

Article

How Much Do We Learn from Addresses? On the Syntax, Semantics and Pragmatics of Addressing Systems

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Abstract: An address is a specification that refers to a unique location on Earth. While there has been a considerable amount of research on the syntactic structure of addressing systems in order to evaluate and improve their quality, aspects of semantics and pragmatics have been less explored. An address is primarily associated by humans to the elements of their spatial mental representations, but may also influence their spatial knowledge and activities through the level of detail it provides. Therefore, it is not only important how addressing components are structured, but it is also of interest to study their meaning as well as the pragmatics in relation to an interpreting agent. This article studies three forms of addresses (i.e., structured as in Austria, semi-formal as in Japan, and descriptive as in Iran) under the principles of *semiotics* (i.e., through levels of syntax, semantics, and pragmatics). Syntax is discussed through formal definitions of the addressing systems, while semantics and pragmatics are assessed through an agent-based model to explore how they influence spatial knowledge acquisition and growth.

Keywords: address matching; syntax; semantics; pragmatics; spatial cognition; spatial linguistics; location-based services

1. Introduction

An address is a specification that refers to a unique location on Earth [1]. It is usually expressed in the form of an addressing system (i.e., as a combination of certain components such as spatial features and their relations, postal codes, etc.). Addressing systems can be distinguished depending on their structure as well as the types of components used, which often correspond to social and cultural aspects [2,3]. For example, in Europe, roads and consecutive building numbers are among the standard addressing components. However, there are other places like Istanbul in Turkey, Maceió and Salvador in Brazil as well as Iran where a name assigned to a building can also have addressing value. Japanese and Korean addressing systems are quite different, where (most) streets have no name, instead, blocks are coded. In addition, building numbers are not ordered along a road, but block-wise and based on the date the buildings were constructed [4]. In Iran, street names are not unique, thus a combination of multiple street names and spatial relations ending up in the destination is used in the form of a way-finding process description in order to make a unique reference.

On the other hand, geocoding (or address matching) refers to the process of relating an address to its corresponding location on a map [1]. It is a straight-forward and well-implemented process for many addressing systems used by different countries. Today, most spatial information systems are equipped with automated geocoding engines, which is one of the prerequisites for providing meaningful location-based services [5–7]. Research on evaluating [2,3,8–15] and improving [16–18] the

accuracy of geocoding generally agrees that an address can be automatically geocoded, if it can be parsed to its components, so that the address can be automatically interpreted and matched on a map. This process mainly depends on the syntactic structure of the corresponding addressing system as well as the richness of the database (cf. gazetteers) used [2,3].

While the goal of GIScience is to formally model the interaction of humans with their environment [19], the interaction of humans with addresses (as verbal descriptions of locations in the environment) has been less explored. People are a major (if not the largest) user group of addresses. They frequently use addresses to find locations in the environment without any machinery aids. As stated in [2], postal addresses are “a common wayfinding resource, used in cities everywhere in the world”. However, there has not been considerable research on how an address is interpretable by humans, and how much it can relate to one’s mental representation. In addition, humans may interact with an address more than just using it as “a specification that refers to a unique location on Earth”. In fact, the information provided by an address may influence peoples’ spatial knowledge and activities such as wayfinding. For example, an address that contains spatial features should provide different spatial information compared to one that includes both spatial features and their relations. Such differences may be considered as one of the within-culture factors that lead to apparent cultural differences that are not due to culture [20].

Modern formal addressing systems are designed to convey locations with great accuracy. However, the everyday spatial descriptions used by people, which are composed of simple spatial relations (e.g., “next to”, “between”, “to the left of”, “in front of”, etc.) between spatial features, is not very precise, but they are frequently produced and readily understood [21]. It seems that the value of such spatial descriptions for spatial communications has been less considered in designing the modern formal addressing systems. One reason may be to avoid the complex structure of natural languages to express such spatial descriptions. In other words, the modern addressing systems seems to “force the users to learn their [spatial] language and to translate their information into this format . . . , which has the potential to limit the user’s [spatial] ability” [22].

As an emerging idea of studying spatial cognitive issues of addressing systems, this article investigated the hypothesis that formal addressing systems (in terms of type, number, and order of components) can influence the speed of spatial knowledge acquisition. As a first step, this hypothesis leads to the following propositions, which will be considered in this paper: (1) Assuming that one is detached from all other sources of spatial information, one can acquire spatial knowledge from addresses; and (2) the addressing system may influence the speed of one’s spatial knowledge acquisition and mental model construction. The results of this pilot study can be further investigated and evaluated by the tools of (spatial) cognitive and linguistic sciences on one hand, and logic for knowledge representation on the other hand.

To answer these research questions, three forms of addresses (i.e., structured as in Austria, semi-formal as in Japan, and descriptive as in Iran) were studied under the principles of *semiotics* (i.e., through levels of syntax, semantics, and pragmatics). Syntax is discussed through formal definitions of the addressing systems, while semantics and pragmatics are evaluated with an eye on the level of spatial information they provide for both human and computer, whether directly or by spatial reasoning. To this end, the concepts of addressing systems as well as the components people often use for addressing were investigated. Then, the addressing systems of Austria, Japan, and Iran were introduced and assessed through an agent-based simulation to explore how they influence spatial knowledge acquisition and growth.

The remainder of this article is structured as follows. Section 2 discusses the idea that addressing systems influence our spatial cognition and the way that people interact with the environment. In Section 3, we provide a classification of different addressing systems based on their structure and types of elements used. Then, the three addressing systems of Austria, Japan, and Iran are introduced. Section 4 introduces the agent-based simulation of spatial knowledge acquisition through the case

addressing systems. Sections 5 and 6 analyze and discuss the findings in terms of semantics and pragmatics. Finally, Section 7 concludes the article and provides ideas for future research.

2. Addressing Systems Influence Our Spatial Mental Representation

Tversky coined the term “spatial mental representation” for categorical spatial relations among elements, which are easily comprehended from language or direct experience. Spatial mental representations can be induced from spatial descriptions composed of simple spatial relations between spatial features, and among other forms, could be in the form of verbal written facts [21]. Moreover, among several aspects, spatial ability refers to the ability to imagine a spatial arrangement from verbal reports or writings, which helps answer questions of identification and description (“What?” and “Where?”) [23]. As such, addresses—as verbal descriptions of the environment—contribute to humans’ spatial knowledge and mental abilities.

As Figure 1 indicates, an address provides people with an interpretation of their surroundings, which is a different, less informative mental representation of space compared to the one resulting from “manipulating and acting in the external environment, which is a fundamental building block for the acquisition of spatial knowledge” ([24], p.161). The difference depends on the addressing components: A Japanese address (which is composed of non-spatial temporally-ordered codes) should provide a significantly different representation of the environment compared to an Austrian address (which contains spatial features and spatially-ordered building numbers), and to an Iranian address (which describes spatial relations among different types of spatial features). More clearly, an address that only contains spatial features helps to acquire *declarative* components of spatial knowledge (which includes knowledge of objects and/or places together with meanings and significances attached to them), whereas addresses with spatial relation components also contribute to acquiring relational or *configurational* components of spatial knowledge (i.e., information about spatial relationships among objects or places) [24]. Spatial relation is a less clearly defined dimension of spatial ability, which is a significant component of everyday spatial behavior [23]: “Environmental cognition is much more than identifying elements of an environment and/or of its representation. It extends beyond to understanding relationships implied by, or latent in, the representation” ([25], p. 267). Amongst others, this aspect of spatial ability corresponds to imagining the space from a verbal description, which includes the case of an address.

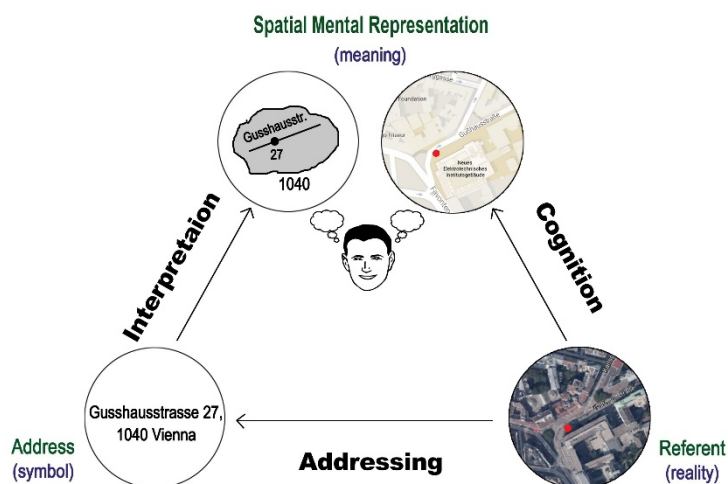


Figure 1. Cognizing a location in reality vs. interpreting its corresponding address (after the map semiotics of MacEachren [26]).

