

Naming and its Regularities in Distributed Environments

Mark Burgin and Anshul Tandon

Department of Computer Science
University of California, Los Angeles
405 Hilgard Ave.
Los Angeles, CA 90095
United States of America

Everything is a naming problem.
Gordon Irlam, 1995

Abstract: *Many of the Internet's problems are related to names. There are many empirical ideas of the further development of naming on the Internet. However, there are no theoretical foundations for efficient development of such systems. In this paper, we take a unique approach to the naming problem in distributed environments. We place the naming problem in a mathematical context of named set theory and show a correlation between naming strategies for the Internet and named sets in mathematics. To achieve this goal, we give (in Section 2) a brief background in named set theory and then develop (in Section 3) an operation algebra on named sets related to problems of naming on the Internet and other distributed systems.*

Keywords: Internet, name, naming, named set, operation, renaming

1 Introduction

Despite its tremendous success, the Internet architecture is widely acknowledged to need further development as the Internet's increasing ubiquity and importance have made its flaws all the more evident and their elimination urgent [2]. Many of the Internet's problems are related to names. Names or identifiers are central to any network or distributed system architecture because they are the handles for remote, ephemeral or non-existing entities [17]. Even more, as Irlam states [12], "Naming is one of the most important and most frequently overlooked areas of computer science." This correlates with the opinion of another expert in computer technology Cunningham, who stated [9] that objects, patterns, Wiki and XP, all are systems of names.

According to a general understanding, a name is a label or representation of a "thing" or place that is normally used to distinguish between one another [18]. Names can have different meanings in different contexts, the particular meaning that is intended is considered as a binding [12]. Names acquire more and more economical value [14].

The Internet is an example of a network for which names and naming have vital importance. The current Internet has only two global namespaces: DNS (the Domain Name System) names and IP addresses. DNS is one of the most widespread uses of naming in the Internet. DNS maps hostnames to IP addresses. If a particular mapping is not found, the DNS server points the client towards another DNS server that may have the answer. In this way, the IP address of the resource in question is eventually returned to the client and the resource may be accessed via routing protocols.

Since both DNS names and IP addresses are tied to pre-existing structures such as network topology, it becomes difficult and inconvenient to move and/or replicate service instances and data [1]. New approaches for naming in the Internet have been proposed that would create a multilayered system for name resolution aimed at allowing Internet objects to be persistently named, accommodating mobility and middleboxes such as NATs and firewalls [1].

Intelligent naming schemes are an important aspect of the Internet because without them, locating and uniquely describing resources would be a difficult task. As Sollins writes [17], “we have been considering the design of naming systems for almost 25 years, but still do not give naming systems their due in the engineering of network systems.” This paper treats the naming problem from an algebraic perspective, developing mathematical models for naming and focusing on named sets and operations with them. The next section provides a basic framework for understanding elements of named set theory. In Section 3, operations with named sets, such as naming, interpreting, renaming, and reinterpreting, are studied.

2 Elements of named set theory

The concept of name brings us to the following structure:

$$\text{Entity 1} \xrightarrow{\text{connection}} \text{Entity 2} \quad (1)$$

This structure is called a *named set* or *fundamental triad*.

Thus, a named set \mathbf{X} consists of three components $\mathbf{X} = (X, f, I)$ and each component plays its unique role and has a specific name: X is called the *support*, I is called the *set of names* or *reflector*, and f is called the *naming relation* or *reflection* of the named set \mathbf{X} .

Named set has a diversity of interpretations both in mathematics and beyond. For instance in mathematics named sets allow one to build more powerful and flexible foundations than those that exist now and are based on sets, categories, and algorithms [7].

There are different kinds of named sets: set theoretical, categorical, mereological, etc. The most customary are set theoretical named sets because all mathematicians are accustomed to talk set theoretical language.

There are different formal mathematical definitions of set theoretical named sets: utilizing the theory of categories [5], theory of sets [4], and as an axiomatic theory [8].

