a common model to make our proposal independent from concrete SWS frameworks. Then, Section 3 further describes, both intuitively and formally, our preference model and its facilities to define preferences within a user request. Finally, we sum up the main characteristics of our solution to model preferences for discovery and ranking in Section 4 discussing its fulfillment degree with respect to our identified challenges on preference modeling.
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1 Introduction

SWS definition frameworks provide comprehensive tools to describe services and their interactions. Although they offer facilities to also state user requests, preferences cannot be described at the same detail level, i.e. users cannot define complex desires for a concrete service request. For instance, Web Service Modeling Ontology (WSMO) user requests, denoted by goals [12], only support the description of requirements about a request in the form of capabilities and interfaces. In turn, preferences to rank services fulfilling those requirements cannot be directly expressed by using a standard WSMO goal definition, which only provides means to define non-functional properties / values pairs. In other words, preferences are not considered first-class citizens in WSMO, in comparison to service capabilities, whose definitions are more expressive. Other frameworks, such as OWL Ontology of Services (OWL-S) [10] or Semantic Annotations for WSDL and XML Schema (SAWSDL) [3], do not even define a specific model to describe user requests at all.

Discovery and ranking proposals try to fill this gap, extending SWS frameworks to support preferences definition [14, 15], or just providing separate user preferences descriptions [11, 9], using different formalisms. Consequently, these formalisms actually determine the level of expressiveness of each proposal, while resulting in a high dependence between user preferences definition and its corresponding discovery and ranking implementations.

In order to overcome these identified challenges in current proposals, we present in this technical report the Semantic Ontology of User Preferences (SOUP), which is a highly expressive, intuitive model of user preferences. This proposal adapts a well-known model designed for database systems [8] that allows to define preferences constructively and user-friendly. Starting from an abstract model that defines both service, user requests and preferences description at the same semantic level, next sections describe our model in detail, also introducing elements that conform the foundations of other proposals on improving discovery [6] and ranking integration [4]. Additionally, in [5] we presented an early version of this model and a thorough validation that consists on the complete definition of a discovery scenario from the SWS Challenge[8]. Particularly, we validated our model using the Logistics Management scenario, that contains several service descriptions and user requests contextualized in a transportation and logistics domain. In the following we use concepts from these domains to illustrate the different facilities provided by our model to define preferences.

2 An Abstract Upper Ontology of Services

As discussed before, service descriptions, user requests and preferences should be semantically described at the same detail level. Therefore, there is a need for the definition of an ontological model that leverages preference descriptions as first-class citizens in the discovery and ranking scenario. Moreover, this model has to provide intuitive and user-friendly facilities to easily define both requirements and preferences, so that service descriptions can be matched with user requests. Furthermore, these facilities have to conform a sufficiently expressive model so that a user can fully describe any preference, without being limited by a concrete formalism or representation.

In order to specify a preference model, firstly we need to establish a clear separation between requirements that have to be met, and preferences that have to be taken into account once requirements have been fulfilled. Typically, requirements are hard constraints that are used to filter service repositories in the discovery process, while preferences are used to rank previously discovered services so that the most appropriate service can be selected after the ranking process. Therefore, preferences define a strict partial order in our model, providing a framework to compare and rank a set of services.

Figure 1 shows the upper ontology of SOUP, which is represented using a UML-based notation for Ontology Web Language (OWL) ontologies [1] that we also use throughout the rest of this report. UserRequest and ServiceDescription are the root concepts in our proposal. On the one hand, a ServiceDescription describes features provided by the service itself, using the hasFeature object property to link corresponding terms about functionality, non-functional property (NFP), input and output parameters, among others. Listing 1 shows an excerpt of an abstract service description from the logistics scenario using our upper ontology, where some of the functional and NFP terms of service :ws1 are defined. Its graphical representation is also depicted in Figure 2 where namespaces are omitted for the sake of clarity.