Consider the following two example addresses in order to better expose the article’s point of view: “Gusshausstrasse 27, 1040 Vienna” refers to the address of the Vienna University of Technology expressed in the Austrian addressing system (i.e., using the structure “streetName buildingNo, districtNo

city". Compare this with "Tehran, North Kargar Ave., 100 m above Jalal Blvd., after post office, No. 63", which refers to the address of Tehran University in an unstructured descriptive fashion. The address is unstructured because in Iran, street names are not unique and an address requires an elaborate description sufficiently detailed enough to make it unique. Moreover, it contains spatial relations between spatial features in order to navigate the user through the space. That is, Iranians use a way-finding process description that needs to be dynamically constructed in order to refer to a certain destination.

A computer that knows the structure of the first address can easily decompose (parse) it to its components, thereby automatically interpreting and matching the components on a map. However, the second address is difficult (if not impossible) to automatically match due to a lack of information about its components to be fully parsed and interpreted.

What about someone who wants to find both addresses and make sense of them, for example, by attempting to reach the destinations and/or integrate this address information in their spatial mental representation? An agent who is unfamiliar with the structure of the Austrian addressing system may not be able to interpret some components (e.g., 1040 as referring to Vienna's fourth district), and thus the process may fail at an early stage of the interpretation phase. In contrast, an agent who knows this addressing structure, but has never heard of "Gusshausstrasse", can only comprehend this address up to the district level. However, interpreting the second address needs other kinds of knowledge as the components are expressed as features that correspond to the actual environment. In addition, an agent who is familiar with the environment that refers to the starting point of the address can follow the description provided by the address (i.e., for them, the address is a form of wayfinding instruction). On the other hand, humans learn from the first address that "Gusshausstrasse" is located in the fourth district of Vienna, which provides the agent with a general idea on where this street is approximately located in the city of Vienna, but no clue about how to get there. The second address, however, indicates that to reach Tehran University, one needs to take "North Kargar" Avenue and pass "Jalal" Boulevard for 100 m. To confirm, it even contains the auxiliary information that she will pass a post office. The second address also implicitly provides humans with the spatial relations among "North Kargar" Avenue, "Jalal" Boulevard, the post office, and "Tehran University", thus enriching their spatial knowledge with more information. We consider that the second address contains more information for wayfinding and for acquiring and improving spatial knowledge.

The above examples indicate that different addressing systems provide different levels of detail and require different levels of prior knowledge about the meaning of the components to be understood. On the other hand, addresses are conceived, interpreted, and integrated into human spatial mental representations differently, depending on the form of the address as well as the type of their components. To integrate an address with their spatial mental representation, humans must first understand the components of the address and understand their interpretation. For this, the addressing structure and meaning of its components must either be self-explanatory or known. Then, someone who knows the environment associates the components with the elements of their spatial mental representation. This process will fail for an unfamiliar human, as they have no spatial mental representation of the environment. On the other hand, the level of spatial information provided by an address may influence how it is further used by people in their spatial activities.

3. Addressing Systems: A Classification

Among the many studies that document different definitions and aspects of addressing, some classify addresses based on the elements they use; Davis and Fonseca [2] classified addresses as either direct or *indirect* references to places, and introduced direct references as structured descriptions composed of spatial elements, and indirect as numbers or codes that refer to a location. A direct address, per se, can be *absolute* (i.e., referring to a definite place) or *relative* (i.e., absolute referencing attached to an indication of relative positioning, say, "100 m above Jalal Blvd."). Moreover, they

enumerate a set of concepts that may have addressing value such as street name, crossing, building number, city sector, neighborhood, city, state, landmark, and postal code.

As many researchers have been inclined to deal with addressing systems for machine-based geocoding [2,11,15,27–30], they have limited their scope to model the syntax of structured addressing systems, which are mostly direct absolute addressing systems and contain those addressing concepts that can be expressed in a structured manner. However, other classes of addressing (e.g., direct relative addresses), along with other addressing concepts (e.g., crossings and landmarks) may be the key aspects of human spatial cognition. For example, landmark recognition is among the first stages of spatial knowledge acquisition [31], whose addressing values have not received much focus in most current research on addressing systems.

In the following, we considered the Austrian, Japanese, and Iranian addressing systems as three classes of addressing with different structures and types of components. Having described each addressing system, its syntax is discussed through its formal description in Backus Naur Form (BNF); and its semantics and pragmatics are evaluated through an agent-based model to explore how they influence spatial knowledge acquisition and growth. The results of this syntactic, semantic, and pragmatic evaluation on the case studies are summarized in Table 7, at the end of the article.

3.1. Austria: Structured Direct Absolute Addressing

Like most Western and European countries, the Austrian official addressing system follows a strict structure (i.e., the order of elements as well as their writing style, e.g., punctuations) are fully standardized: Austrian addresses begin with the street name along the house number separated by a blank space, which could be a single number (e.g., 27) or two numbers separated with a dash (e.g., 27–29), referring to several houses (as Figure 2 illustrates, the building numbers are ordered along the street, with odd and even numbers on different sides). If there are different units in the house, the unit (door) number comes after the house number separated by a slash (e.g., 27/12). In the case of having a block, an additional number comes between the house and the unit number, again separated by a slash (e.g., 27/8/12). Then, a comma and the district number along with the city name are written, which are separated by a blank space:

street_name building_no/block_no/door_no, district_no city



Figure 2. The components of an Austrian address.

The Austrian system is a direct absolute addressing system, which uses definite street names; nothing descriptive or out of the pre-defined structure is allowed. Such a structured system will provide a unique address for every location (the only exception is buildings with more than one entrance from different streets).

Note that there are other addressing conventions in Austria and other countries that have structured addressing systems, which may be used for specific purposes. Moreover, addresses are subject to small changes in verbal and written communication. For example, the order of components may change, which is compensated by human or machine flexibility. However, unless it is mentioned, here we refer to the official addressing systems (i.e., postal addresses).

3.2. Japan: Semi-Structured Indirect Addressing

The Japanese addresses are based on a hierarchical subdivision named by alphabetical or numeral codes (Figure 3). An address begins with the largest and ends with the smallest subdivision level. The country is divided into 47 “prefectures”, as the largest geographical subdivision level. All prefectures have a “-ken” suffix, except for “Tokyo-to”, “Kyoto-fu”, “Osaka-fu”, and “Hokkaido-do”, which have their special suffixes. The prefecture’s suffix may be omitted in the addressing.

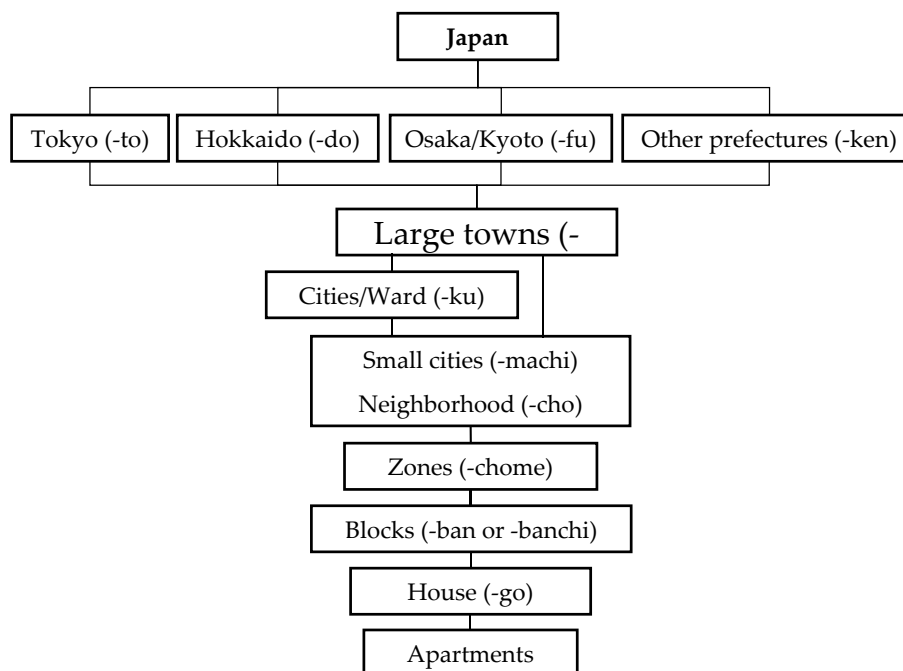


Figure 3. The hierarchy of the Japanese addressing system.

Prefectures are divided into large towns, suffixed by “-shi”, which may also be omitted in the addressing. These large towns are themselves divided into small cities, suffixed by “-machi”, or neighborhood, suffixed by “-cho”. In very large cities, there may be an additional subdivision called “ward” with the suffix “-ku” between large towns and small cities/neighborhoods. Small cities (machi) and neighborhoods (cho) are divided into numbered zones, suffixed by “-chome”.

