# Pushing the Role of *Information* in *I*CN

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***Abstract*—This paper proposes a semantic-based approach to naming and retrieval of content in Information-centric Networking (ICN). The approach stems from the need to realize the idea, originally conceived with ICN principles, of communication based on content exchange. In particular, the paper shows how, by adopting a vocabulary in Resource Description Framework for content description, it is possible to retrieve resources answering a request for content. An example scenario in the domain of Intelligent Transportation Systems works as proof-of-concept for the proposed approach.**

***Index Terms*—ICN, Semantic-based Naming Scheme, Semantic-Based Named-Object Retreival, RDF, DBPedia**

## I. Introduction

Already seven years ago, Jacobson *et al.* [1] introduced Content-Centric Networking (CCN) as a revolutionary perspective on communication. In authors' original idea, this new vision is aimed at bridging the gap between the ways in which, on the one hand, users perceive and, on the other hand, communication protocols manage, the same information source, *i.e.*, Internet. In particular, people are interested in *what* they find in Internet, while communication is traditionally set in terms of *where* information may be found.

In contrast, Content-Centric Networking (CCN) conceives a paradigm shift from communication between named-hosts to exchange of named-data. This new idea paved the way for one of the most prolific research topics in information technology over the last few years: *Information-centric Networking* (ICN).

Several ICN architectures have in fact been proposed in the literature, also in different application contexts (see [2] and [3], just to name a few), and investigated in a significant number of research projects over the last years ([4], [5],[6],[7],[8],[9],[10],[11],[12],[13],[14]). As a consequence, a number of surveys address different ICN issues from general ([15],[16],[17],[18]) or specific [19] perspectives. The strategic impact of this research topic is testified also by the settlement of the Information-Centric Networking Research Group (ICNRG) [20] in the Internet Research Task Force (IRTF).

All such research efforts, either devoted to the realization or to the standardization of ICN architectures, show the feasibility of the paradigm shift. In other words, a re-definition of communication protocols over Internet in terms of exchange of named-content is possible and represents a standing reality.

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Nevertheless, all proposed solutions seem to fail in realizing the original idea, which the whole ICN stemmed from. As a matter of fact, an Internet user still cannot express her request in terms of *what* she is searching for. This continues to be true even though the name of the resource of interest successfully replaced its IP address in the search process. Of course, ICN specifications do cover resources naming mechanisms and name-based matching algorithms. Some work has been in fact devoted to define standard name schemes [21] and requirements for good name schemes ([22], [23], [24]). On the contrary, a problem completely neglected by the literature in this field is how to assign to resources names whose *meaning* is shared by requesters and providers.

In this paper, it is proposed a semantic-based approach for the assignment of names to pieces of content. The approach does not cope with issues of ICN architectures: it considers the communication as a black-box to which providing names for content to be shared. In other words, the approach hereby proposed associates semantics to names, but it is built on top of ICN architecture. Therefore, associating semantics to names comes at no cost for the communication, *i.e.*, it does not affect the performance of named-objects exchange, thanks to the choice of decoupling the semantic-based assignment of names from communication.

On the contrary, the semantic-based characterization of named-objects may really add value to communication in ICN. First, it allows the searching mechanisms to retrieve named-objects satisfying the user request, even when perfect matching of names is not available. Second, it makes more objective and easy to automate the process of assigning names, which has always been treated as subjective and manual in ICN. The approach hereby proposed envisages two phases for names assignment. In the first phase, names are written according to a vocabulary, as shared and standard as possible, formalized in a language equipped with semantics. At this stage of work, this phase is supposed to be manual, as traditionally performed in ICN. In the second phase, names are processed by taking into account the semantics underlying the used vocabulary, so to make the whole search process semantic-based.

The complexity of reasoning over names depends on the expressive power of the modeling language and on the vocabulary size. For this reason, the approach performs better for tailored knowledge domains, described by vocabularies written in not very expressive languages. Therefore, even though a standard, huge and general-purpose vocabulary, like *DBPedia*[1], is adopted in the proposed example, such a vocabulary has been tailored to the domain of the example: Intelligent Transport System (ITS). The restriction of *DBPedia* to the only information of interest ensures feasibility.