Listing 1: Example of an abstract service description

```plaintext
:ws1 a soup:ServiceDescription;
  soup:hasFeature :transOrder, :basePrice. # among others...

:transOrder a soup:FunctionalTerm;
  soup:refersTo logistics:TransportOrder.
:basePrice a soup:NonFunctionalTerm;
  soup:refersTo logistics:BasePrice.
```

On the other hand, a UserRequest is the materialization of user desires with respect to a particular service request. These desires are described using requirements and preference terms, which are linked with the particular UserRequest instance using respectively hasRequirement and hasPreference object properties. Terms related with requirements state hard constraints that have to be fulfilled in order to consider a certain service as a matching candidate with respect to the user request. For instance, users searching for services usually interpret functionality, service classification terms, input and output parameters, among others, as requirements on their desired service. In turn, preferences can be considered as soft constraints whose degree
of fulfillment determine to what extent a candidate service is preferred against other candidate services that also fulfill the user requirements. In other words, ranking mechanisms evaluate preference terms in order to obtain the best candidate service with respect to a user request.

An example of a user request :goalD1 defined within the SWS Challenge logistics scenario is showcased in Listing 2 along with its graphical representation in Figure 3. This request comprises a complex functional requirement term, which may contain pickup and delivery time among other information regarding the transportation of clothes, and a preference term referring to the base price.

Listing 2: Example of an abstract user request

```prolog
:goalD1 a soup:UserRequest;
soup:hasRequirement :clothesOrder;
soup:hasPreference :lowestPrice.
:clothesOrder a soup:FunctionalTerm;
soup:refersTo logistics:TransportOrder.
:lowestPrice a soup:PreferenceTerm;
soup:refersTo logistics:BasePrice.
```

Both requirements and preferences are related with one or more DomainConcept classes, which are referred inside each term, and explicitly stated using the refersTo object property. Domain concepts usually represent service properties related to the domain-specific ontology used for service description, such as functional classification, input and output parameters types, process description, behavioral parameters, and non-functional properties, with the latter being specially important for preference terms definition. The above examples contains some logistics concepts such as a transport order and the base price for shipping.

Both functional and non-functional requirements specification has been widely discussed in the literature \[13\], and SWS frameworks provide sufficiently expressive facilities to define them, so in the following we will focus on preference modeling. Moreover, the validation scenario
3 SOUP: Defining an Ontology of User Preferences

Concerning preference terms, Figure 4 presents the middle ontology of SOUP, where we differentiate atomic preferences from composite ones. Thus, a PreferenceTerm can be an Atomic Preference, or a composition of two preference terms by applying a Composite Preference. On the one hand, atomic preferences are those which refers to a single domain concept, and can describe either a qualitative or a quantitative preference that users may have with respect to the referred service concept. On the other hand, composite preferences relate different preferences between them, so that a complex preference can be described using the hasOperands to associate a composite preference with its components.

As a preference is always related to some domain concepts, it can be intuitively expressed as “I prefer y rather than x”, where x and y are instances of those concepts. This relationship between concept instances can be mathematically interpreted as a strict partial order. Therefore, we define a preference in general as:

**Definition 1 (Preference)** Let $C$ be a non-empty set of domain concepts, and $\text{dom}(C)$ the set of all possible instances of those concepts. We define a preference as $P = (C, <^P)$, where $<^P \subseteq \text{dom}(C) \times \text{dom}(C)$ is a strict partial order (irreflexive, transitive and asymmetric), and if $x, y \in \text{dom}(C)$, then $x <^P y$ is interpreted as “I prefer y rather than x”.

If we consider a finite set of concept instance pairs $(x, y) \in <^P$, $P$ can be represented as a directed acyclic graph, also known as Hasse diagrams [2], where each node corresponds to

Figure 4: Middle ontology of preferences

described in [5] consists on a series of user requests whose requirement terms can be simply considered as property/property value pairs, so it is not necessary to define a complex hierarchy of functional terms in order to validate the upper ontology. Nevertheless, concrete applications may extend our upper ontology adding specialized terms in order to achieve a better integration with their discovery and ranking mechanisms, as in the case of our filtered discovery solution presented in [6].
3.1 Qualitative atomic preferences

The first group of preferences that we present in the following corresponds to the qualitative and atomic constructs, which means that every preference \( P = (C, <^P) \) that belongs to this kind refers to a single domain concept that represents a non-numerical service property, i.e. \( |C| = 1 \).