Interestingly, (most) streets do not have names in Japan; as Figure 4 illustrates, they are just empty spaces between the blocks! The blocks are numbered across each zone (chome), which are suffixed by “-ban” in new parts and by “-banchi” in old parts of the cities. The suffix “-ban” may be omitted in the addressing, unlike the suffix “-banchi”, which is mandatory to mention. At the lowest level, houses on a block are numbered with the suffix “-go”, which could be omitted in the addressing. The order of house numbering is based on the date the houses are constructed, which leads to houses that are not spatially consecutively numbered within a given block. Apartment number (if any) would often come

after the building number with or without the suffix “-go” (e.g., 5-103 or 5-103-go), or seldom as a single number at the end of the address (e.g., 5-go, 103). Different combinations of “block–house–apartment” could be created from these rules, but some are more common (10-5-103-go/10-ban; 5-103-go/10; 5-103/10-5-103/9-banchi; 5-103).

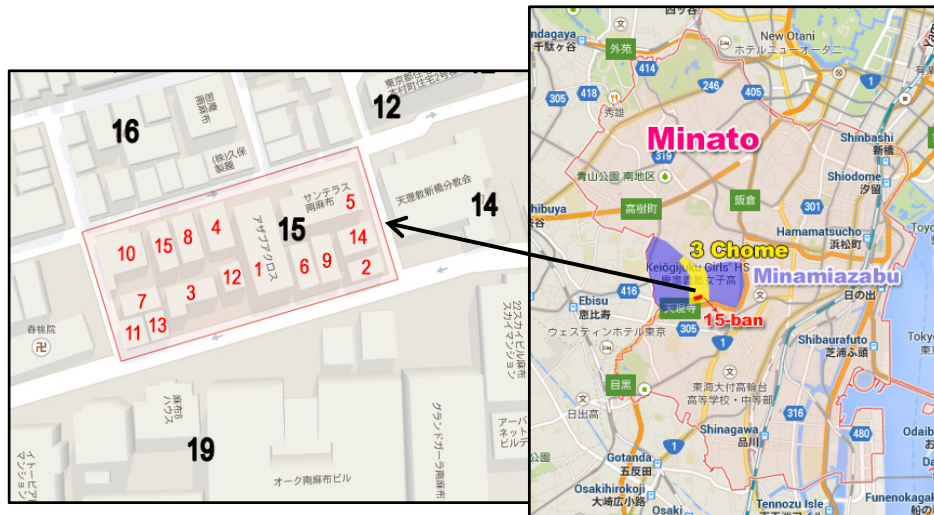


Figure 4. The components of a Japanese address. Note that there are no street names for the streets, but blocks are numbered. The buildings of block #15 are assigned imaginary numbers by the authors for more clarity.

The Japanese addressing system is semi-structured: there are certain formatting rules depending on the subdividing types (i.e., a certain location corresponds to a single type of addressing, but different subdividing types are addressed differently), and the writing styles (i.e., suffixes, block–house–apartment numbering, etc.) are flexible. Moreover, it is an indirect addressing, as different codes and numbers are the major elements of this addressing system.

3.3. Iran: Non-Structured Direct Absolute/Relative Addressing

In contrast to the above examples, sometimes there is no addressing structure whatsoever, and instead, addresses are expressed differently. An interesting example is Iran, where street names are not unique in a certain city, and thus additional procedural information is needed to make a unique reference. In Iran, people express addresses as a sequence of spatial features (e.g., streets, squares, landmarks, etc.), and their spatial relations (e.g., 100 m *after*, a few steps *before*, *in front of*, etc.) starting from a known element. For example, in Figure 5, the address of point A based on route #1 is “*Shariati Ave., Gholhak, Pabarja St., Ayeneh Blvd., West corner of Gol-e-yakh Alley, No. 2, Unit 9*”. The “*Shariati Ave.*” may be omitted if the receiver already knows *Gholhak*; or “*After Zafar St.*” may be added after “*Shariati Ave.*” to provide a less familiar receiver with some estimation on the part of the long “*Shariati Ave.*” we are talking about. Even worse, the same place could be equally referred to in completely different ways because different starting points or spatial elements may be used [32]. For example, based on route #2 in Figure 5, point A is referred to as “*Daroots, Shahrzad Blvd., Pabarja St., Ayeneh Blvd., West corner of Gol-e-yakh Alley, No. 2, Unit 9*”. This is somehow similar to a route description, but in a more formal manner, as no complete sentence is used; instead it is mostly composed of discrete spatial names and relations. It is also comparable to the *destination description* introduced by Tomko as a convention used by people with a shared knowledge of an environment to communicate a destination through its relations to the surrounding features, which allows the user to flexibly use the most relevant features (e.g., landmarks, path, district) in the generated descriptions [33].



Figure 5. The case of Iran: Location A is referred to in two equally valid ways using different starting points and spatial elements.

An Iranian address is a combination of direct addressing with absolute or relative references: any addressing concepts (street, junctions, landmarks, etc.) may be considered to have an addressing value and be used in the address in an absolute or relative form. Moreover, the addressing element and the level of detail used may differ from one user to another based on her prior knowledge about the environment, addressing purpose, starting point, etc.

4. Spatial Knowledge Acquisition through Addresses: An Agent-Based Simulation

The above theoretical investigations suggest that a formal pre-defined structure of some addresses puts limitations on peoples' natural spatial language while expressing the address of a place. In other words, having in mind that an address is supposed to be a piece of spatial information for fulfilling the everyday way/destination finding task, defining a strict structure for addressing leads to restrictions on adding relevant and necessary spatial information for such user-specific tasks. In order to investigate the effect that different addressing systems may have on peoples' spatial knowledge, a plain agent-based model was proposed to simulate spatial knowledge acquisition through addresses. We followed a two-phase procedure for modeling each addressing system: first by defining a grammar for each addressing system to make it decomposable by a computer; and second, by designing a learning scheme for agents to obtain possible knowledge from addresses.

4.1. Parsing of Addresses

Address parsing is the process of decomposing an address as a string of spatial information, whether expressed in formal or natural language, to its components. The output of this process is the discrete set of spatial and/or code-based components, which are extracted from the address. This process is directly related to the syntactic aspects of the addressing systems and thus is typically performed by geocoding machines to press out the matching components from addresses and relate them to the corresponding elements in the databases or on digital maps. The extracted components yielded by the address parsers are later used by the agent for the learning process. In point of fact, the knowledge blocks of the agent's knowledge base are constructed from the components provided by the parsing phase.

Details on the agent's parsing phase are mentioned in the following *syntax* subsection of each addressing system and are described in Backus Naur Form (BNF).

4.1.1. Parser of Austrian Addresses

An Austrian address is composed of the following elements, which are the tokens of the formal language of the Austrian addressing system:

$$\text{TokenAUS} = \{\text{STR}, \text{HAUS}, \text{BLK}, \text{TUR}, \text{BZR}, \text{ORT}\}$$

which respectively stand for Strasse (=street), Haus (=house), Block, Tür (=door), Bezirk (=district), and Ort (=city). The combination rules to produce/parse an Austrian address are:

```
addressAUS := (strasse " " gebaude ", " bezirk " " ort)

strasse    := name → [STR]
gebaude    := (haus "/" block "/" tur) | (haus "/" tur) | haus
haus       := (number "-" number) | number → [HAUS]
block      := number → [BLK]
tur        := number → [TUR]
bezirk     := number → [BZR]
ort        := name → [ORT]
```

The rule “*addressAUS*” is the start symbol of the language. The rule “*gebaude*” (=building) and “*haus*” (=house) are the only non-terminal symbols of the language (i.e., have several forms of variation). The rest are terminal symbols, which are indicated as “ $x \rightarrow y$ ”, meaning that x is a terminal symbol of the token type y . For example, the expression “ $\text{name} \rightarrow [\text{ORT}]$ ” means that the output name is the name of a city (i.e., ort). Table 1 illustrates the results of applying the above parser to two Austrian addresses.

Table 1. Results of applying the parser of the Austrian addressing system to two addresses.

Address	Component	Type
Gusshausstrasse 27, 1040 Vienna	Gusshausstrasse	STR
	27	HAUS
	1040	BRZ
	Vienna	ORT
Gusshausstrasse 27–29/8/12, 1040 Vienna	Gusshausstrasse	STR
	27–29	HAUS
	8	BLK
	12	TUR
	1040	BRZ
Vienna	ORT	

The language defined for the Austrian addressing system confirmed that this addressing system is fully formal: all of the tokens appear in every single address. There is only one start symbol, and the combination rules mostly lead directly to terminal symbols (i.e., directly result in tokens). Even the punctuation is fixed, and thus could be directly mentioned in the start symbol. The only exceptions are the tokens “block” and “tur” and the non-terminal symbol “gebaude”, which occurs because of different types of buildings (i.e., buildings with or without blocks/units), thus this is not the matter of addressing standard, but building type. Nevertheless, such exceptions have a minimal effect on the addressing structure: as a single rule “gebaude” appears in the start symbol and handles all the building types and captures all the variations (i.e., “/block” and/or “/tur” may be added after the building number).

