Semantic Model and Architecture in Inframobility System

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Abstract: - This paper explores the development of an architecture and a model for building a service-oriented information mobility system, which enhances user service quality by utilizing open data and services in travel planning. We have developed a multimodal route planning method that distinguishes it from existing systems using fuzzy set theory, ontology management, context management, system analysis, privacy protection, search, and recommendation generation. This method can combine applications for local, regional, national, and international trips, utilizing public and private transportation.

Key-Words: - infrastructure, multiples theory, multimodality, ontology, travel planning, fuzzy systems.

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1 Introduction

Scientists have developed the concept of a pleasant living environment by analyzing the issues surrounding the development of road infrastructure. One of the traits is the capacity for comfortable mobility. Therefore, having a well-developed transportation system and accessible pedestrian infrastructure are crucial elements, [1]. We must thoroughly analyze all possible forms of transportation and the current road infrastructure to enhance the effectiveness of urban transport planning management. A city's size and features have a significant impact on the variety of transportation options it uses. The selection of transportation options is typically not a major issue for a small community. Individual modes of mobility, such as walking, bicycling, or driving, can satisfy the majority of city people's demands. Cities with a high population or low motorization levels must provide public transportation services. Therefore, only small cities with a high degree of motorization can deem an unimodal car-road system, augmented by pedestrian infrastructure, sufficient and effective, [2], [3], [4]. The necessity for public transportation, which has a large load capacity, grows as cities get bigger. Simultaneously, the overuse of limited territorial resources, negative externalities, and the usage of cars in urban areas give rise to a variety of issues. As a result, these communities ought to implement a well-rounded transportation system.

In order to improve users' mobility and convenience of movement both during trip planning and while traveling, this effort aims to develop a service-oriented info mobility system that gives users access to multimodal, dynamic, personalized information that is matched to context services. The system aims to provide users with knowledge derived from a conceptualization that describes a collection of items and ideas, as well as the knowledge and connections among them, through the processing and utilization of services as information sources. The principles that underpin the approach and derive from the requirements include the openness of data and services, the use of ontologies, distributed architecture, user orientation, contextual information use, self-contextualization of services, real-time operation, multimodality of routes, and user privacy. By adhering to these guidelines, the customer will receive high-quality services that will guarantee their mobility and meet the fundamental criteria.

Navitime, a mobile navigation service, is accessible in Japan, [5]. Through the integration of many transportation modes, including pedestrian routes, personal automobiles, trains, taxis, and airlines, Navitime offers customers route calculation and advisory services. By transforming it into four standard forms, Navitime aggregates mobility data from various data sources. The publicly accessible documentation does not specifically mention Navitime's compliance with current mobility information storage and exchange standards, [6], [7], [8].

The iTransit Integration Environment serves as the foundation for a multi-layered intelligent system architecture that combines modern and traditional intelligent transportation vehicles, [9]. A layered object data model serves as its foundation. The model provides a unified mechanism for requesting and processing data from heterogeneous transport networks, and it incorporates the geographical and temporal elements of traffic and transportation data. The global information layers also incorporate the area's geography and transportation system. Web services and CORBA technology serve as the foundation for data interchange among the systems that comprise the iTransit architecture.

In [10] describes the design ideas used to create China's passenger information system on highways. An environment that facilitates communication across dispersed heterogeneous systems is the goal of the HTIS architecture. The HTIS architecture prioritizes highway monitoring and control information over end-user-focused contextual components such as location and activity. We highlight the integration paradigm of distributed and heterogeneous information systems, which is based on multi-level architecture, common protocols, and data formats, [11].

In Norway, Arktrans serves as the setting for multimodal intelligent transportation systems, [12], [13]. In terms of standard functions and interfaces for communication between various transport systems, its goal is to establish a shared viewpoint on the transportation problem area for all modes of transportation (air, train, sea, and road). The system's primary function is to help users plan their trips; the navigation service integration is not yet complete.

As part of a collaborative initiative at the Vienna Research Center for Telecommunications, the local helper is a prototype UMTS guide. Lol is a location-based travel service that uses the OCA/Parlay and SIP (Session Initiation Protocol) protocols. It offers navigation services to visitors on preset routes. Lol employs a variety of locating techniques, including GPS, mobile network-based, and user-inputted manual location.