Figure 5 shows the available hierarchy of preference terms belonging to this group. Note that different terms use specific object properties to associate their operands to values from the referred domain concept, depending on the semantics of each preference construct. In each example, *italics* text correspond to service property values or instances used as operands, while *typewriter* text are used to denote domain concept classes that represents those properties.
Definition 2 (FavoritesPreference) Let $FAV \subseteq \text{dom}(C)$ be a non-empty, finite set of preferred values for property $C$, and $x, y \in \text{dom}(C)$ property values from two services. $P_{FAV} = (C, \prec^{FAV})$ is a FavoritesPreference iff

$$x \prec^{FAV} y \iff x \notin FAV \land y \in FAV$$

A favorites preference defines a finite set of property values that constitute the desired values of the referred service property. Thus, services whose value for that property is a member of the favorite set are preferred to services that provide any other values from the property domain. An instance of this preference constructor has many operands as the cardinality of the favorite values set, associated using the favors object property.

**Example:** I prefer services that provide carriageForward as a possible PaymentMethod.

Definition 3 (DislikesPreference) Let $DIS \subseteq \text{dom}(C)$ be a non-empty, finite set of disliked values for property $C$, and $x, y \in \text{dom}(C)$ property values from two services. $P_{DIS} = (C, \prec^{DIS})$ is a DislikesPreference iff

$$x \prec^{DIS} y \iff y \notin DIS \land x \in DIS$$

As opposite to FavoritesPreference, a dislikes preference defines a set of property values that the service should not provide for the referred property in order to be preferred to another service whose property values coincide with any of the values in the associated dislikes set. In this case, operands are linked to the term via the disfavors object property.

**Example:** I prefer SWSs that do not offer refundForDamage as an available Insurance option.

Definition 4 (FavoritesAlternativePreference) Let $FAV \subseteq \text{dom}(C)$ and $ALT \subseteq \text{dom}(C)$ be two non-empty, finite sets of preferred values for property $C$, and $x, y \in \text{dom}(C)$ property values from two services. $P_{FAV,ALT} = (C, \prec^{FAV,ALT})$ is a FavoritesAlternativePreference iff

$$x \prec^{FAV,ALT} y \iff (x \in ALT \land y \in FAV) \lor (x \notin FAV \land x \notin ALT \land y \in ALT) \lor (x \notin FAV \land x \notin ALT \land y \in FAV)$$

A favorites or alternative preference is an extension of FavoritesPreference, where there are two favorite sets. The second set is called alternative set, and links their values with the altFavors object property. In this case, services whose property values are in the favorite set are the most preferred. Otherwise their values should be on the alternative set. If this is not the case either, then the corresponding services will be undesirable, because their property values are not member of any of the two sets. Note that favors property is inherited because of the subclass relationship between FavoritesPreference and FavoritesAlternativePreference.

**Example:** I prefer SWSs whose PaymentMethod is carriagePaid, but if that is infeasible, then it should be carriageForward.
Definition 5 (FavoritesDislikesPreference) Let $FAV \subseteq \text{dom}(C)$ and $DIS \subseteq \text{dom}(C)$ be two non-empty, finite sets of preferred and disliked values for property $C$, and $x, y \in \text{dom}(C)$ property values from two services. $P_{FAV,DIS} = (C, <_{FAV,DIS})$ is a FavoritesDislikesPreference iff

$$x <_{FAV,DIS} y \iff (x \in DIS \land y \notin FAV) \lor (x \notin DIS \land x \notin FAV \land y \in FAV)$$

It is also possible to combine a FavoritesPreference with a DislikesPreference in the following form: a given service property should have a value on the defined favorite set. Otherwise, values should not belong to the dislike set. If none of these two conditions hold, then the service will be less preferred than others fulfilling the first or the second condition. Again, subclass relationships bring both favors and disfavors object properties to this preference term.