People meet named sets constantly in their everyday life. People names play an important role in social relations. Experimental findings show that people with desirable or attractive names are treated more favorably by others than are those with undesirable or unattractive names. Also, persons with undesirable or unattractive names tend to be handicapped in their personal, social, and work-related activities.

In addition to everyday life, people find named sets in many fundamental structures of the universe. They can even see some of fundamental triads. Many mathematical systems are particular cases of named sets or fundamental triads. The most important of such systems are fuzzy sets [19] and multisets [13], graphs and hypergraphs [2] because they all are natural generalizations of the concept of a set and have many important applications. Moreover, any ordinary set is, as a matter of fact, some named set, and namely, a singlenamed set.

There are many examples of named sets related to computers and different networks, including the Internet. For instance, file systems are naming systems. Operating systems and especially, distributed operating system use their capabilities to name the object being manipulated. Unix architecture involves placing everything into a single universal hierarchical name space - files, external devices, and executable content. Here are some more examples.

Example 2.1. The Domain Name System (DNS) of the Internet gives names to specific domains or network locations. Thus, DNS is a dynamic named set in which the set of names (the namespace) consists of URLs, such as `www.ucla.edu` or `http://www.world-academy-of-science.org`, while the support of this named set consists of specific domains or network locations.

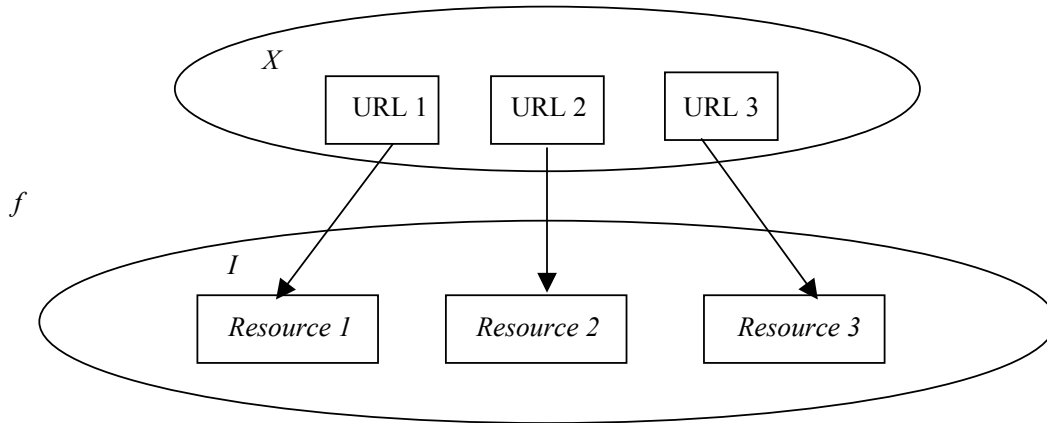


Fig. 1. The DNS named set

Example 2.2. The namespace IP addresses is also a named set in which the set of names (the namespace) consists of strings of numbers, such as 192.0.34.65 or 64.139.27.165, while the support of this named set consists of services.

Example 2.3. Mirroring process on the Internet also generates a named set (see Fig. 2).