The primary drawback of the services mentioned is their insufficient geographic reach. While there are broad maps available everywhere, each location has a very different set of details and services offered. For instance, not all cities have a traffic schedule, not all available transportation is covered, and CIS and Asian users are unable to view many events on the map (just traffic is displayed). They process data for their own services semi-automatically, and both services depend on third-party services for additional information, [14], [15], [16], [17].

2 A Conceptual Model of Inframobile System

The architecture of an inframobility system must satisfy the following criteria in order to be developed: The architecture of an inframobility system must support a diverse variety of mobile devices, be scalable, incorporate new components that offer additional features, and are accessible to a broad user base, and allow for unrestricted interactivity. The system's development must incorporate ontology, which provides the following benefits: it enhances interoperability, reduces development complexity due to the variety of technologies used, and facilitates user engagement with computer systems. Services must be available via Bluetooth or wireless LAN, among other wireless technologies.

Using open data, an open information system that includes transportation services that give information based on the user's location (weather, attractions), information exchange mechanisms, and methods to guarantee semantic interoperability should be the main goals of the built system. This criterion also outlines the optimal use of a distributed architecture for coordinating service collaboration. This method makes support for a wide range of devices and information services feasible. Launching a new service adds new functionality without requiring a significant overhaul of the system. Additionally, we must plan routes that are compatible with various vehicles and individual means of transportation, and ensure a change in modes of transportation if necessary, [10].

We can specify preferences by building a user profile that captures the fundamental traits of the person. By utilizing smart spaces technology, it is possible to define a user profile in the form of an ontology.

The system must provide real-time information and assistance, which includes traffic data, prompt traffic jam detection, object search on a map, and current object operation information.

In order to offer the best assistance options for the user at any given time, the inframobility system must consider the present circumstances while it is operating. As an illustration, suggest items on the map based on the time of day (it is preferable to visit the park during bright weather and wait out the rain at the nearby cafe, which has received many favorable reviews) Figure 1 (Appendix).

In contrast to the centralized design, the distributed design imposes additional responsibilities related to user privacy protection. A centralized infrastructure has the benefit of processing all data in a single, independent setting. Establishing a secure channel enables the transmission of all processed data without ever leaving the environment. Unauthorized parties cannot access each user's personal information due to their segregation from the others. A distributed architecture requires the simultaneous sending and gathering of data for several services, some of which may come from a third party (e.g., gathering images of specified coordinates). We must further develop mechanisms to guarantee the users' personal protection in this regard.

3 Semantic Modeling of an Inframobile System

We define the agents and subjects of the model in the form of semantic networks (Figure 2). The diagram represents objects from the external environment: user and expert. The decision support system and the information system present the essence of each other, with a data link facilitating interaction with expert agents and the user. Table 1 includes a coding system that identifies the primary objects and their relationships within the model.

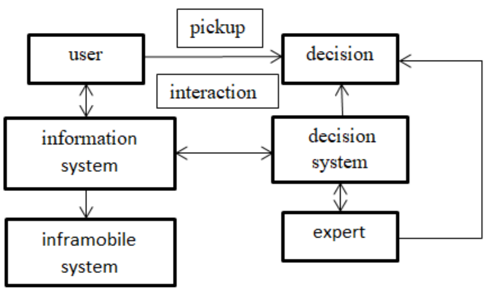

Fig. 2: Semantic model of the information system

Table 1. Coding system and relations

Substance	
User	U={u1, u2,…,un}
Inframobile system	IS={s1}
Decision system	DS={d1}
Expert	E={e1, e2,…,en}
Decision	D={o1, o2,…,on}
Transport	T={t1, t2,…, tn}
Predicate designation of connections in the semantic network	
accept	A(sop,dop)
interact	In(sop,dop)
contain	C(sop,dop)
save	Sv(sop,dop)
affect	If(sop,dop)
planning	P(sop,dop)
control	Ct{sop,dop)

Using tabular values, we can formalize the main tasks and axioms of the semantic model of the information system (IS), [18], [19], [20], [21]. User task:

$$\exists u_i \forall o_i P(u_i, o_i) \equiv \exists u_i In\big(u_i, In(s_1, e_1)\big) \wedge \exists o_i(s_1, o_1) \wedge \exists d_i A(u_1, d_1) \quad (1)$$