4.1.2. Parser of Japanese Addresses

A Japanese address is composed of a subset of the following tokens:

$$\text{TokenJPN} = \text{PRF} \mid \text{SHI} \mid \text{WARD} \mid \text{MACHI} \mid \text{CHO} \mid \text{CHOME} \mid \text{BLK} \mid \text{HOS} \mid \text{APT}$$

The combination rules to produce/parse a Japanese address is:

```

addressJPN  := prefecture sep town sep region sep block sep building)

prefecture  := (name "-" prfSuffix) | name → [PRF]
prfSuffix   := "to" | "do" | "fu" | "ken"

town        := (shi sep ward) | shi
shi         := (name "-shi") → [SHI] | name → [SHI]
ward        := (name "-ku") → [WARD]
region      := (area sep zone) | area
area        := (name "-machi") → [MACHI] | (name "-cho";) → [CHO]
zone        := (number "-chome") → [CHOME]
block       := (number "-banchi") | (number "-ban") | number → [BLK]
building    := (house sep apartment) | house
house       := (number "-go") | number → [HOS]
apartment   := (number "-go") | number → [APT]

sep         := "-" | "," | ";"

```

The rule “*addressJPN*” is the start symbol of the language. Due to the many forms of variation that exist in the components of Japanese addresses, several non-terminal symbols appear in the parser. However, the variations are simply captured by defining multiple rules as they are described through a clear hierarchy (see Figure 3). The results of applying the above parser to two Japanese addresses is illustrated in Table 2.

Table 2. Results of applying the parser of the Japanese addressing system to two addresses.

Address	Component	Type
Hokkaido-do, Sapporo-shi, Teine-ku, Maeda-machi, 10-Chome, 2-8-25-go	Hokkaido	Prefecture
	Sapporo	Shi
	Teine	Ward
	Maeda	Machi
	10	Chome
	2	Block
	5	House
Tokyo, Minato, Minamiazabu, 3-Chome, 15-9	25	Apartment
	Tokyo	Prefecture
	Minato	Shi
	Minamiazabu	Machi
	3	Chome
	15	Block
	9	House

The Japanese addressing system can be formally defined, which confirms that it follows a structure, and can be defined with only a single start symbol. However, only a subset of tokens appear in a certain address and there exist more non-terminal symbols when compared to the Austrian system. Another difference lies in the combination rules due to different types of addressing components used based on the subdivision type of the location to be referred. In other words, the order of elements of addresses does not change (and thus a single start symbol could capture all of the cases), but the definitions of elements may differ from case to case (for example, a town could be of type shi-ward or shi). Furthermore, the optionally used prefixes, different types of punctuation and, especially, different writing formats for the “block–house–apartment” combination, made the rules more complicated, as they had to be defined in a way so that all of the variations were captured.

4.1.3. Parser of Iranian Addresses

An Iranian address may consist of any number of spatial groups (SG) that are composed of [32]:

1. Geo-names (GN)

- 1.1. Constant geo-names (CGN): avenue, street, alley, and so on.
- 1.2. Variable geo-names (VGN): names of the constant geo-names (street name, for example).

2. Relations:

- 2.1. Spatial relations (SPR): after, before, in front of, right of, left of, and so on.
- 2.2. Metric relations (MTR): composition of a numeral value (e.g., 100), a unit (e.g., meter, steps, minutes), and a spatial relation (e.g., after). Note that only a subset of spatial relations is relevant here. For example, "100 m in front of" is not a logical composition!

Therefore, the tokens of an Iranian address are:

$$\text{TokenIRN} = \text{SPR} \mid \text{MTR} \mid \text{CGN} \mid \text{VGN}$$

and the combination rules to produce/parse an Iranian address are as follows:

```

addressIRN  := {spGrp sep}

spGrp       := gn | (rel gn)

gn          := (cgn vgn) | (vgn cgn) | vgn
cgn         := "ave." | "avenue" | "st." | "street" | "blvd." | "alley" |
              "number" | "unit" → [CGN]

vgn         := name → [VGN]

rel         := spRel | (mtRel spRelType1)
mtRel       := (number unit) → [MTR]
spRel       := spRelType1 | spRelType2
unit        := "meter" | "m" | "steps"
spRelType1  := "After" | "Before" → [SPR]
spRelType2  := "In front of" | "Opposite to" | "Left of" | "Right of" →
              [SPR]
sep         := "-" | "," | ";" | " " | "."

```

Here, only a small number of the constant geo-names, spatial relations, and distance units are mentioned. Table 3 illustrates the results of applying the above parser to two Iranian addresses.

Table 3. Results of applying the parser of the Iranian addressing system to two addresses.

Address	Component	Type
Kashani Blvd., Keyhan Avenue, Before Sazman Avenue, 4th Keyhan alley, In front of Jame Mosque, number 13, unit 6	Kashani Blvd.	[VGN CGN]
	Keyhan Ave.	[VGN CGN]
	Before Sazman Avenue	[SPR VGN CGN]
	4th Keyhan Alley	[VGN CGN]
	In front of Jame Mosque	[SPR CGN]
	number 13 unit 6.	[CGN VGN] [CGN VGN]
Kashani Blvd., Keyhan Avenue, Before Sazman, 4th Keyhan Alley, 100 m after Jame Mosque, number 13, unit 6	Kashani Blvd.	[VGN CGN]
	Keyhan Ave.	[VGN CGN]
	Before Sazman	[SPR VGN]
	4th Keyhan Alley	[VGN CGN]
	100 m after Jame Mosque	[MTR SPR CGN]
	number 13 unit 6.	[CGN VGN] [CGN VGN]

The Iranian addressing system had the least structure among the addresses explored in our case study. The start symbol “*addressIRN*” indicates that an address is a set of spatial groups separated by various symbols, but has no information about the order or even the number of them. Furthermore, a spatial group could be either a spatial element “*gn*” (absolute addressing) or a relation “(*rel gn*)” (relative addressing), so the corresponding list of tokens is only a limited number of abstract concepts (i.e., spatial relation “*spRel*”, metric relation “*mtRel*”, etc.). The most problematic issue here for machine-based geocoding is the terminology: constant geo-names (*ave.*, *avenue*, *st.*, *street*, etc.), spatial relations (*after*, *before*, *in front of*, etc.), and units (*meter*, *steps*, etc.) are infinite lists in reality; there are unlimited terms that people may use for spatial elements and relations. Generally, in the absence of any standards, people may express addresses differently in terms of terminology, order, combinations, etc. Clearly speaking, this addressing is a natural language that cannot be fully formalized [22,34]. Therefore, not only the matching, but also the parsing process for some components may fail. This seems to be the reason that this class of addressing system has been mostly ignored by researchers due to its complex syntax modeling for computers.

Note that the tools of *Information Extraction Systems* [35,36] (which automatically extract structured information from unstructured and semi-structured documents) may provide solutions for easing the parsing of Iranian descriptive addressing. There are also knowledge-based approaches such as *shallow parsers* [37] (also called *chunking* or *light parsing*), which may be helpful in this regard. On the other hand, *lexico-syntactic patterns* [38,39] might be able to handle many forms of variation of expressions in a descriptive address without needing to list all possibilities. However, even if such approaches succeed for this aim, it is an indication that parsing descriptive addresses needs extensive effort compared to structured and semi-structured ones.

4.2. Spatial Learning Process

This section implements a module for simulating spatial knowledge acquisition from addresses by an agent. Similar to an address matching engine in first encountering an address, the human brain starts by decomposing the address and extracting its components. Then, it tries to interpret the components and relate them to the corresponding elements that might have existed in its spatial mental representation. If this process terminates in the interpretation phase, then the person should probably look for external sources of help and information (e.g., asking people who are familiar with the surroundings or making use of maps or digital services with address matching capabilities like navigation systems). In other respects, if the person successfully passes the interpretation phase but could not match the components with corresponding elements in their spatial mental representation, they essay a reasoning process in the spatial knowledge already coded in their cognitive map to figure out the address. If this fails, they might again need assistance from external sources of information. In any case, these pieces of spatial information are either stored as a new knowledge block and added to the spatial mental representation, or just stimulate the already known knowledge blocks and make them more persistent.

The exact same strategy is taken for the design and implementation of an agent’s spatial knowledge acquisition from addresses. A simple table-form knowledge base (KB) stores the *spatial knowledge blocks* of the agent. The fields of this table are possible addressing components (e.g., street name, building no., district, city, etc.), and two more fields, the *impression factor* (IF) and *learning score* (LS), which will be explained shortly in detail. For each address, the agent first parses it to its components and then either adds it to KB (if it is a new piece of information), or reinforces the existing records with a defined impression factor to spell out the more frequent elements of addresses.