The paper is organized as follows. In the next section, ICN literature is briefly reviewed. Some background knowledge indispensable for paper understanding is provided in Section III, before detailing the semantic-based approach to named-object retrieval in Section IV. The feasibility of the proposed approach is shown w.r.t. an example scenario in ITS domain in Section V, before concluding the paper.

## II. Related Work

A thorough literature review of research proposals and projects involving ICN is out of the scope of this paper. Several surveys already address this issue at different stages of ICN advancement, as shortly recalled in the following.

The work in [18] summarizes main commonalities and differences in proposed ICN architectures and extracts from this analysis a research agenda focused on topics deserving attention.

Ahlgren *et al.* [17] focus only on what they define as the main components of ICN architectures: named data objects, naming and security, API, routing and transport, and caching. With reference to such components, the work compares and discusses design choices and features of four research projects under development at the time of authors' writing: Data-Oriented Network Architecture (DONA) [25], Named Data Networking (NDN) [9], Publish-Subscribe Internet Technology (PURSUIT) [13] and Scalable and Adaptive Internet Solutions (SAIL) [11]. Moreover, the authors sum up main advantages with ICN approaches.

Xylomenos *et al.* [15] review key concepts and principles of ICN and adopt five dimensions of analysis –naming, name resolution and data routing, caching, mobility and security– to compare existing ICN architectures. In particular, the paper considers the same four projects as in [17] and three more ones: COntent Mediator architecture for content-aware nETworks (COMET) [7], CONVERGENCE [12] and MobilityFirst [8].

Piro *et al.* [16] very recently analyzed the state of the art on ICN research under a different lens: they not only provide on overview of ICN solutions, but also expose standardization activities related to ICN, illustrate pioneering use cases involving ICN-based approaches and investigate on the integration of ICN paradigm into traditional network infrastructure.

This paper proposes an approach to semantic-based assignment of names to objects retrievable in ICN architectures. For this reason, only approaches coping with naming issues in ICN are reviewed here. As testified by its relevance in the works recalled so far, naming plays a crucial role in the working flow of ICN architectures.

[1] http://dbpedia.org/about

In particular, design choices in developed projects seem to converge to two different naming scheme alternatives, hierarchical and flat, where the latter is the most used. The main features and pros/contra of both alternatives are summarized in the work in [24]. The authors motivate reasons why flat names should be preferred. Hierarchical names allow the system to scale via aggregation and may be human-readable, but ask for an external binding between the name itself and data location. This binding is not required for flat names, which are also called self-certifying just because they embed an identifier of the real-world entity who is the principal for the data corresponding to the name. Such an advantage is paid in terms of non readability by humans of names. In [24], it is argued that also flat names allow for aggregation and that aggregation with hierarchical names is possible only if the hierarchy somehow reflects the physical distribution of data (which is clearly against the principles inspiring ICN). Moreover, it is argued that human-readability asks for a shared and unambiguous understanding of terms used for assigning names. To this end, we note that, by assigning names on a semantic basis, this common understanding is ensured by the use of a shared vocabulary, and new forms of aggregation based on data content become possible.

In [19], the authors review naming schemes and routing mechanisms of DONA, NetInf [10], NDN and PURSUIT projects. Their comparative analysis supports the choice of flat self-certifying names and suggest to give up to human-readability of names and add to flat names owner-selected keywords related to data content. In other words, the authors suggest to associate to names content-related metadata, as a semantic-based definition of names automatically does.

The work in [22] deals with the identification of the right level of information to embed in names and therefore represents one of the few attempts to design names. In particular, the authors denote by the term *information exposure* the amount of information about a content object revealed to network entities by its name and/or through the name resolution process. The paper aims at identifying requirements of information exposure and then the types of information that should or should not be exposed. Although focusing on the design of names, even this work neglects the benefits of conveying data semantics through names.

Blefari Melazzi *et al.* [23] propose Internames, an architectural framework realizing a name-to-name network in which names are used to identify all entities involved in communication: content, users, devices, logical points, and services. Internames is supported by a Name Resolution Service (NRS) that maps names to network locations according to a somehow hierarchical naming scheme. The authors argue that the cost of this kind of binding is worth being paid to realize principles inspiring ICN, so shifting the focus of name design to the crucial role that information should have in names.