The predicate expression describes the task for the Expert object:

$$\exists t_i In(t_i, e_i) \equiv \exists d_i In(e_1, Sv(s_1, d_1)) \quad (2)$$

The following formula represents the accumulation of knowledge:

$$\exists o_i In(o_i, e_i) \equiv \exists d_i In(e_1, Sv(s_1, d_1)) \quad (3)$$

In order to specify the process of solving a certain problem, a set of formal axioms is introduced in (4), on which the logic of interaction between agents and model objects is built when searching for a solution:

$$\begin{cases} \exists u_i In(u_i, s_1) \wedge \forall o_i \exists u_i Sv(u_i, o_i) \rightarrow P(u_i, o_i) \\ \exists u_i In(u_i, e_1) \wedge \forall d_i \exists u_i A(u_i, d_i) \rightarrow If(u_i, d_i) \\ \exists t_i In(t_i, e_1) \wedge In(s_1, e_1) \rightarrow In(t_i, s_1) \\ \exists d_i C(d_i, e_1) \wedge \exists t_i C(o_i, s_1) \rightarrow If(o_1, d_i) \\ \exists d_i \exists t_i \forall u_i Ct(t_i, u_1) \equiv If(t_1, d_i) \end{cases} \quad (4)$$

The Moore automaton model describes an IC automaton model in the form of a graph and a direct table of transitions and outputs, [22], [23], [24], [25], [26]. The semantic model of IS defines the essence of a decision-making system and specifies its composition. To do this, we introduce a formal description of the semantic model (Figure 3).

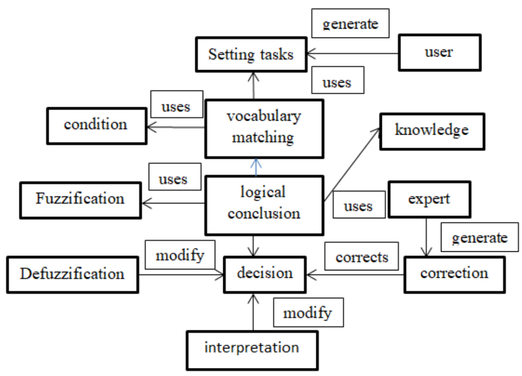

Fig. 3: Semantic model of the inframobile system

The "setting tasks," "vocabulary matching," and "condition" objects serve as agents in pairing the internal model and objects, thereby establishing a logical and meaningful connection between the external environment and the system. The objects "interpretation," "correction," and "decision" also represent this relationship. The objects of "logical conclusion," "knowledge," "fuzzification," and "decision" introduce the semantic basis of the model, [27], [28], [29], [30], [31]. Their main purpose is to establish a logical connection between all internal objects of the IS model and to provide a formal specification of the process of solving the assigned problems, [32], [33]. The object of defuzzification represents the process of bringing clarity to the result. For the semantic web, we introduce multi-instance notations for all entities and relationships.

Table 2. Coding objects and relations

Substance	Finite Set
User	$U=\{u_1, u_2,\dots,u_n\}$
Interpretation	$J=\{j_1, j_2,\dots,j_n\}$
Input conditions	$C=\{c_1, c_2,\dots,c_n\}$
Setting tasks	$S=\{s_1, s_2,\dots,s_n\}$
Expert	$E=\{e_1, e_2,\dots,e_n\}$
Decision	$D=\{d_1, d_2,\dots,d_n\}$
Vocabulary matching	$V=\{v_1, v_2,\dots,v_n\}$
Fuzzification	$F=\{f_1\}$
Logical conclusion	$L=\{l_1\}$
Defuzzification	$R=\{u_1\}$
Correction	$K=\{k_1, k_2,\dots,k_n\}$
Knowledge	$B=\{b_1, b_2,\dots,b_n\}$
Predicate designation of connections in the semantic network	
generate	Gr(sop,dop)
uses	Us(sop,dop)
modify	Md{sop,dop)
corrects	Ct(sop,dop)

We present the formal tasks of User and Expert, respectively, using the notations found in Table 2.