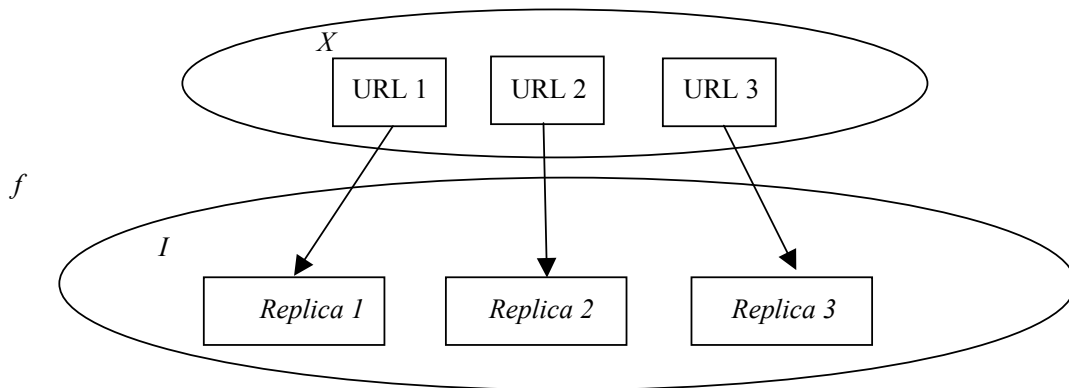


Fig. 2. The named set that emerges in a mirroring process

Remark 2.1. Both constructive and axiomatic definitions of named sets use concepts from other mathematical theories. Constructive approach is developed inside the theory of categories and theory of sets and classes, while the axiomatic design is based on mathematical logic. This causes an illusion that constructions of logic, sets, and/or categories are more fundamental than named sets. However, this is not true: the concept of a named set has, at least, the same level of fundamentality as basic logical concepts and concepts of a category and set.

Definition 2.1. A named set \mathbf{X} is called: (1) normalized if $N_f(\mathbf{X}) = N(\mathbf{X})$; (2) a singlenamed set if $N_f(\mathbf{X})$ consists of a single element; (3) (partially) functional if the naming relation $n(\mathbf{X})$ is a (partial) function; (4) disjunctive if $X \cap I = \emptyset$.

Definition 2.2. A named set $\mathbf{X} = (X, r, I)$ is called set theoretical if X and I are sets and r is a subset of the direct product $X \times I$, i.e., $r \subseteq X \times I$.

There are named sets that are not set theoretical, e.g., algorithms.

Definition 2.3. If $\mathbf{X} = (X, r, I)$ and $\mathbf{Y} = (Y, q, J)$ are named sets, then a mapping of \mathbf{X} into \mathbf{Y} is a pair $F = (f, g)$ where $f: X \rightarrow Y$, $g: I \rightarrow J$ are relations and $fq = rg$.

Definition 2.4. A mapping $F = (f, g)$ of \mathbf{X} into \mathbf{Y} is called a projection (injection) if both $f: X \rightarrow Y$ and $g: I \rightarrow J$ are projections (injections).

Proposition 2.1. If \mathbf{Y} is a disjunctive (normalized) named set and $F: \mathbf{X} \rightarrow \mathbf{Y}$ is a functional mapping (projection), then \mathbf{X} is also a disjunctive (normalized) named set.

Definition 2.5. A named set $\mathbf{Y} = (Y, b, J)$ is called a named subset (a weak named subset) of the named set $\mathbf{X} = (X, a, I)$ if $Y \subseteq X$, $J \subseteq I$ and $b = a|_{(Y, J)}$ (and $b \subseteq a \cap (Y \times J)$). Such relation between named sets is called the inclusion (the weak inclusion) and denoted by $\mathbf{Y} \subseteq \mathbf{X}$ ($\mathbf{Y} \subseteq_w \mathbf{X}$).

3 Operations on named sets and naming strategies on Internet

There are six main operations with named sets related to problems of the Internet: naming, renaming, denaming, interpreting, reinterpreting, and deinterpreting. It is possible to define these operations in algebraic categories and develop their categorical theory. However, here as we are interested in network applications, we construct operations in a set-theoretical setting.

Let X be a set.

Definition 3.1. An operation that corresponds a named set $\mathbf{X} = (X, a, I)$ to X is called *naming*.

Informally, a naming operation starts with a set of objects (it can be one object) and corresponds names to these objects. This produces a named set \mathbf{X} .

Example 3.1. We encounter a paradigmatic naming in human society when we give a name to a child.