The impression factor (**IF**) is a factor used by the agent to distinguish different levels of familiarity with the address and specifies how much an address contributes to acquiring or completing the agent’s spatial knowledge. Given a certain address, each of its components is searched in the existing agent’s KB. Any new component is assigned $IF_e = 0$ and those components that already exist in the KB are assigned $IF_e = 0.01$. Then, the **IF** of the address is the sum of the IF_e of all of its components. In other

words, any component that already exists in the KB would increase the *IF* of the address by 0.01. For example, if an Austrian address is completely unknown to the agent (i.e., none of the district, street, and building numbers exist in its KB), then *IF* = 0. If, however, the agent already knows the district, then *IF* = 0.01. Note that a numerical value such as building number (which is not unique in the entire city) cannot be considered as known information (and thus increase the *IF*) unless its combination with its upper level non-numerical value makes a unique reference (i.e., exists in the KB).

Learning score is the cumulative measure for the impression factors (i.e., the sum of impression factors for all records (Equation (1)).

$$\text{Learning Score} = \sum_{i=1}^j \text{IF}_i; \quad j = \# \text{ rows} \quad (1)$$

This measure can convey the amount of spatial knowledge acquired by addresses, and therefore can be considered as a quantitative base for the learning curve analysis in Section 4.3.

4.2.1. Spatial Learning for an Austrian Agent

As mentioned before, the initial step for an agent's learning process is address parsing. As an example, consider the input address as "Mayerhofgasse 7, 1040 Vienna". The parser would return the list as follows:

[("Mayerhofgasse",STRS), ("7",HAUS), ("1040",BZR), ("Vienna",ORT)]

In the second step, the agent constructs the knowledge base according to the defined structure:

No.	STR	HAUS	BZR	ORT	IF	LS
1	Mayerhofgasse	7	1040	Vienna	0.0	0.0

As of now, the agent adds the components of each address to the existing KB. The consequential part, however, is the search that should be operated in the KB to find the correct IF for newly imported addresses. The search function used here is a plain string search operator applied on each column in the sequence of district, street, and house number. In other words, by providing new addresses to the agent, it first checks out the district column to assign the correct IF. If there is no matching district number in the KB, the agent would proceed to street column and then to house number. Although it might seem that due to the uniqueness of the street names in Vienna, the search can easily be run only on this field, there exist some exceptions like the long street of Mariahilferstrasse, which lies in two districts (1060 and 1070).

For instance, in the case of importing "Gusshausstrasse 27, 1040 Vienna" and then "Gusshausstrasse 36, 1040 Vienna", the KB is completed as follows:

No.	STR	HAUS	BZR	ORT	IF	LS
1	Mayerhofgasse	7	1040	Vienna	0.0	0.0
2	Gusshausstrasse	27	1040	Vienna	0.01	0.01
3	Gusshausstrasse	36	1040	Vienna	0.02	0.03

4.2.2. Spatial Learning for Japanese Agent

Almost the same process as that of the Austrian agent's learning process was carried out for the Japanese addressing system. The main difference is that the *Chome*, *Block*, *House*, and *Apartment* fields are numerical. Thus, as mentioned earlier, they increase the IF only if their combination with all upper level fields until the first non-numerical field exists in the KB. For example, if "Machi Maeda, Chome 10, Block 2" exists in the KB, then "Machi Minamiazabu, Chome 10, Block 2" is considered as new

knowledge. The parser for Japanese addresses returns the components in a table format, just like in the Austrian case:

No.	Prefecture	Shi	Ward	Machi	Chome	Block	House	Apartment	IF	LS
1	Hokkaido	Sapporo	Tiene	Maeda	10	2	5	25	0.0	0.0
2	Tokyo	Minato	-	Minamiazabu	3	15	9	-	0.0	0.0
3	Hokkaido	Sapporo	Tiene	Maeda	5	7	6	12	0.04	0.04

4.2.3. Spatial Learning Process for an Iranian Agent

The same parsing procedure was performed on Iranian addresses as explained in Section 4.1.3. The output of this phase is the addressing components, of which there are three kinds: variable and constant geo-names, and spatial relations. Since Iranian addresses are expressed in natural language, the whole learning process as well as the spatial reasoning part become more intricate and, of course, more difficult. In order to ease this complication, especially in the spatial reasoning process, a binary relation structure is defined for the addressing components. In other words, the reasoning process is based on the extraction of all possible pairwise relations between the components. Let us consider n to be the number of elements in an address. According to Equation (2), there exist $\frac{n(n-1)}{2}$ relations between pairs of components.

$$\#Relations = \frac{n(n-1)}{2} ; n = \# \text{ elements in an address} \quad (2)$$

For instance, consider “street x , after passing street y , no. 2” and its schematic sketch (Figure 6).

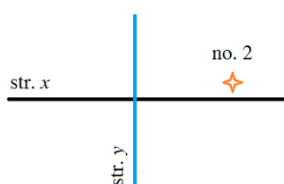


Figure 6. Two examples of crossing streets x and y and building no. 2 located in street x .

Both theoretically and discernibly, there exist three pairwise relations between three elements of the address: $\langle \text{str. } x, \text{str. } y \rangle$, $\langle \text{str. } y, \text{no. } 2 \rangle$, and $\langle \text{str. } x, \text{no. } 2 \rangle$. These relations indicate “connection” (i.e., streets x and y are connected), “sequence” (i.e., building no. 2 is located after street y), and “containment” (i.e., street x contains building no. 2), respectively. However, these pairwise relations are not always logically meaningful. For example, regard the previous address as “street x , street y , no. 2” (Figure 7). By excluding the spatial relation between x and y from the previous address, the binary relation $\langle \text{str. } x, \text{no. } 2 \rangle$ is no longer true.

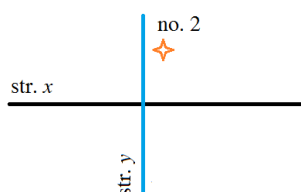


Figure 7. Two examples of crossing streets x and y and building no. 2 located in street y .

Accordingly, we should define some constraints to filter the list of pairwise relations of addressing components to reach a list of legitimate relations both logically and spatially. After examining over a hundred Iranian addresses, a set of four simple rules were defined to filter the initial list of binary

relations. It is noteworthy that although these rules were taken into account based on typical addresses in Iran, since Iranian addresses are expressed in natural language, one can never guarantee coverage of all instances of an address given by different people.

These rules are expounded in the following categories of addresses:

- **Linear instructions:** Addresses of this category are similar to simple route instructions that lead you from an origin to a destination by following a linear path described. An example would be “street x , after passing street y , in front of building b , no. 2” for which the schematic sketch is shown in Figure 8.
- **Linear instructions ending with the spatial element “alley”:** Since in Iran, and particularly in Tehran (as the case study in this article), the residential areas are planned to end up in alleys instead of streets, most Iranian addresses that refer to houses and apartments end with a building number in an alley. This spatial element would interrupt the continuous relation between pairs. In other words, the elements that come before the keyword “alley” would no longer have any relation with the elements that are coming afterward. An example of this category is “street x , after passing street y , before reaching to street z , alley a , no. 2” (Figure 9).
- **Linear instructions with explicit change in the direction:** Sometimes it happens that Iranian addresses (even the ones that are given for postal delivery services) contain terms like “turn left/right to street x ”. This explicit change in the direction interrupts the linear instruction just the same as the foregoing category (i.e., it severs the relations between the elements coming before and after this term). To further clarify, consider “street x , after passing street y , turn left to street z , alley a , no. 2” as an example (Figure 10).
- **Linear instructions with implicit change in direction:** In contrast to the preceding category, most of the time, Iranian addresses have one or more changes in direction that are implicitly mentioned. The most common example would be when the address has the component of “crossing”, or two streets/avenues following each other without any further relations. Consider “street x , cross c , street z , alley a , no. 2” or “street x , street z , alley a , no. 2” (Figure 11). Obviously, by turning to street z , all the relations connecting x or y to a or $no. 2$ are severed.

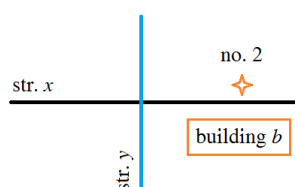


Figure 8. An example of simple linear instruction addressing.

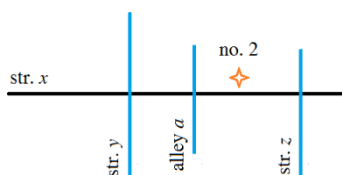


Figure 9. An example of linear instructions addressing ending to the spatial element “alley”.

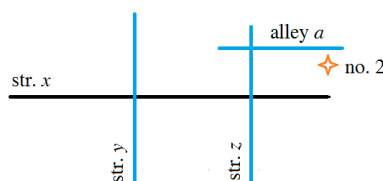


Figure 10. An example of linear instruction addressing with explicit change in the direction.

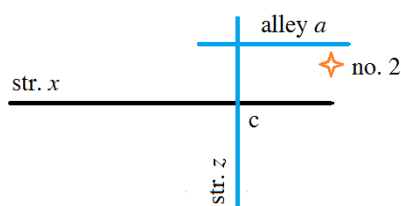


Figure 11. An example of linear instruction addressing with implicit change in the direction.