$$\forall u_i \exists d_i Gr(u_i, d_1) \equiv \exists v_i \exists s_i \exists b_i \exists c_i Us(l_i, Us(v_i, s_i) \wedge \quad Us(v_i, c_i)) \wedge Us(l_1, f_1) \wedge \exists b_i Us(l_1, b_1) \tag{5}$$

$$\exists e_i \exists b_i Ct(e_i, d_i) \equiv \exists e_i Gr(e_i, c_i) \wedge Ct(c_1, d_1) \tag{6}$$

To solve the tasks of the agents, we introduce a system of axioms that allows us to draw conclusions about goals (5) and (6):

$$\begin{cases} \exists u_i \exists s_i Gr(u_i, s_1) \rightarrow \\ \exists v_i Us(v_i, s_i) \wedge \exists v_i (s_i, c_i) \\ \exists d_i Gr(l_i, d_1) \rightarrow \exists b_i Us(l_i, b_i) \wedge Us(l_i, f_i) \\ \wedge \exists v_i Us(l_i, v_i) \wedge Us(d_i, r_i) \\ \forall k \exists e_i Gr(e_i, k_1) \rightarrow \exists d_i Ct(k_1, d_1) \\ \forall d_i \exists j_i Md(j_i, d_1) \end{cases} \tag{7}$$

System (7) demonstrates that the models' axioms serve as input for the relationships with entities and agents, which are essential for facilitating data exchange and control signals among the components of real systems. A Moore automaton describes the algorithmic model through a graph and a direct table of transitions. To describe the behavior of the semantic models in the work, a formal description of the logical conclusion was developed. Let us introduce a set of linguistically expressed facts F and their corresponding predicate expressions P.

$$w(f, p): F \rightarrow P \tag{8}$$

According to equation (8), we obtain a system of several predicate formulas:

$$\begin{cases} \exists x_i P_1^{(1)}(x_1) \wedge\rightarrow \forall x_2 \exists y_2 P_2^{(1)}(x_2, y_2) \\ \rightarrow \exists z_i D_1^{(1)}(z_1) \\ \forall x_2 \exists y_2 P_2^{(2)}(x_2, y_2) \exists v_2 (P_2^{(2)}((P_3^{(2)}) \supset P_3^{(2)} \\ \equiv P_4^{(2)}(v_2) \rightarrow \exists q_2 \forall z_2 D_1^{(2)}(q_2, z_2) \\ \exists x_n \exists y_n \forall q_n P_1^{(n)}(x_n, y_n, q_n) \rightarrow \\ \exists z_n D_1^{(n)}(q_n) \end{cases} \tag{9}$$

Let us take system (9) as a predicate description of the initial conditions, which includes n local predicates of arbitrary order [34], [35], [36], [37], [38]. This software has proven or accepted the consequences on the right-hand side of each implication relation. Let us construct a derivation matrix for (9) containing $D_j^{(i)}$ the right-hand side of system (9), i = 1,…,n, j = 1,…,m. Consequently, we are left with the following vector:

$$D_j^{(i)} = \begin{pmatrix} D_1^{(1)} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ D_1^{(n)} & \cdots & 0 \end{pmatrix} \tag{10}$$

where each of the lines $D_j^{(i)}$ describes the logical consequences. The essence of the "solution" of the semantic model is a process aimed at obtaining a k-dimensional vector solution $D^{(n+1)}$:

$$D^{(n+1)} = (D_1^{(n+1)}, \dots, D_k^{(n+1)} \tag{11}$$

where k is a finite non-negative integer, $D_1^{(n+1)} \neq 0$, $D_k^{(n+1)}$ can be zero provided k>1. Considering (9), (10) and (11), a system of rules and the purpose of fuzzy inference are specified:

$$\begin{cases} \exists x_i P_1^{(1)}(x_1) \wedge \forall x_1 \exists y_1 P_2^{(1)}(x_2, y_2) \\ \wedge \ldots \exists z_i D_1^{(1)}(z_1) \\ \forall x_2 \exists y_2 P_2^{(2)}(x_2, y_2) \exists v_2 (P_2^{(2)}\left((P_3^{(2)}\right) \supset P_3^{(2)} \\ \equiv P_4^{(2)}(v_2) V \ldots \rightarrow \exists q_2 \forall z_2 D_1^{(2)}(q_2, z_2) \\ P_{n+1}(X, Y, \ldots, Q) \rightarrow \exists z_{n+1} (D_1^{(n+1)}(z_{n+1}) \\ \wedge \ldots \vee D_k^{(n+1)}(z_{n+1})) \end{cases} \quad (12)$$

The vector appears on the right-hand side of rule (11). The vector appears on the right-hand side of rule (11).