Example 3.2. During her or his life, each person acquires a quantity of names that represent her or his role in a family (a child, son, daughter, brother, sister, mother, father, grandfather, etc.), in society (a student, teacher, professor, director, employee, owner, etc.), in professional sphere (an engineer, scientists, mathematician, linguist, physicist, biologist, etc.).

Example 3.3. In science, when a new entity is discovered, those who made the discovery give a name to this entity. For example, when a new chemical element is found or a new substance is synthesized, this element or substance is named. In biology, where there is a huge diversity of different species, special rules for naming are developed by biologists. Biologists have two official systems of naming rules: International Code of Zoological Nomenclature adopted by the General Assembly of the International Union of Biological Sciences [11] and International Code of Botanical Nomenclature [10]. In these cases, names are given not to individual objects but to collections of similar objects.

It is an important problem to elaborate efficient rules for Internet naming. Now we have the following rules [3]. Uniform Resource Name (URN) assignment is delegated to naming authorities, who give persistent and globally unique names. It is left up to each naming authority to determine conditions under which it will issue a URN. Some names may be assigned permanently, while others may be available for re-use over time.

Let $\mathbf{X} = (X, r, I)$ be a named set.

Definition 3.2. An operation that corresponds a named set $\mathbf{Y} = (X, q, J)$ to \mathbf{X} is called *renaming*.

Informally, a renaming operation starts with a set of objects with names (it can be one object) and eventually changes these names. This changes a named set \mathbf{X} to a named set \mathbf{Y} .

Example 3.4. In the zoological nomenclature [11], there are special rules how to change a name when an existing name is found invalid or unfit. Such change is renaming.

Example 3.5. Coming to America, many people changed their names. It was a renaming operation.

Example 3.6. When women get married, many of them change their last name to that of their husband's. This is also a form of renaming.

Definition 3.3. An operation that corresponds the set X to the named set $\mathbf{X} = (X, a, I)$ is called *denaming*.

Informally, a denaming operation starts with a set of objects with names (it can be one object) and deletes these names forming a set X .

Example 3.7. As it is discussed in Example 3.2, each person acquires a quantity of names that represent her or his role in a family (a child, son, daughter, brother, sister, mother, father, grandfather, etc.), in society (a student, teacher, professor, director, employee, owner, etc.), in professional sphere (an engineer, scientists, mathematician, linguist, physicist, biologist, etc.). These names are not only given to a person but also taken away. For instance, when a student graduates, she or he loses the name student.

Remark 3.1. Operations of naming and renaming are not defined in a unique way - the result may be any named set with a given support, while the result of denaming is uniquely determined by the initial named set. Thus, denaming is a genuine unary operation, while naming and renaming are set valued operations: it is possible to consider the result as the collection of all named set with a given support.

Proposition 3.1. The sequential composition of a naming and a renaming of named sets is a naming of named sets.

Proposition 3.2. The sequential composition of a renaming and a denaming of named sets is a denaming of named sets.

Proposition 3.3. Any renaming can be decomposed into the sequential composition of a denaming and naming.

Proposition 3.4. The sequential composition of renamings of named sets is a renaming of named sets.

These results explicate algebraic structures in systems of naming operations such as semigroups, monoids, and polygons.

Semigroup is a set in which an associative binary operation is defined. A semigroup with an identity is called a *monoid*.

A *right polygon* P over a monoid M is a set in which a binary operation $P \times M \rightarrow P$ is defined and for all r, s in M , x in P , we have $x(rs) = (xr)s$ and $1x = x$.

Corollary 3.1. Operations of renaming form a monoid.

Corollary 3.2. Operations of naming form a right polygon over the monoid of renamings.

Proposition 3.5. The sequential composition of a denaming and a naming of named sets is a renaming of named sets.

Example 3.8. There are many processes of renaming in science when these processes consist of consecutive application of denaming and naming. Here is one example from contemporary theoretical physics. For a definite period of time, such particles as proton, neutron, different types of mesons had a common name "elementary particle" as it was assumed that they did not have components. When it was found that these particles consisted of quarks, the name "an elementary particle" was excluded from a correct usage in microphysics. Instead, physicists started to use the name "a subatomic particle."

