Prometheus – Fuzzy Information Retrieval for Semantic Homes and Environments

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Abstract. This paper introduces a novel vision for further enhanced Internet of Things services. Based on a variety of data – such as location data, ontology-backed search queries, in- and outdoor conditions – the Prometheus framework is intended to support users with helpful recommendations and information preceding a search for context-aware data. Adapted from artificial intelligence concepts, Prometheus proposes user-readjusted answers on umpteen conditions. A number of potential Prometheus framework applications are illustrated. Added value and possible future studies are discussed in the conclusion.


I. INTRODUCTION AND RELATED WORK

In the epigrammatic triumphant history of the Internet, first the World Wide Web (WWW) was created as a “Conseil Européen pour la Recherche Nucléaire” (CERN) project initiated by Timothy Berners-Lee. In the early Web, retrospectively referred to as Web 1.0, a small number of so-called information producers published their insights as a collection of static pages of Hyper Text Markup Language (HTML) and a great mass of consumers was opposed to these insights.

In the late 90s DiNucci first mentioned the term Web 2.0 and thus caused the advent of a new slogan. Afterwards O’Reilly declared that Web 2.0 technically did not differ from the earlier Web 1.0. In contrast to static expert-generated content, interactive elements are crucial in Web 2.0. Ever since the first use of the term Web 2.0 Berners-Lee deployed it as a marketing buzzword. He tried instead to advertise his future visions of the WWW with his ideas about the Semantic Web. The Semantic Web is an emerging development of the Internet in which not only the meaning or semantics of information is defined but also services on the Web, making it possible for machines to understand and satisfy the requests of both people and machines. Because of the enhancement to a machine-understandable Internet, the Semantic Web is sometimes called Web 3.0. Berners-Lee specified the Semantic Web as a component of Web 3.0.

In late fall 2009, O’Reilly and Battele went further by defining another upcoming buzzword “Web Squared”, where the Web no longer is a collection of static pages that describe something in the world. Instead they outline in [1] the Internet of Things. The Internet of Things exemplifies ubiquitous computing and “things that think”. It describes a form of physical computing and is a non-deterministic, open network in which self-organized or intelligent entities will be interoperable and able to act independently – pursuing their own or shared objectives – depending on the context, circumstances or environment as described in [2].

These networks are delineated as ubiquitous computing models, which are post-desktop models of human-computer interaction, considered as an advancement from the desktop paradigm. However, when Web meets the world the vast data produced are mostly stored or provided in an unstructured way distributed on different systems; globally considered. An important case in ubiquitous computing for this reason is to find relevant information.

To find context relevant information in connection to real-world human-settled-environment services, processes and systems become more crucial. A viable way to improve existing searches and to approach a universal Semantic Web – that is the virtual Internet together with the real Internet of Things – is to teach the Web based on an automatically built ontology, the meaning of real world parameter values. Additionally machine learning (ML), a scientific discipline that is concerned with the design and development of algorithms, can be used to learn based on sensor and/or Internet data as Bishop elucidates in [3]. After Kasabov approaches to ML are expert systems whereby “an expert system is a program that can provide expertise for solving problems in a defined application area in the way the experts do” as explained in [4].

To present expert-system-based real-time information in a clever way and to force the users to interact with the information, real and virtual worlds can melt into a new augmented reality (AR). Thus AR can be considered as an event of ubiquitous computing where virtual computer-generated symbolisms are superimposed into physical real-world environments, creating a mixed reality as Azuma et al. explain in [5].

In Greek mythology, Prometheus (Ancient Greek for forethought) was a champion of humankind known for his intellect. He is said to be the benefactor of culture and the great instructor of all human beings. The ambitious project’s goal, named after this transcendent ideal, is to offer the human race further techniques to master their human duties and responsibilities in an easier way by pooling virtual and real world aspects.
II. APPLICATIONS OF FUZZY SETS THEORY

This section aims to introduce some concepts of fuzziness which deals with vague reasoning. To emphasize the benefits that fuzziness brings to artificial intelligence the first section 2A brings the affinity of human thinking and fuzziness in. Section 2B introduces fuzzy set theory and classification and section 2C fuzzy expert systems.

A. Fuzziness and the Human Factor

Mentioned in [6] inter alia, fuzzy logic – a particular type of multi-valued logic emerged as a corollary of Zadeh’s proposition of fuzzy set theory – follows the way humans think and helps to better handle real world facts, since human reasoning is un-dichotomic, contrasting computers, where all is either true (1) or false (0). It deals with haziness and the conceptions are polysemous in terms of that they cannot be sharply defined. Fuzzy logic brings imprecise humans facts over to accurate mathematical models.