The analysis of formal inference algorithms in fuzzy systems showed that the main difference between each of them is the type of graph for the membership function of the output packets, [34], [39], [40]. If the system (12) contains predicate linguistic variables on the right-hand side of the rules, then a linguistic variable is introduced to describe each of the solutions $D_k^{(n+1)}$:

$$V^d = \langle N^d, T^d, Z^d, G^d, M^d \rangle \quad (13)$$

where N^d is the name of the linguistic variable; $T^d \in ^{Zd}$ is a set of terms belonging to the universal set Z^d; G^d are operations on sets of terms T^d; M^d is a semantic procedure generating the simple permutations of terms generated by G^d, where for each vector the following is true:

$$D_j^{(i)} \leftrightarrow V_j^{(d)} \quad (14)$$

To formalize the data, we will introduce a new frame description.

$$F=(S,L,C,O) \quad (15)$$

where S is a set of slots, L is a set of links, C is a set of applicability conditions, and O is a set of operations on frames. The set S contains four second-level slot elements: s^1 = "car," s^2 = "bike," s^3 = "public transport," s^4 = "walker," s^5 = "combined transport," and s6 = "on foot." We will refer to the slots s(i), where i=$\overline{1.4}$, as conceptual slots because they are situated in the subframe headers [41], [42], [43]. They describe the four main concepts of the selected software. The set of connections L is a collection of objects that determines the relationships between the vertical slots in each frame F, ranging from a generalized concept to a detailed one. Each $l_i \in L$ connects a pair of slots $(s_x, s_{(x+1)}) \in S$, that is, in general form:

$$f(l_x): L \rightarrow S \quad (16)$$

Each applicable condition $c_k \in C$ is set for a slot $s_j^{(i)} \in S$ and is described by logical expressions in the language of predicate calculus, [44], [45], [46], [47]. The set O represents several operations and actions that add and change data represented in frames of the form (15). Let's denote the operations to add a slot as A(sop, dop), to delete a slot as D(pp), and to change a slot as M(op), where sop and dop represent the source and destination operands for dual operations, or the operand designation for a single-place operation, [48], [49], [50], [51]. If we add a slot, the role of SP is played by some slot $s_{i-1} \in S$, under which a new s_i is attached. Elements from the sets S, L, or C can replace the operands of each change and delete operation. The addition of s_i slot, connections l_i, and applicability conditions of c_i can be defined as A(s_i, s_(i-1)), A(s_i, s_{i-1}), A(sl_i, s_i) и A(c_i, s_i), respectively. All slots with a higher stake level relative to s_o also undergo deletion. To avoid unnecessary waste of resources, we propose a method for i-dimensionally connecting slots in a database frame. It basically says that a similarity network will connect the slots s_m^1, s_k^1, s_l^1, and s_h^1, where m, k, l, and h have values between 1 and n for some frequency $f_i \in F$, but only if each applicability condition c_i, i=1,n, has common predicate sequences. We can represent each similarity network as a matrix, whose elements correspond to the network indices:

$$\left(\begin{array}{c|c} & c_{1,} \quad c_2 \ldots c_n \\ f_1 & \tilde{x}_{11}, \tilde{x}_{12} \ldots \tilde{x}_{1n}, \\ f_2 & \tilde{x}_{21}, \tilde{x}_{22} \ldots \tilde{x}_{2n} \\ \ldots & \ldots \ldots \ldots \ldots \ldots . \\ f_n & \tilde{x}_{31}, \tilde{x}_{32} \ldots \tilde{x}_{nn} \end{array} \right) \quad (17)$$

where $\tilde{x}_{ij}$ is a sign that the applicability condition c_i, subfrejma $f_i \in F$, $f_i \in \overline{1,n}$.

4 Inframobility System Architecture

Figure 4 depicts the infomobility system's architecture. The developed model demonstrates the use of a service-oriented methodology in the construction of the architecture.