The approach hereby proposed aims at associating to names the information content of data to exchange, independently on the adopted naming scheme. Either hierarchical or flat names may be enriched by a semantic-based characterization of data content, so to realize a semantic-based search while trying to affect as less as possible communication.

## III. Background

Basic notions of Resource Description Framework (**RDF**), the language hereby adopted for representation and reasoning over names, are briefly recalled.

**RDF** [26] is a framework for the description of resources, *i.e.*, pieces of content accessible at a Uniform Resource Identifier (URI), which represents their unique name. Resources are described through statements given in the form of so-called triples, *i.e.*, terns of the form $s\ p\ o$, where $s$, $p$ and $o$ are resources representing the subject, the predicate and the object of a statement, respectively.

**RDF** allows to define also anonymous resources (or blank nodes), which describe a piece of content without providing a retrievable name for it: every blank node corresponds to an existentially quantified variable, where the scope of the quantification is the document the blank node occurs in.

We denote by $U$ the set of all URIs, by $B$ the set of all blank nodes, and by $L$ the set of all possible literals, *i.e.*, values interpreted as themselves. The union of the above three sets, $U \cup B \cup L$ is the set of *terms*. An ***RDF**-graph* is a subset of the set of all possible triples in $(U \cup B) \times (U) \times (U \cup B \cup L)$.

The semantics of **RDF** is given in terms of set-theoretic interpretations $I$. Given two partially overlapping sets of *resources* $R_I$ and *properties* $P_I$, terms in $U \cup B$ are mapped by an interpretation function $I$ into $R_I \cup P_I$. Intuitively, terms that occur in triples only as subjects or objects can be mapped into $R_I$, terms that occur only as properties can be mapped into $P_I$, while terms that appear *both* as properties and as subjects/objects must be mapped into $R_I \cap P_I$—which explains why $R_I$ and $P_I$ must overlap.

Entailment in **RDF** comes in three forms, called entailment regimes: Simple Entailment, **RDF**-Entailment, and **RDF-S**-Entailment. Simple entailment corresponds to the usual entailment definition in logic: a Simple Entailment relation between a graph $G$ and a graph $H$, denoted by $\models_S$, states that $G \models_S H$ if every interpretation $I$ that satisfies $G$ satisfies also $H$. Every statement which holds for Simple Entailment holds also for stronger entailment relations, such as **RDF**-Entailment, and **RDF-S**-Entailment, which add to simple entailment further constraints, according to which entailment must hold.

Due to the simplicity of knowledge representation, **RDF** has realized what is nowadays known to be the biggest shared knowledge base: the so-called Web of Data [27]. Such an information source has led to the availability of a huge amount of perfectly interconnected and machine-understandable data, modeled as **RDF** resources, usually addressed as Linked (Open) Data (LOD).

In the next Section, we show how naming content in an ICN by using the Web of Data as common vocabulary allows for associating semantics to names without making subjective assumptions or sharing application-specific namespaces.

## IV. Semantic-based Named-object Retrieval

In this section, the whole approach to semantic-based naming and retrieval of content in an ICN architecture is formally detailed. We immediately point out that the approach is independent of the language adopted for knowledge representation: given a knowledge base $K$ in a language $L$ endowed with formal semantics, it is always possible giving to a piece of content a name according to $K$ and reasoning over such names (at a computational cost which depends on the expressiveness of $L$). Nevertheless, in the following we focus the description on **RDF**, which is the language we adopted for to ICN.

We recall that in **RDF** any content accessible through a URI is defined as a *resource*, causing the terms URI and resource to be often used as synonyms. The proposed approach requires pieces of content to be described according to the definitions below.

*Definition 1 (Content Description):* Given a dataset $V$ and a resource $s$ to be made available by an owner, the *content description* $D$ of $s$ is an **RDF**-graph rooted in $s$ and defined by the owner according to $V$ to describe $s$.

*Definition 2 (Content Request):* Given a dataset $V$, a *content request* $R$ is an **RDF**-graph defined by the user to describe a content to be searched for, according to $V$.