While variables in mathematics usually take numerical results, in fuzzy logic, the non-numeric linguistic variables are often used to cultivate the location of rules and facts. A linguistic variable such as “size” can have a value just like ‘tall’ or its antonym ‘short’. However, the great utility of linguistic variables is that they can be modified through linguistic transformation which can be associated with given functions. The question whether a person is ‘tall’ cannot be unmistakably answered, because it is not possible to clearly state if a person is ‘tall’. An answer may depend on individual cognition and further for the individual itself it may even not be feasible to give a strict answer for the simple reason that belonging to a set (e.g. size) is often not sharp but fuzzy, involving a partial matching expressed in the natural language by the expressions ‘quite’, ‘slightly’, ‘more or less’, etc.

![Figure 1: The fuzzy height set illustrate the continuous membership function for the linguistic variable ‘tall’](image)

Figure 1 shows a tender varying curved line that passes gently from ‘not-tall’ to ‘tall’. Therefore this line stipulates the transition of the linguistic variable “size”. Both people are ‘tall’ to some degree – as both people are ‘short’ to some degree – but the female is significantly ‘less tall’ than the male. The vertical axis is an index reputed with the membership value between 0 and 1; the curve is noted as membership function.

B. Introduction to fuzzy set theory and classification

Fuzzy sets are an extension of the classical sets and thereby have special membership levels (as seen in 2A). In classical set theory, the membership of elements in a set is assessed in binary terms according to a two-valued condition; an element either belongs or does not belong to the set. By contrast, fuzzy set theory permits the gradual assessment of the membership of elements in a set; this is described by dint of a membership function valued in the real unit interval [0..1]. Therefore fuzzy sets generalize classical crisp sets, since the indicator functions of classical sets are special cases of the membership functions of fuzzy sets.

Fuzzy classification is an upgrading of traditional classification; equally fuzzy sets extend classical sets. The term classification describes the way of clumping elements into clusters, so that elements in the same cluster are as identical as possible, and elements in different clusters are as diverse as possible. In sharp classification, each element is associated with just one cluster. As a result the belonging of the elements to clusters are reciprocal and exclusive. On the other hand fuzzy classification allows elements to belong to several clusters at the same time; and again like fuzzy sets, each element has a membership degree which reveals how far it belongs to the various clusters. Thereto fuzzy clustering algorithms allow the modeling of uncertainty associated with vagueness and imprecision and putting this into mathematical equations as described in [7]. In general fuzzy clustering algorithms a fuzzy cluster is represented by a representative element – typically the cluster centre – and the membership degree of an element to the cluster is decreasing with increasing distance to the cluster centre.

To minimize elements with a small distance to the cluster it should be assigned a high membership level whereas elements with larger distances should have low membership levels. A clustering algorithm begins with a random initialization and updates the membership levels and the prototype in an iterative procedure.

C. Fuzzy Expert Systems

Expert systems – introduced by Feigenbaum – are proliﬁc examples within the wide scope of artificial intelligence as in [8] explained. Expert systems are knowledge-driven systems that can form conclusions based on knowledge on a particular field. The knowledge is represented by ‘if-then’ rules. By applying consequences on the stated rules, expert systems may deduce optimal decisions.

The major challenge is tocommute the experts’ knowledge into ‘if-then’ rules which are exact given that the human representation of the knowledge cannot be well-deﬁned determined. This downside is hurdled by ush fuzzy rules as in [9] exempliﬁed.

Fuzzy rules are a collection of linguistic statements that describe how to make a decision regarding classifying an input or controlling an output:

```
if (input1 is membership function1) and/or (input2 is membership function2) and/or (…) then (outputn is output membership functionn)
```
Consider the following rule for instance:

\[
\begin{align*}
& \text{if} \\
& \text{person is short} \\
& \text{and} \\
& \text{weight is high} \\
& \text{then} \\
& \text{person is overweight}
\end{align*}
\]

There would have to be membership functions that define what we mean by ‘short persons’ (input₁), ‘high weight’ (input₂) and ‘overweight’ (output₁).

The process of taking an input such as “size” and processing it through a membership function to decide what ‘short’ means is stated fuzzification. The principle at that is once more to map the inputs from a set to values \([0..1]\) using a set of input membership functions.