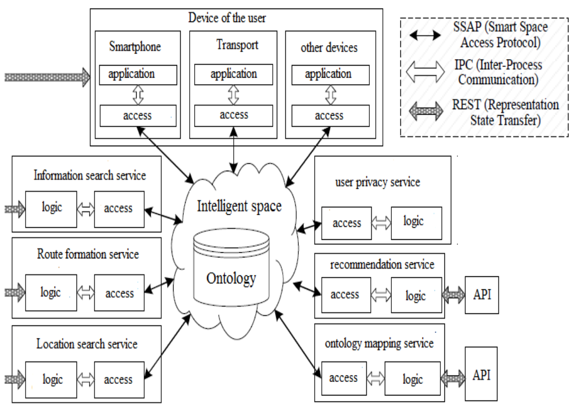

Fig. 4: Service Oriented Architecture

Users' devices and the servers running the infomobility system install services that serve as sources and processors of knowledge and information. We carry out service interaction using the "blackboard" architectural model, which is based on intelligent space technology ontologies, distributed architecture, user orientation, contextual information use, self-contextualization of services, real-time operation, multimodality of routes, and user information privacy, [52], [53]. By adhering to these guidelines, the customer will receive high-quality services that will guarantee their mobility and meet the fundamental criteria. Reusability is one of an ontology's primary benefits. A service's ability to self-describe and change its context is what makes it work. This can be done by either making the ontology narrower by getting rid of unnecessary concepts or making it wider by adding new ones. Each service defines the terminology that best captures the pertinent subject area. Services can modify the knowledge description model to better suit the current situation, allowing them to adapt to its change. We will discuss the future approach to developing the key services of the infomobility system.

5 Conclusion

In this work, the authors have proposed an approach to building an inframobility system based on the use of services as sources of information and knowledge. One of the main advantages of the built ontology is its reusability. This enables services to self-describe and modify the context, either by expanding and incorporating new concepts or by eliminating unnecessary ones. Services can change the knowledge description model to better fit the current situation, allowing them to respond adequately to its change.

We have built a semantic model that allows organized inference, requiring less data storage resources and processing time. The database organization describes system knowledge using predicate expressions. The use of such a description simplifies the implementation of data collection and storage and also makes it possible to speed up fuzzy inferences at the stage of drawing up the initial premises. A methodology for applying predicate knowledge representation in frames can be used in various software where the data represent large classifications of software objects and concepts. The evaluation of a subject-specific knowledge base revealed that minimizing the writing time in a slot can equalize the execution time of basic operations with the knowledge base while minimizing time waste.

Future software design will facilitate organized shared data access for inframobility system services. We will implement the IS application in a modular architecture based on the object-oriented paradigm. This will allow expansion and additional functionalities.

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Conflict of Interest

The authors have no conflicts of interest to declare.

APPENDIX

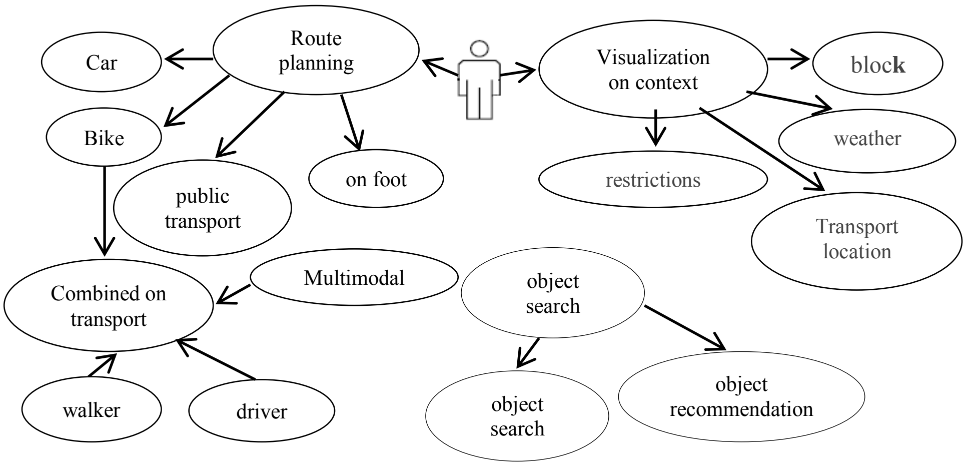

Fig. 1: Situation model diagram