Example: I prefer SWSs that provide refundForLoss as an option for Insurance, but if that is infeasible, then it should not be refundForDamage.

Definition 6 (ExplicitPreference) Let $G = \{(v_1, v_2), \ldots\}$ be a non-empty, finite directed acyclic graph that represents “better-than” relationships between its nodes $v_i \in \text{dom}(C)$ corresponding to values of property $C$, and $V$ be the set of nodes belonging to $G$. Then, a strict partial order $E = (V, <_E)$ is induced as follows:

\begin{enumerate}
  \item $a) (v_i, v_j) \in G \implies v_i <_E v_j$
  \item $b) v_i <_E v_j \land v_j <_E v_k \implies v_i <_E v_k$
\end{enumerate}

Therefore, given $x, y \in \text{dom}(C)$ property values from two services, $P_E = (C, <_E)$ is an ExplicitPreference iff:

$$x <_E y \iff x <_E y \lor (x \notin V \land y \in V)$$

An explicit preference can be used to explicitly represent the strict partial order between a pair of property values. Thus, a directed acyclic graph comprising better-than relationships can be defined using several explicit preferences. In this case, prefersMore denote the value that is considered better than the prefersLess value.

Example: SWSs that provide carriageForward as a possible value for the PaymentMethod are more preferred than those that provide the carriagePaid value.

3.2 Quantitative atomic preferences

When the referred domain concept of an atomic preference is a numerical property, the quantitative constructs shown in Figure 6 may be used to express user preferences on that single property. Therefore, $\text{dom}(C)$ values are numbers that support the total order operator $<$ and the subtraction $-$. 
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Figure 6: Quantitative atomic preference terms hierarchy

**Definition 7 (LowestPreference)** Let \( x, y \in \text{dom}(C) \) be values for property \( C \) from two services. \( \mathcal{P}_L = (C, <^{P_L}) \) is a **LowestPreference** iff:

\[
x <^{P_L} y \iff x > y
\]

A **lowest preference** does not have any operand, but prefer services whose property values are as low as possible for the referred service property.

**Example:** I prefer SWSs that provide a **BasePrice** as low as possible.

**Definition 8 (HighestPreference)** Let \( x, y \in \text{dom}(C) \) be values for property \( C \) from two services. \( \mathcal{P}_H = (C, <^{P_H}) \) is a **HighestPreference** iff:

\[
x <^{P_H} y \iff x < y
\]

In opposition to the last constructor, a **highest preference** is used when property values should be as high as possible.

**Example:** I prefer SWSs that provide a **PaymentDeadline** as long as possible.

**Definition 9 (AroundPreference)** Let \( z \in \text{dom}(C) \) be the most preferred value of \( C \). For all values \( v \in \text{dom}(C) \) we define:

\[
dist(v, z) = |v - z|
\]

Then, given \( x, y \in \text{dom}(C) \) property values from two services, \( \mathcal{P}_z = (C, <^{P_z}) \) is an **AroundPreference** iff:

\[
x <^{P_z} y \iff \text{dist}(x, z) > \text{dist}(y, z)
\]
An *around preference* determines which property value is better by determining the distance of each values to a concrete value provided as an operand of this preference term using the `hasValue` object property. Thus, services which provide exactly that value are preferred to the rest of them. If this is infeasible, services with closer values to the operand are preferred.

**Example:** I prefer SWSs that provide a `BasePrice` closer to 180 Euros.

**Definition 10 (BetweenPreference)** Let `[low, up] ∈ \text{dom}(C) × \text{dom}(C)` be the preferred values interval of `C`. For all values `v ∈ \text{dom}(C)` we define:

\[
dist(v, [low, up]) = \begin{cases} 
0 & \text{if } v \in [low, up] \\
low - v & \text{if } v < low \\
v - up & \text{if } v > up
\end{cases}
\]

In this case, given `x, y ∈ \text{dom}(C)` property values from two services, `P_{[low,up]} = (C, <^{P_{[low,up]}})` is a *BetweenPreference* iff:

\[x <^{P_{[low,up]}} y \iff \text{dist}(x, [low, up]) > \text{dist}(y, [low, up])\]

In this case, a service should have values for the referred property between a range that are defined as operands in the preference (using `hasLowerBound` and `hasUpperBound` to actually define range bounds). If this is not the case, *between preferences* prefer services closer to the interval boundaries, computing the distance as in around preferences.