Intuitively, the approach supposes an agreement between the owner and the user on the dataset to be used, but this does not make it less attractive for at least a couple of reasons. Firstly, all ICN architectures proposed so far rely on the definition of a shared namespace, *i.e.*, a form of agreement between the user and the owner is an unavoidable process. Secondly, several well-known, standard and general-purpose **RDF** vocabularies (see *DBPedia*, as an example) exist and may be employed for describing a content request/description without an explicit agreement process.

*Definition 3 (Content Match):* Given a content request $R$, a content description $D$ and an entailment-regime $E$, there is a *content match* between $D$ and $R$ if and only if $D \models_S R$ according to $S$.

Ideally, the search for a content in an ICN architecture should find resources whose content matches the request, but this is clearly unfeasible, due to the complexity of evaluating entailment. For this reason, we propose a process for the deployment an the search for content, tailored to ICN requirements. The deployment process follows the workflow described by the pseudocode given in Algorithm 1. Notably, it allows for keeping as much as possible the expressiveness of content description during the search, while still making the communication feasible.

Algorithm 1 takes as input a resource $s$ to deploy and an **RDF**-graph $D$ defined by the owner to describe $s$ and extracts from $D$ a set, $Name$, of strings representative of the content of $s$. We remark that the unique name associated to the resource is its URI $s$: the set $Name$ collects the content strings associated to $s$, to be investigated during the search phase.

The extraction process is guided by the definition of a set $P$ of predicates and a maximum distance $n$ to be explored in the

**ContentClassifier**($s$, $D$, $P$, $n$)
**Input** : An **RDF**-graph $D$ rooted in $s$, a set of predicates $P$, an integer $n$
**Output**: A set of strings $Name$
**let** $V$ the reference **RDF** dataset;
**let** $Name$ be a global set of strings;
**foreach** $s\ p\ o. \in D$ *with* $p \in P$ **do**
  **add** $p$+$o$ **to** $Name$ ;
  $P_n = \{p\}$;
  **if** $n > 0$ **then** $Name = Name \cup ContentClassifier(o, V, P_n, n-1)$ **else return** $Name$;

**Algorithm 1:** Extraction of content strings

graph $D$ to search for strings. In other words, the algorithm allows to set which predicates have to be investigated and how far from $s$ in the dataset $V$ the search for content strings has to be performed. In practice, values for $P$ and $n$ are set on the basis of experiments and application scenarios.

The content owner is then just asked to provide a description in **RDF** of the resource $s$ she is going to deploy. Remarkably, providing such a description is not necessarily more difficult than giving a name according to a name scheme: although the approach works for any **RDF** description, the owner may revert to a description, which is as easy-to-write as a name in ICN.

The process for composing a query follows a workflow dual to the deployment one, described by the pseudocode in Algorithm 2.

**QueryComposer**($R$, $P$)
**Input** : A Content Request $R$, a set of predicates $P$
**Output**: A set of strings $Query$
**let** $Query$ be a set of strings;
**foreach** $s\ p\ o. \in R$ *with* $p \in P$ **do add** $p$+$o$ **to** $Query$ ;
**return** $Query$

**Algorithm 2:** Composition of the query

Also in the process of querying, a user is asked to provide a **RDF** description of the content she is searching for, which may be also written in an easy-to-write form. In Section V we will show how even such easy-to write content descriptions and requests open interesting retrieval chances. Algorithm 2 transforms the content request $R$ in a set of strings $Query$, which includes names to be searched for.

The search process, addressed by Algorithm 3, works by comparing results of Algorithm 1 and Algorithm 2. In particular, a query composed starting from the content request is compared with the different content strings associated to a resource $s$.

## V. Example Scenario

In this Section, the proposed approach is exemplified w.r.t. a tiny application scenario in ITS domain, as extensive as possible, due to space limitations.