Based on these four categories, the list of possible relations would be filtered. The refined list of relations makes the spatial knowledge blocks for the agent's knowledge base. By feeding the agent with new addresses, the agent would carry out several steps for each address:

- It first parses the address to its components:

Parsing “number 5, 4th Keyhan alley, Keyhan ave.”:

```
[[("Keyhan", VGN), ("ave.", CGN)], [("Kehan4", VGN), ("alley", CGN)],
[("5", VGN), ("number", CGN)]]
```

- Then makes all the pairwise relations and refines them based on the rules:

Making relations:

```
[(["Keyhan", "ave."], ["4th Keyhan", "alley"]), (["Kehan", "ave."], ["5", "number"]),
(["4th Keyhan", "alley"], ["5", "number"])]
```

Applying filters:

```
[(["Keyhan", "ave."], ["4th Keyhan", "alley"]), (["Kehan4", "alley"], ["5", "number"])]
```

and then with the outputted relations makes the knowledge base as follows:

No.	VGN1	SR_ID	VGN2	IF	LS
1	Keyhan	1	4th Keyhan	0.0	0.01
2	4th Keyhan	2	5	0.01	

The impression factor here was considered to be 0.01 for any new record of spatial relation. For instance, if street x was already available in the knowledge base, and a new address contains y , which is somehow connected to x , this piece of information $\langle x, y \rangle$ would get 0.01 as its impression factor, and 0 for repetitive knowledge blocks.

In descriptive addresses and route descriptions in general, the many terms for spatial relations like “near”, “left/right of”, “at the corner”, etc., promote the spatial reasoning process. In order to ease this process for our agent, a column labeled as “SR_ID”, which stands for *Spatial Relation ID*, was added to the knowledge base. This field contains codes from 1 to 6, each showing different kinds of spatial relation between the variable geo-names, according to Table 4.

Table 4. Different kinds of spatial relations between variable geo-names.

SR-ID	Second Component	Relation	First Component
1	$\forall x \in U_{SE}$	“connected”	$\forall x \in U_{SE}$
2	$\forall x \in U_{SE}$	“located in”	No./ Landmark
3	$\forall x \in U_{SE}/\text{Landmark} + (\text{after}/\text{before})$	“sequence”	$\forall x \in U_{SE}/\text{Landmark} + (\text{after}/\text{before})$
4	$\forall x \in U_{SE}/\text{Landmark} + (\text{after})$	“after”	No./ Landmark/ $\forall x \in U_{SE}$
5	$\forall x \in U_{SE}/\text{Landmark} + (\text{before})$	“before”	No./ Landmark/ $\forall x \in U_{SE}$
6	$\forall x \in U_{SE}/\text{Landmark} + \forall SR \in U_{SR}$	“related to”	No./ Landmark

To map each qualitative spatial relation to a code, consider the set $U_{SE} = \{\text{street, st., avenue, ave., cross, sq., square, alley}\}$ as the set of *spatial elements* presenting pathways, and U_{SR} as the set of *spatial relations* (e.g., at the corner of, in front of, left of, right of, except for two relations “before” and “after” used in addressing). The reason to exclude them from the set of spatial relation is their importance in spatial reasoning: if, in a linear settlement, *A* is located *after B* and *B* is located after *C*, then it can be inferred that *A* is located after *C*. This train of thought helps the construction of a mental street network in one’s cognitive map through such spatial description analysis. Accordingly, the first row of Table 4 indicates that if both variable geo-names (VGN1 and VGN2) are pathway spatial elements, and no spatial relation is explicitly mentioned between them in the address, then the easiest relation to infer would be *connection* (i.e., these two paths are connected. This junction is documented by the code “1”. The second row describes the situation where a building number or a landmark (any salient building that is easily distinguishable and has addressing value) is mentioned in a street or other kinds of pathway spatial elements, then an *inclusion* relation can be inferred. If the address contains two spatial elements/landmarks each having sequential relations “before” and “after” (e.g., “after passing street *x*, before reaching building *b*”), a simple *sequence* relation is not only convenient for the purpose of this article, but it also eliminates the complexities. This sequence relation is reported by the id of “3” in the agent’s knowledge base. Another similar, but more specific, case with these two sequential relations (“before” and “after”) happens when only one variable geo-name is expressed with relations *before* or *after* (e.g., “street *x*, after passing building *b*”). Unlike the previous situation, this combination explicitly specifies the sequence to be *before* or *after*. In a linear constellation of spatial features like urban street networks, knowing the specific sequential relation between elements would provide a practical reasoning platform. Therefore, such relations are identified by ids “4” and “5” for *after* and *before*, respectively. Any other kind of spatial relation a landmark or a building can have with other spatial elements (e.g., “at the corner of the old café, no. 5”) simply conveys a *relation* (e.g., between old café and building no. 5), which is coded with number “6” in the knowledge base.

As a matter of course, there might exist other combinations of spatial elements and relations used in addresses, which would lead to different triples of $\langle \text{VGN}, \text{SR}, \text{VGN} \rangle$ and were not considered here in this article. In fact, what is introduced here to model descriptive addresses is a simple sample of what can practically be obtained from natural language processing of descriptive addresses. For the sake of this article, which was to prove that descriptive addressing can carry and hand over a considerable amount of information and knowledge to people, this small set of examples would work properly.

These codes were assigned to each triple that had been added to agent’s knowledge base to run a spatial reasoning process. The existence of spatial relations in descriptive addresses or any kind of spatial description provides the remarkable capability of spatial reasoning procedures. In other words, this salient capability is not just beholden to the number of elements a descriptive address can carry. In fact, it is achieved by the simple use of spatial relations in such addresses and descriptions. Relations play a critical role in the spatial reasoning process and also connect different parts of spatial mental representation to each other.

By taking advantage of this source of information in descriptive addresses, here, we performed a reasoning process based on the spatial relation ids assigned to each row. Each time, by adding a new address to the knowledge base, a search process is initialized through the whole rows by the agent not only to assign the correct IF value, but to also derive the new possible pieces of information through the reasoning process. This second affair leads to gaining more knowledge than was implied in the address. An undemanding set of *if-then-else* rules is applied on the SR_IDs to gain new knowledge as follows:

SR_ID Value	Statements	Concluding Statement
$SR_ID_{\langle x, y \rangle} = 5$	x is located <u>before</u> y	$SR_ID_{\langle x, z \rangle} = 5$ x is located <u>before</u> z
$SR_ID_{\langle y, z \rangle} = 1$	y is <u>connected</u> to z	

Accordingly, not only are the two rows of $\langle x, 5, y \rangle$ and $\langle y, 1, z \rangle$ added to the knowledge base, but the inferred row $\langle x, 5, z \rangle$ is appended. This very process causes a substantial growth in the agent's knowledgebase, which is later analyzed by learning curves in the following sections.

4.3. Spatial Learning Rate

In order to compare the spatial knowledge acquired from different classes of addresses, *learning rate* was deployed, which is a quantitative measure used to show the speed of a learning process and determines to what extent the volume of information is increasing in an agent's mind [40]. Learning processes are usually analyzed through learning attained by time, experience, cost, number of iterations, effort, etc. As the objective of this article states, we aspired to examine spatial learning acquired by *the number of addresses* provided to an agent.

There are many ways to compute a learning rate, however, an easy way is to calculate it from the corresponding learning curve. A learning curve is a graphical representation of the increase of learning (vertical axis) with respect to experience, time, or any other factor of interest (horizontal axis) [41,42]. To plot a learning curve, one should first determine the factor of learning and also the factor against which the learning is contemplated. In our case, the learning scores (LS) that were added up by the agent for each address were considered to be the learning factor; and the number of addresses provided to the agent played the role of the horizontal axis.

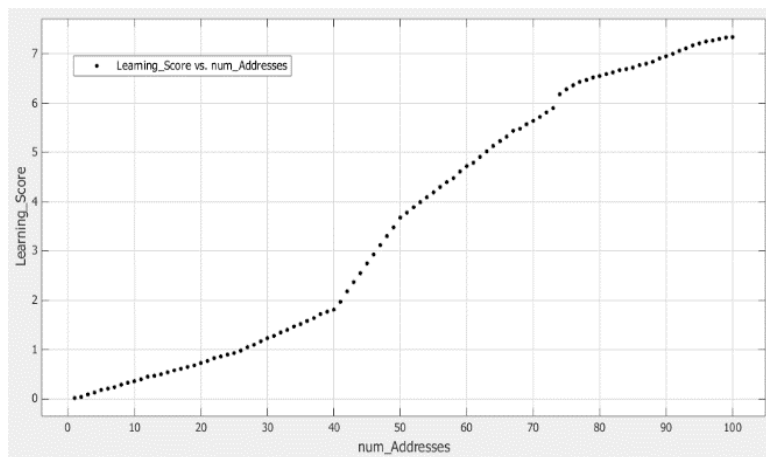
The critical issue here is that in order to have a fair comparison, the distribution of addresses must be relatively equal in each case city. For example, having to compare the effect of 100 addresses distributed through Tehran with the area of 950 km^2 with the same number of addresses distributed over Vienna with 414 km^2 is definitely not reasonable (Figure 12).