**Example:** I prefer SWSs that provide a `PaymentDeadline` within the interval of `[45, 60]` days.

**Definition 11 (ScorePreference)** Let `f : \text{dom}(C) → \mathbb{R}` be a scoring function and `<` the usual less-than order in \(\mathbb{R}\). `P_f = (C, <^{P_f})` is a *ScorePreference* iff for `x, y ∈ \text{dom}(C)`:  

\[x <^{P_f} y \iff f(x) < f(y)\]

A *score preference* basically defines a scoring function (i.e. a utility function like in \[7\], linked via `hasScoringFunction`) that takes a property value as its argument and returns a real value that can be interpreted in the following form: the higher the value returned by the function is, the more preferred the property value entered as the argument. Note that this kind of preference is not as intuitive as the rest, but it is still useful when a user wants to express complex grades of preference, using for instance a piecewise function depending on the property values.

**Example:** I prefer SWSs with the highest score with respect to `Price PerKg`, where the scoring function is defined as:

\[f(\text{pricePerKg}) = \frac{-1}{50} \text{pricePerKg} + 1\]
3.3 Composite Preferences

The last group of preference constructs are used to compose two different preference terms by stating the preference relationship between each component term, which can be also a composite preference. Composite preferences refersto property associate the preference with the union of the properties referred by component preferences.

These complex constructors are defined in the following for two preferences, though they can be trivially generalized to a greater number of preferences. Consequently, our model does not initially restrict the number of preference terms that can be composed using composite preferences.

Definition 12 (BalancedPreference) Let $P_1 = (C_1, \prec_{P_1})$ and $P_2 = (C_2, \prec_{P_2})$ be two different preferences defined after $C_1$ and $C_2$ properties, and $x = (x_1, x_2)$, $y = (y_1, y_2) \in \text{dom}(C_1) \times \text{dom}(C_2)$ be two value tuples for each property. $P = (C_1 \cup C_2, \prec_{P_1 \otimes P_2})$ is a BalancedPreference iff:

$$x \prec_{P_1 \otimes P_2} y \iff (x_1 \prec_{P_1} y_1 \land (x_2 \prec_{P_2} y_2 \lor x_2 = y_2)) \lor (x_2 \prec_{P_2} y_2 \land (x_1 \prec_{P_1} y_1 \lor x_1 = y_1))$$

A balanced preference $P$ combines two preference terms $P_1$ and $P_2$ using the Pareto-optimality principle, which considers that $P_1$ and $P_2$ are equally important preferences. Thus, a service $SWS_1$ is better than another service $SWS_2$ with respect to $P$, if $SWS_1$ is better than $SWS_2$ with respect to $P_1$ and $SWS_1$ is not worse than $SWS_2$ with respect to $P_2$, and vice versa. Intuitively, this preference balance the fulfillment of each preference component, so that the composite preference is the average degree of preference taking both components into account.

Example: I prefer SWSs that best fit (with an average satisfaction) the following three (atomic) preferences: the lowest BasePrice, the PaymentDeadline within the interval of [45, 60] days, and provided Insurance options of refundForLoss or refundForDamage.

Definition 13 (PrioritizedPreference) Let $P_1 = (C_1, \prec_{P_1})$ and $P_2 = (C_2, \prec_{P_2})$ be two different preferences defined after $C_1$ and $C_2$ properties, and $x = (x_1, x_2)$, $y = (y_1, y_2) \in \text{dom}(C_1) \times \text{dom}(C_2)$ be two value tuples for each property. $P = (C_1 \cup C_2, \prec_{P_1 \otimes P_2})$ is a PrioritizedPreference iff:

$$x \prec_{P_1 \otimes P_2} y \iff (x_1 \prec_{P_1} y_1 \land (x_2 \prec_{P_2} y_2 \lor x_2 = y_2)) \lor (x_2 \prec_{P_2} y_2 \land (x_1 \prec_{P_1} y_1 \lor x_1 = y_1))$$
dom($C_2$) be two value tuples for each property. $\mathcal{P} = (C_1 \cup C_2, <^P_1 \& <^P_2)$ is a PrioritizedPreference iff:
\[ x <^{P_1 \& P_2} y \iff x_1 <^{P_1} y_1 \lor (x_1 = y_1 \land x_2 <^{P_2} y_2) \]