Let I be a set.

Definition 3.4. An operation that corresponds a named set $\mathbf{X} = (X, a, I)$ to I is called *interpreting*.

Informally, an interpreting operation starts with a set of objects (it can be one object) and uses these names as names for other objects. The second set of objects assigns some meaning for the objects from the first set. This produces a named set \mathbf{X} .

Example 3.9. To achieve the destination, data packets on the Internet are sent from one router to the next. Each router reads the IP address of a packet and decides which path will be the fastest. The IP address of a packet is a name of this packet. When the router corresponds a path to the IP address of the packet, it performs interpreting of IP addresses.

Example 3.10. Resolution of DNS names is an interpreting operation. As it is stated in [17], “we have three major groups of characteristics of name systems: characteristics of the namespace itself (the set of names in the corresponding named set), the name assignment process (naming), and the name resolution mechanism (interpreting).

Example 3.11. A solution to the mirroring problem [3] is to assign location-independent names to files (the first naming operation) and to provide a name-to-location service that given a name, returns a list of locations for that name (the second naming operation).

Let $\mathbf{X} = (X, r, I)$ be a named set.

Definition 3.5. An operation that corresponds a named set $\mathbf{Y} = (Y, q, I)$ to \mathbf{X} is called *reinterpreting*.

Informally, a reinterpreting operation starts with a set of names of objects and eventually changes these names. This changes a named set \mathbf{X} to a named set \mathbf{Y} .

Example 3.12. When a router reads the IP address of a packet and decides which path will be the fastest. The IP address of a packet is a name of this packet. Corresponding a path to the IP address of the packet by the may be also considered as operation of reinterpreting.

Definition 3.6. An operation that corresponds the set I to the named set $\mathbf{X} = (X, a, I)$ is called *deinterpreting*.

Informally, a deinterpreting operation starts with a set of objects with names (it can be one object) and deletes these objects forming a set I .

Example 3.13. When a resource provider moves some resources from one place to another, the old name-to-location bindings are changes to new ones. This is a deinterpreting operation.

Remark 3.2. Operations of interpreting and reinterpreting are not defined in a unique way - the result may be any named set with a given set of names, while the result of deinterpreting is uniquely determined by the initial named set. Thus, deinterpreting is a genuine unary operation, while interpreting and reinterpreting are set valued operations: it is possible to consider the result as the collection of all named set with a given set of names.

Proposition 3.6. The sequential composition of an interpreting and a reinterpreting of named sets is an interpreting of named sets.

Proposition 3.7. The sequential composition of a reinterpreting and a deinterpreting of named sets is a deinterpreting of named sets.

Proposition 3.8. Any reinterpreting can be decomposed into the sequential composition of a deinterpreting and interpreting.

Proposition 3.9. The sequential composition of reinterpretings of named sets is a reinterpreting of named sets.

Proposition 3.10. The sequential composition of a deinterpreting and an interpreting of named sets is a reinterpreting of named sets.

All this shows that interpreting operations form definite algebraic structures.

Corollary 3.3. Operations of reinterpreting form a monoid.

Corollary 3.4. Operations of interpreting form a right polygon over the monoid of reinterpretings.

4 Conclusion

We have constructed mathematical models for studying naming operations in a distributed environment, as well as for the development of efficient and flexible naming architectures and schemas. Theoretical results of this paper form a base for an efficient mechanism for directly and persistently naming data and services. At the same time, utilization of multilayered naming systems for the Internet (cf., for example [1]) brings us to a more complex mathematical model

called a named set chain [6]. Thus, an important direction for the future research is a study of operations with named set chains.

Another practical direction is to develop an algebra of named set operations in such a way that expressions of this algebra would determine rules for routing and navigating the Internet.

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