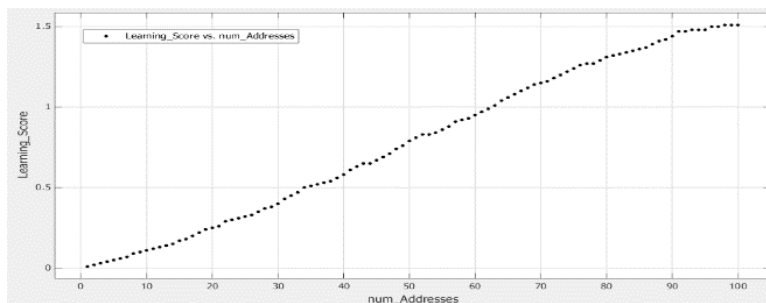
Figure 12. The maps of the three study cities and their areas.

Two approaches can be used in this situation: either to choose the number of addresses in correspondence to the area of the study region, or to limit the area of different study regions to be relatively equal and pick the same number of addresses. The latter was applied in this study. The total area of nine administrative districts (nos. 1,2,3,4,6,7,8,11,12) in Tehran is equal to 419 km^2 , which makes it comparable to Vienna in an acceptable approximation, which also applies to Tokyo. Therefore, 100 addresses were distributed over this limited area of Tehran, Tokyo, and the city of Vienna to analyze the learning rates of the agent in each case.

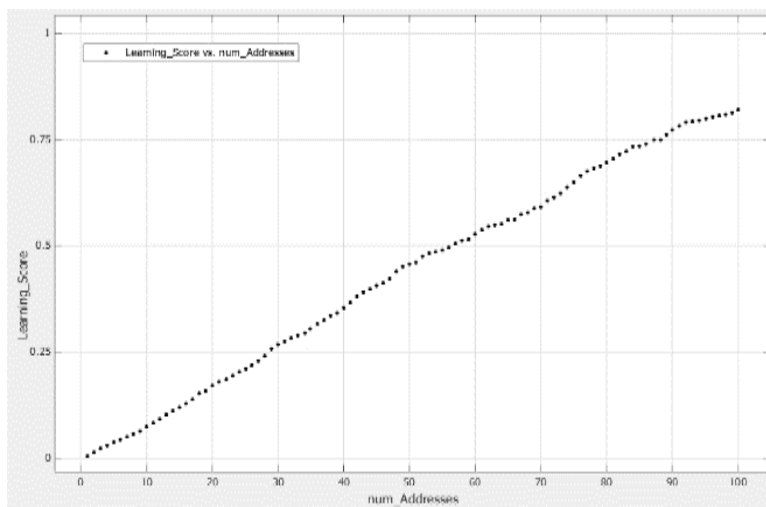
As mentioned earlier, here we considered the LS as the learning measure and the number of addresses (which was 100 in all cases) as the experience factor to plot the learning curve corresponding to each addressing system. After plotting these values against each other, a smoothing function was applied to the raw learning curve to make the computation of its derivative less demanding. The average derivative amount of each learning curve was considered as the learning rate corresponding to that addressing system. Figure 13 illustrates the initial plots of LS to 100 for the three cases of addresses.



Initial learning curve of Iranian addresses



Initial learning curve of Austrian addresses



Initial learning curve of Japanese addresses

Figure 13. The initial plots of LS to 100 for each case of addresses.

The fitting functions for all cases here comply with logistic function (Equation (3)).

$$f(x) = \frac{L}{c + e^{-k(x-x_0)}} \tag{3}$$

where e is the natural logarithm base (also known as Euler’s number); x_0 is the x -value of the sigmoid’s midpoint; L is the curve’s maximum value; and k is the steepness of the curve. Table 5 reports the parameters of the logistic functions fitted in each case.

Table 5. Parameters of the logistic functions fitted in each addressing system.

Fitness Function Parameters	Iran	Austria	Japan
C	0.023	0.062	0.083
K	0.092	0.013	0.009
L	0.169	0.099	0.076

Finally, the learning rates for each case addressing system were computed according to Table 6.

Table 6. Learning rates for each addressing system.

Iran	Austria	Japan
9.2	1.3	0.9

The implementation results underline the impact that the amount and the kind of spatial information coded in the address can have on peoples' spatial knowledge as well as their spatial mental representation. Furthermore, the types and constellation of spatial information mentioned in the addresses would provide different levels of spatial knowledge. It was observed that structured addresses, which have less flexibility in adding proper spatial information, would provide less information either for fulfilling destination-finding tasks or for gaining spatial knowledge. In particular, the hierarchical code-based structure of the Japanese addressing system as well as its temporal order convention within a block severely influences the speed of spatial knowledge acquisition.

The most significant part in the learning process is carried out by reasoning. The reasoning process in a spatial problem is based on the number of relations one can infer from the objects' constellation. The more the relations are mentioned either explicitly or implicitly, the more new relations and information are inferred. The exact manner is the reason for the learning rate gained through Iranian descriptive addresses to be seven times more than what is gained through Austrian structured and 10 times more than Japanese semi-structured code-based addresses. In other words, the relations mentioned between elements in Iranian addresses seem to make the spatial mental representation richer in information, and expedites the place-learning, especially in urban areas.

5. Semantic and Pragmatic Analysis of the Case Addressing Systems

Derived from the agent-based simulation and rooted in the implementation outcomes, this section reviews the case addressing systems under the principles of semantic and pragmatic analysis with an eye on linguistic aspects. Human spatial language can be considered as a sign that provides the means for people to communicate with the environment, and therefore, can be examined through levels of syntax, semantics, and pragmatics. Here, we consider an address as a spatio-linguistic proposition containing necessary information for making a location uniquely recognizable. The following subsections look into semantic and pragmatic analysis for the Austrian, Japanese, and Iranian addressing systems.

5.1. Semantics and Pragmatics of the Austrian Addressing System

An Austrian address consists of a "containment" relation between the street and the district (street **S** is contained in district **D**). Moreover, the building number mentioned in the address has addressing value as buildings are spatially ordered along the street, with odd and even numbers belonging to different sides. Therefore, an Austrian address means:

- Containment: Relation between the street and district.
- Spatial order: Relation between the building number and the street.
- Orientation: Relation between the building number and sides of the street.

Putting the above information together, the users know the district and street of the location and can estimate the position and orientation of the target place with respect to the street.

From a pragmatic point of view, to interpret an Austrian address, prior knowledge of the agent about the addressing structure is essential. The agent should know the order of components and their corresponding interpretation. They cannot understand components like 27–29/8/12 or 1040 unless they know the structure (see Section 3.1). Nevertheless, the structure of the Austrian addressing system is easy to learn because there are no exceptions or variations; once an agent learns this structure, they are able to interpret any Austrian address.

An Austrian address provides information on the <district–street>, <street–building>, and <street side–building> relations. The address only specifies the city, the district, and the street; but as absolute addressing, it provides no clue as to relations among them (e.g., if one is in the district, she is not instructed how to reach the street). Therefore, the address is a fair estimation of the location as well as how to navigate there, depending on the prior knowledge of the agent. For example, if one only knows the district, but not the street, their estimation is up to the district level, which is partially helpful to navigate through.

Finally, the Austrian addressing system contains spatial features “street” and “district” (i.e., a direct addressing). As above-mentioned, the building number is also considered a spatial concept. Therefore, the Austrian addressing system can contribute to improving the spatial mental representation in terms of street–district relation. Nevertheless, a human needs to already know the street, or at least the district, in order to imagine the location to some extent. In other words, one cannot have an image from the location to which an address refers, unless some of the spatial elements of the address already exist in their spatial mental representation.

Table 7 summarizes the syntactic, semantic, and pragmatic evaluation on the case studies.

5.2. Semantics and Pragmatics of the Japanese Addressing System

A Japanese address reveals the containment relations between prefectures, large towns (shi), cities (ward), and small cities/neighborhoods (machi/cho). However, this is not the case for zones (chome), blocks (band or banchi), and building numbers (go), because they restart from 1 at each upper subdivision (for example, each zone has blocks #1, #2, #3, ...), and thus are less spatially informative. In particular, the building numbers are temporally-ordered and provide no information about the spatial relation between the buildings. Therefore, a Japanese address means:

- Containment: Relations between prefectures, large towns (shi), cities (ward), and small cities/neighborhood (machi/cho).
- Temporal order: Relation between the building number and construction date.

The above information provides the users with the prefecture, large town, city, and small city/neighborhood of the location. However, the zone, block, and especially the temporally-ordered house numbers, are less spatially meaningful.