In the case of a prioritized preference $\mathcal{P}$ that compose two preference terms $\mathcal{P}_1$ and $\mathcal{P}_2$, $\mathcal{P}_1$ is considered more important than $\mathcal{P}_2$. Thus, $\mathcal{P}_2$ is evaluated only if $\mathcal{P}_1$ does not mind (i.e. service property values compared using $\mathcal{P}_1$ do not return enough information to rank those services). In this case, operands have to be evaluated in a specific order, so the hasOperands property should be properly specialized to account for operands ordering. For instance, the range of the property could be defined as an Resource Description Framework (RDF) list.

**Example:** I prefer SWSs that provide carriageForward as a possible PaymentMethod. In the case of equal satisfaction degree on that preference, I prefer SWSs whose BasePrice are closer to 180 Euros.

**Definition 14 (NumericalPreference)** Let $f$ and $g$ be two scoring functions that define score preferences $\mathcal{P}_f = (C_1, <^{P_f})$ and $\mathcal{P}_g = (C_2, <^{P_g})$, respectively, and $F: \mathbb{R} \times \mathbb{R} \to \mathbb{R}$ be a combining function. For $x = (x_1, x_2), y = (y_1, y_2) \in \text{dom}(C_1) \times \text{dom}(C_2)$, $\mathcal{P} = (C_1 \cup C_2, <^{\text{rank}_F(P_f, P_g)})$ is a NumericalPreference iff:
\[ x <^{\text{rank}_F(P_f, P_g)} y \iff F(f(x_1), g(x_2)) < F(f(y_1), g(y_2)) \]

Finally, a numerical preference is the combination of a number of score preferences using a function that takes the values returned by the score preferences as its arguments and returns another real number that gives information about the global preference, considering all the properties referred by concrete score preferences. Notice that component preferences must be score preferences in order to properly compose them using a combining function, which is associated with this term using the hasCombiningFunction object property.

**Example:** Provided that $f(\text{basePrice})$ and $g(\text{pricePerKg})$ are already defined and they range within the interval [0, 1], I prefer SWSs that have a higher combined score, where the combining function is defined as:
\[ F(\text{basePrice}, \text{pricePerKg}) = 0.8 \times f(\text{basePrice}) + 0.4 \times g(\text{pricePerKg}) \]

## 4 Conclusions

In this report, a highly expressive preference model for SWS discovery and ranking named SOUP is described. This model, specified as an ontology, represents a novel approach that leverages preference descriptions so that they become a first-class citizen in SWS frameworks. Additionally, SOUP has been validated using a complex discovery scenario from the SWS Challenge in order to prove the applicability of our solution to an actual discovery and ranking scenario [5]. The main benefits of our proposed model can be summarized as follows:

- **Expressiveness.** The model is sufficiently expressive to describe complex user desires about requested services, providing a comprehensive hierarchy of preference terms.
• **Intuitive semantics.** Based on a strict partial order interpretation of preferences, the model is user-friendly and machine-readable, so preferences may be automatically processed and inferred.

• **Qualitative and Quantitative.** Available constructs allow to express both qualitative and quantitative preferences, and even combine them in a general preference term.

• **Independence.** Our proposal is not coupled with a concrete SWS solution, neither with a discovery nor ranking mechanism, so it is not limited by the formalisms used to implement these mechanisms.

• **Extensibility.** Because the model is presented as an ontology, it can be further extended with new preference constructs with ease.

• **Applicability.** Our model can be implemented within any SWS framework, extending current proposals to leverage preference descriptions.

**References**