Thus fuzzy expert systems are usually involved when processes cannot be described by exact algorithms or when these processes are difficult to model with conventional mathematical models.

III. CHALLENGES AND RELATED COMPONENTS

This section intends to introduce the faced challenges and their related components. Section 3A clarifies fundamental challenges to be outgrown in the Internet of Things applications. Section 3B highlights the semantic homes and environments.

A. Fundamental challenges

Coming to a new unknown public place like a railway or underground station, airport, hospital, mall, industrial facility, corporate office, university campus all of us can remember trying to quickly find the right location, information desk, directional hint and other service availability information. Environments with quickly changing geographical parameters like hospitals, care houses, logistic units, military and production line facilities are other problematic control domains.

Static information assistance systems related to mass produced products became a reality by the introduction of bar codes. Using modern data gathering technologies like radio-frequency identification (RFID), near field communication (NFC) and wireless sensor networks (WSN), it is possible and rational to associate various real-world entities with personalized dynamic content from weblogs, social networks, news feeds, location and condition tracking systems and so forth.

Semantically relevant suggestions to the recognized intentions can be delivered to the user in many ways starting from simple visualization hints, to enhanced human-machine interface (HMI) influences directly on human action as in [10, 11] illustrated. Embedded devices for implementation of such systems will vary from the everyday smart phone to newly developed augmented reality systems.

B. Semantic home and environment

According to scientific studies, the average urban human spends about 80 to 90% of his time indoors. Buildings, houses, public places, industrial and military facilities, and even private and/or public transportation allow mankind to penetrate into all of our planet’s places despite a variety of external conditions. The main indoor environment metagols of security, safety, comfort and energy-efficiency have been implied since the very beginning of civilization. However, the approaches to pursue them are mainly restricted by the technological level available. The Internet technologies are widely distributed today, giving us an opportunity to consider, evaluate, process and optimize the semantics behind previously developed indoor services. Semantic home and environment is the concept of “thinking ambient intelligence” that is aware of its inhabitants (humans, animals, robots and smart objects).

Human actions, behaviors, habits, thoughts, intentions, emotions and health conditions are the key factors that have to be considered while tackling semantic home and environment systems. Context awareness is a fundamental component for informational assistance and intelligent environment behavior systems requiring constant intelligence rule updates as in [12] illustrate. On the other side the replayed scenarios are usually accompanied by a certain precondition sets, like current time, action sequence and weather conditions.

Looking from the conceptual point of view, true informational assistance is hardly imaginable without bijective correspondence between real world and the informational model of reality. Hence, bidirectional communication methods between chip-enabled real physical objects and their informational copy are another necessary component of the ambient intelligence needed here. Following the requirements, the concepts of the Internet of Things have recently made an impressive step towards implementing the one-to-one world-to-model paradigm.

IV. SYSTEM CONCEPT DESCRIPTION

This section characterizes the system concept. Section 4A reveals an innovative information retrieval approach for future searches. Section 4B illustrates building blocks of the Prometheus framework. Based on ontologies, section 4C shows in brief, how to train the intelligent environment itself the semantic of human-used terms. Section 4D presents retrieved semantic data and human-environment interaction.

A. Towards an innovative information retrieval method

The data is no longer produced by humans alone but more and more by sensors as well. As in [1] conceptualized, today’s cameras and phones are mutuated into artificial ears and eyes like a sort of “sixth sense” applications. Sensors for motion and location for example provide continual detail where someone is, what one is looking at and how fast and in which direction one is moving. In this spirit data can be gathered and offered on a real time basis. In order to arrange these loose data first, they need to be collected form adequate and trustworthy sources. For this purpose information retrieval (IR) – which establishes the retrieval of information from a document as outlined in [13] – comes in. In view of this, IR represents the entire searching science for documents, for information within documents and for metadata about documents, as well as that of searching databases and the WWW and available sensor data. The second significant part of IR, is in decision making expert systems, benefiting from using fuzzy...
Generally, IR systems are used to diminish what is called information overload. On the basis of the fully automatized ontology with the aid of different sensors the IR-located information will be arranged in a helpful manner for the user in his circumstances (e.g. location, connection speed, etc.). To contrive this, Prometheus draws on a fuzzy expert system (see sec. 2D).

Paraphrased in [14], AI is the intelligence of machines that perceives its environment and takes actions which maximize its chances of success. A major focus there is to train the system to recognize patterns and make intelligent decisions based on this data without human intervention. However, the term of AI itself goes beyond the human intelligence limits and contains computational, memory and solving abilities and properties that humans do not possess.