**Match**($R$, $D$, $P$, $n$)
**Input** : A Content Request $R$, a Content Description $D$ rooted in $s$, a set of predicates $P$, an integer $n$
**Output**: A boolean value
Query = QueryComposer($R$, $P$, $n$);
Name = ContentClassifier($s$, $D$, $P$, $n$);
**if** $Query \subseteq Name$ **then return** $true$ **else return** $false$;

**Algorithm 3:** Matching of named-content

In the following, we use Turtle notation [28] for **RDF** and prefixes are resolved in the following.

```
@prefix dbr: <http://dbpedia.org/resource/> .
@prefix dbc: <http://dbpedia.org/resource/Category> .
@prefix dct: <http://purl.org/dc/terms/> .
@prefix skos: <http://www.w3.org/2004/02/skos/core#> .
```

Imagine a citizen in the need for a mobility solution compatible with temporary restrictions to transportation, due to environmental reasons. The search for such an information may be translated to the following simple content request:
$R$ = `:_r skos:broader dbc:Sustainable_transport .`

For the sake of example, consider, as dataset $V$, only the following triples taken from *DBPedia* on February 2016:

```
dbc:Bicycle_sharing skos:broader dbc:Sustainable_transport .
dbc:Green_vehicles skos:broader dbc:Sustainable_transport .
dbc:Car_sharing skos:broader dbc:Sustainable_transport .
dbc:People_mover dct:subject dbc:Green_vehicles .
dbr:Natural_gas_vehicle dct:subject dbc:Green_vehicles .
dbr:Passenger_Carrying_Vehicle dct:subject dbc:Transport .
```

Imagine now that 5 different services owners deployed the following information about their services at URIs `s_1`, `s_2`, `s_3`, `s_4`, `s_5`.

$D_1$ ={`s_1 dct:subject dbc:Car_sharing` .}
$D_2$ ={`s_2 dct:subject dbc:People_mover` .}
$D_3$ ={`s_3 dct:subject dbr:Natural_gas_vehicle` .}
$D_4$ ={`s_4 dct:subject dbc:Bicycle_sharing` .}
$D_5$ ={`s_5 dct:subject dbr:Passenger_Carrying_Vehicle` .}

The content strings in Table I are extracted by applying Algorithm 1 to each of the five pieces of content above, with $P = \{$`skos:broader,dct:subject`$\}$, $n = 2$ and $V$ made up by the triples above.

The reader may verify that the content request $R$, processed by Algorithm 2, is translated in the following set: $Query = \{$*skos:broaderdbc:Sustainable_transport*$\}$ By applying Algorithm 3 to compare $R$ with each description in $\{D_1, D_2, D_3, D_4, D_5\}$ (with $P = \{$`skos:broader,dct:subject`$\}$ and $n = 2$), it is easy to notice that all contents but `s_5` satisfy the request.

Remarkably, in a classical ICN approach, the user needs to search for the exact name of a content to find it. On the contrary, in the proposed approach, a description of the searched content w.r.t. a well-known dataset, like *DBPedia*,

TABLE I
CONTENT CLASSIFICATION

| URI | Name |
|---|---|
| s_1 | {*dct:subjectdbc:Car_sharing*, *skos:broaderdbc:Sustainable_transport* } |
| s_2 | {*dct:subjectdbc:People_mover*, *dct:subjectdbc:Green_vehicles*, *skos:broaderdbc:Sustainable_transport* } |
| s_3 | {*dct:subjectdbr:Natural_gas_vehicle*, *dct:subjectdbc:Green_vehicles*, *skos:broaderdbc:Sustainable_transport* } |
| s_4 | {*dct:subjectdbc:Bicycle_sharing*, *skos:broaderdbc:Sustainable_transport* } |
| s_5 | {*dct:subjectdbc:dbr:Passenger_Carrying_Vehicle*, *dct:subjectdbc:Transport* } |

allows for retrieving useful content even when no resource perfectly matching the request name exists.

## VI. CONCLUSION

This paper proposes an approach to semantic-based naming and retrieval of content in an ICN. The approach allows users for searching content by just describing, according to an **RDF** vocabulary, the request they have in mind. Coherently with ICN inspiring principles, it realizes the independence of the request formulation of the physical location of content. Notably, as distinguishing feature, it also enhances the independence of the request formulation of the resource name, grounding the whole search process on the exchange of pieces of content.

Future work will be devoted to the integration of the proposed approach in an ICN architecture, to the evaluation of complexity and scalability in real-world scenarios, and to the comparative analysis of retrieval times and results w.r.t. approaches adopting traditional naming schemes.

Moreover, Natural Language Processing techniques should be investigated for making automatic the process of extracting names from verbose descriptions of resources on the basis of their content.

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