B. The Prometheus framework

Prometheus is a software/hardware information retrieval data processing system for the provision of the most relevant context aware information. The system uses fuzzy logic to construct the term ontology based on sensor and network distributed data. The core of Prometheus is a distributed cognitive and decision making software framework meant to be flexibly usable by humans and other software/hardware services and systems.

Functional components of Prometheus include:

- Data input subsystem gathering and moving data between sensors, middleware and data bases
- Cognitive ability subsystem implemented using several approaches from cognitive sciences (symbolic, static, behavioral, emotional)
- Context aware decision making subsystem based on ontology and fuzzy expert systems
- Interaction subsystem with multiple machine-to-machine and human-to-machine interfaces unified with a backend
- Adaptable to environment communication framework allowing automatic transparent data commutation between (upcoming) Wireless Body Area Network (WBAN), Wireless Personal Area Network (WPAN), Wireless Local Area Network (WLAN) and Internet Protocol version 6 (IPv6)

Several significant impacts of Prometheus include but are not limited to:

- Increased ability for context prediction and accountability
- The user information overload will be diminished by filtering out the data relevant for the context
- Personnel workflow optimization in team- and innovation-oriented project environments
- Increased energy efficiency, comfort and security of human environments

C. Ontologies and information retrieval for semantic homes and environments

Looking at implementation, the IR service is primary based on fuzzy expert systems with help of a weak term ontology. An ontology is, following Gruber, a "formal, explicit specification of a shared conceptualization", that is a formal notation of a concept set within a domain and the relationships between those concepts as in [15] exemplified. An ontology is often needed to reason about the properties of a domain and can be used to define a field itself.

In [7] it is shown, how folksonomies’ subjacent tags can be harvested. To this Portmann and Meier apply particular metrics such as the Jaccard coefficient in order to meter the proximity between tags. The ontology can then be compiled without human intervention on basis of fuzzy clustering algorithms. Nevertheless, on the basis of this ontology the meaning, or semantic, can be deduced.

The Prometheus object and service search is based on a previously fuzzy-built and constantly automatically updated ontology, enriched with inferences from fuzzy expert systems, in order to arrive to satisfactory solutions. Fuzzy expert systems (sec. 2D) are fitting instruments for this kind of reasoning.

The interconnection between terms in the ontology allows the intelligent house to associate the user behavior and intentions with physical, economical and social parameters of the environment.

Depending on past user behavior and current context-relevant information, the Prometheus framework adaptively learns from each individual user. Behavior analysis requires storage of goals, actions and results made and achieved previously by the user. As a result, prediction-based behavior assistance can be provided on the basis of fuzzy expert systems by the recognition of personal patterns from frequently repeated operations at newly visited unknown environments.

The goal of such assistance is to keep the confidence and comfort at an expected level for people dealing with unknown environments. However, every new environment will most likely not contain an exact copy of previously used objects, services and processes. In this case the most logical solution is to find objects with similar functionality and to inform the user about differences and optimal ways to access them. Moreover, informational assistance can be given directly at the “thinking event” moment, not later when the focus has already been switched to another topic.

D. Retrieved semantic data

Enhancing the system with external data can not only improve usability but also bring an added value in a form of new location-based services as refer to in [16]. Adapted from an ontology to help an end-user to get along in an unknown environment, the Prometheus framework draws on, in different dimensions available, input data such as Internet data (e.g. train connections, ratings, directions, indoor plots, taxonomies) and diverse surrounding sensor data (e.g. precise position, weather conditions, traffic jams, local accidents, door or elevator malfunctions, power losses, water and heating shut offs) to present intelligent
suggestions (e.g. fastest directions to a certain destination, the next train station including connections or prices, ratings, pictures, descriptions of a specific product).

Additionally, for the moment “not relevant” data like changing weather conditions while shopping is frequently useful right at the next moment because it can influence the user’s (buying) preferences and decisions.

Data to be shown has to be chosen according to the user role, current semantic context and current goal set. Moreover, the group of people has to be also considered while designing the communication dataset. Requirements like people group-oriented data availability, people collaboration encouragement, environment adaptability, accountability, security and privacy shape the dataset.

E. Environment and building interaction

To reveal relevant data, the Prometheus framework decides under given circumstances also how to interact in an optimal way. For example, using human-computer interaction the building can adapt by changing visual, audio, kinetic, thermal, humidity, pressure and other physical environment parameters depending on the mood of a tenant.

The search query itself is usually considered as an interface between the user and a search engine. Prometheus is extending the understanding of search queries towards user goals, intentions and behavior. The system does not simply provide the string search box with historically based associative suggestions, but also keeps in mind the semantic context of the user or client system.

The way the semantic environment interacts with a human strongly overlaps with studies from the field of human-computer-interaction (HCI), as for instance the basic requirement of interface simplicity. Also, display design principles remain the same.

However, different semantic system parameters define specific functional constraints leading to the terms of human-building-interaction and human-environment-interaction. The relevant data will be presented in a for the user appropriate way adapted for the subjacent hardware.

Table 1: Parameters impact

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Impact factor on an action</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Indoors</td>
</tr>
<tr>
<td>Weather conditions</td>
<td>2</td>
</tr>
<tr>
<td>Customization</td>
<td>4</td>
</tr>
<tr>
<td>Location</td>
<td>3</td>
</tr>
<tr>
<td>Security</td>
<td>4</td>
</tr>
<tr>
<td>Comfort</td>
<td>5</td>
</tr>
<tr>
<td>Safety</td>
<td>4</td>
</tr>
<tr>
<td>Time</td>
<td>2</td>
</tr>
<tr>
<td>Cost</td>
<td>4</td>
</tr>
</tbody>
</table>

This work associates buildings with being indoors while environment with being outdoors. The main difference between these two types of human interaction is characterized by different impact factors of the common life-value parameters. This parameter list is not hard-fixed for every person. It is mainly provided for a demonstrative purpose.

Table 1 contains several parameter impact factors belonging to the range [1...5]. The highest value corresponds to the highest impact factor.

We know that weather conditions and time of day have much stronger influence on human actions outdoor than indoor. The human action impact of customization and comfort is in opposite relatively little outdoor and significantly high inside of the buildings. Security, safety, location and cost are equally important for human interaction independent of the environment.

V. PRACTICAL APPLICATION

The previous more theoretically oriented sections showed stimuli for this section. As an example, a personal digital assistant (PDA) concept for embedded devices like smart phones and house appliances is presented.

For improved support a future system, like a smart phone, should help people in the same way that present personal digital assistants do. Based on the proposed ontology the digital assistant could educe feasible suggestions for the user. To come up with such suggestions, a future smart phone’s built-in personal digital assistant, here referenced as a part of Prometheus system, has to learn first from the elapsed user’s environmental data. Then it would be possible to pick (for the user) the best solution based on the fuzzy expert systems method.

A major challenge hereby is to teach the digital assistant appropriate solutions. Therefore the user has sometimes to interact with the personal digital assistant. As known from supervised learning, the user should correct potential personal digital assistants misbehavior. Learning inputs can also come from environmental sensor data in which no user interaction is required.

The simplest example is based on the current (indoor or outdoor) location data and needs of the user. For example, the optimal solution for a query on “shoes” will include costs, time, warranty conditions, the (indoor or outdoor) way, and connection for public transportation. Figure 2 shows the particular possible use case while utilizing the Prometheus framework components.

![Figure 2: The Internet-, sensor- and user-preference-data are expected come up with bright solutions for the user.](image-url)
VI. CONCLUSION AND OUTLOOK

After a short introduction into the fuzzy set theory and its applications, this paper presented the main foreseen challenges to be faced by shaping semantics behind the existing living infrastructure. The presented approach of the Prometheus framework depicts a vision towards a solution of these challenges with the novel approach based on fuzzy set theory in the rapidly developing area of the Internet of Things. Furthermore the dataset considerations for semantics implementation a particular attention was given to the new terms of human-building and human-environment interaction.

Further subjacent studies on the issue of appropriate outcome-rules for the fuzzy expert system will be needed. It might be that the proposed approach could be improved by taking into account other machine-learning strategies. At the moment Prometheus is thought to be based on fuzzy rules, but in the future it is not limited to only this.

Another point is a possible enhancement of the fuzzy-built ontology towards integrating further sensor data as for example intelligent clothes. Wearable computing is a vigorous research topic, containing user interface design-, augmented reality-, pattern recognition-, use of wearable’s for specific applications or disabilities-, electronic textiles- and fashion design studies.

The CEESAR-iHomeLab is working on one hand on forming a scientific community for cutting-edge international research projects in the area of ambient intelligence, human-building interaction, user behavior analysis, and assisted living and on the other hand the Research Center FMsquare implements the ideas of fuzzy methods to various scope of applications, and for this reason both research centers appreciate cooperation with researchers and practitioners.

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