In terms of pragmatics, similar to the Austrian, the Japanese addressing system needs prior knowledge to be conceived: there are several structures with different types of components for different types of administrative units. The situation is even more difficult as most of the suffixes may be dropped and can be written in different formats, therefore, considerable practice is needed to learn that in “*Osaka-fu, Yokohama, Hommachi-cho, 4-7-203*”, the “*Yokohama*” and “*4*” are “a town” and “a block in new part of *Hommachi* neighborhood”, respectively. The major difficulty seems to be that the components are mostly related to code-based administrative units (i.e., indirect addressing), which is not necessarily compatible with the spatial elements of human cognition.

Table 7. Summary of the syntactic, semantic, and pragmatic evaluation of the case addressing systems.

Addressing System.	Type		Description	Syntactics			Semantics	Pragmatics		
	Direct			Structure	Writing Style (e.g., Punctuations, Suffixes)	Automated Geocoding		Corresponding To spatial Mental Representation	Wayfinding	Spatial Knowledge Acquisition
	Absolute	Relative								
Austrian	•			Structured. There is a unique address for every location.	Writing style is strict.	The address can be automatically parsed, interpreted and matched on the map, because types and order of the addressing components as well as the writing style are pre-defined.	<i>Containment</i> : Relation between the street and district <i>Spatial order</i> : Relation between the building number and the street <i>Orientation</i> : Relation between the (odd and even) building number and sides of the street.	Prior knowledge about the addressing structure is essential to interpret an address. The “district–street” relation and the building number with the odd–even rule provides an estimation of the location, depending on the prior spatial knowledge of the agent from the area.	The “district–street” relation and the building number with the odd–even rule provides an estimation of how to navigate there, depending on the prior spatial knowledge of the agent from the area.	The “district–street” relation and the building number with the odd–even rule contribute to improve the spatial mental representation, in terms of street-district relation.
Japanese		•	An address is a hierarchical subdivision named by alphabetical or numeral codes. Streets have no name; instead blocks are numbered. Building of a block are numbered ordering by the construction date.	Semi-structured. There is a unique address for every location. However, various addressing structures are used for different types of subdivisions.	Writing style is flexible, because most of the suffixes may be dropped. Especially there are different writing styles for block-building-unit combinations.	The address can be automatically parsed, interpreted and matched on the map. The parsing is complex, though, as different addressing structures (in terms of components’ type, order and writing style) must be captured.	<i>Containment</i> : Relations between prefectures, large towns (shi), cities (ward), and small cities/neighborhood (machi/cho) <i>Temporal order</i> : Relation between the building number and construction date.	Prior knowledge about the addressing structure is essential to interpret an address. The non-spatial temporally-ordered codes allow less spatial inference to correspond an address to the spatial mental representations.	The non-spatial temporally-ordered codes allow less spatial inference for wayfinding, due to absence of any information about spatial relations between the subdivisions.	One can only learn the relations between the subdivisions mentioned in the address. No information about a neighbor subdivision can be inferred.
Iranian	•	•	An address is expressed, in the form of a route description, as a sequence of spatial features and relations starting from a known element. Street names are not unique.	Non-structured (natural language). Infinite forms of addressing to a certain location is possible depending on the start point and the spatial features/relations used.	The writing styles is free: any punctuation symbol may be used. The prefixes and suffixes may be written differently (i.e., <i>avenue, ave., street, st., etc.</i>).	The parsing, interpreting, and matching is very difficult (if not impossible), because of non-structured format, various addressing features used, and free writing style.	<i>Process</i> : Quantitative and qualitative spatial relations between a set of consecutive spatial features in the form of rote description process <i>Spatial order</i> : Relation between the building number and the street <i>Orientation</i> : Relation between the building number and sides of the street.	Components can be easily interpreted as the address is self-explanatory expressed in the form of a natural language.	The address is already expressed as a route description.	The address has information about the relations between several spatial elements, which helps to improve spatial knowledge. The address can be expressed in the LoD relevant for the receiver.

On the other hand, the Japanese addressing system consists of different levels of spatial elements up to small cities/neighborhood (i.e., prefecture, shi, ward, and machi/cho). However, the zones, blocks, and building numbers repeat at each upper subdivision, and thus allow less spatial inference. Once in the subdivision level n , one has to search for subdivision level $n + 1$, on their own as the address has no information about the spatial relations between the subdivisions. In other words, if one has been in block, say 14, they may not necessarily imagine the location of block 15. Even if one knows the block, they cannot imagine where the building number refers to unless they have been there before, and found it on the map or other forms (e.g., verbal spatial information). In any case, this information would not depend on the numbering provided by the address, but it has more connections to the spatial features of the environment. In other words, the information provided by the address does not considerably contribute to associating it with the spatial mental representation or wayfinding. This seems to be one reason that Japanese business cards typically have small maps of the area on the back to indicate the location of the desired place.

Finally, this addressing is free of relations between spatial elements. This spatially-inconsecutive indirect code-based addressing seems does not seem to be so compatible with the human spatial thinking. Once you know a block, you can remember where it is, but its relation to other blocks and relations between the buildings of the block are not necessarily added to the spatial knowledge due to the inconsecutive numbering. There is evidence, to which many Japanese post services also refer, clearly pointing out the fact that in some parts of the country (e.g., Kyoto, where there is often more than one neighborhood with the same name within a single ward, making the system extremely confusing), people tend to use spatial elements like landmarks or naming the intersection of two streets and then indicating if the address is north, south, east, or west of the intersection, in order to somehow interact with the environment and realize their cognitive knowledge.

5.3. Semantics and Pragmatics of the Iranian Addressing System

The Iranian addressing system expresses an address in the form of a route description process starting from a known place for the receiver. It describes the spatial relations (e.g., before, after, front, opposite, intersection, next, etc.) between a set of spatial features. The relations could be quantitative (e.g., 100 m) or qualitative (e.g., a few steps, a few minutes walking, in the middle of), and the spatial features could be anything with an addressing value, ranging from streets and crossings to city sectors, neighborhoods, landmarks, buildings, etc. Moreover, as in Austria, the building numbers are spatially ordered along the street, with an odd and even rule. Therefore, an Iranian address means:

- Process: Quantitative and qualitative spatial relations between a set of consecutive spatial features in the form of rote description process.
- Spatial order: Relation between the building number and the street.
- Orientation: Relation between the building number and sides of the street.

The above combination is a process that provides the users with the position of the target location.

From the viewpoint of pragmatics, the Iranian addresses are self-explanatory and need minimum prior knowledge to be interpreted because the components and combinations are mostly naturally expressed. It is a set of spatial groups, each of which provides information about the spatial features (CGN and VGN) or relations (SPR and MTR). It is already a route description, which starts from a place known to a familiar, or well-known enough for an unfamiliar agent to be easily reached, then continuously navigates through the destination referring to the spatial features of the environment. If an agent knows the start point and the spatial features, they can imagine and estimate the destination. Nevertheless, it requires that the agent knows the starting point and is able to interpret and match the instruction to the spatial features she encounters along the way.

This direct absolute/relative addressing system frequently exposes the agent to the spatial features of the environment as well as their spatial relations. Such descriptive addresses not only specify the

destination, but also navigate through the location step-by-step. Therefore, they have a considerable contribution to acquiring spatial knowledge.

A distinct characteristic of the Iranian addressing system is its flexibility: an address could be any number and order of expressions as long as they obey the rule of spatial groups. The starting point and the level of detail provided in the address are flexible and depend on the current location as well as the spatial knowledge of the agent. The address can be changed in a way that the two parties can go to a level of detail that is comprehensible (based on their knowledge about the environment, their spatial abilities, etc.) for both sides. This pragmatic communication depends on the spatial knowledge of the communication parties as well as what their expectation of the other communication party's spatial knowledge. However, their mental models are not necessarily identical. Therefore, the negotiation continues over the proper amount of level of detail and continues until the differences are eliminated and a shared spatial representation (i.e., a common ground) is reached [43,44].

This flexibility also provides an opportunity for better place learning. As Golledge and Stimson [24] argued, place learning "is a cognitive process guided by spatial relationships rather than by reinforced movement sequence . . . there are clear implications that places are learned, that possible connections between them are built up over time, and that individuals develop a capacity for linking previously unknown [locations] . . . by referring to a general spatial schema that incorporates concepts of [spatial relations]". An Iranian address flexibly provides various movements to reach a certain location, rather than a fixed movement sequence.

6. Discussion

Humans organize spatial memory in two different ways: linear path and hierarchical regional subdivisions [31]. A survey on the case addressing systems shows that Austrian and Iranian systems follow this organization: they contain a hierarchical subdivision to approximately refer to a place, and then a linear oriented second part accompanies it to accurately specify the destination. The first part gives a cognitive LoD description, which to some extent, different users may interpret and learn from, and the second part adapts locally. However, the level of success differs depending on the addressing concepts used. However, in the Japanese addressing system, the hierarchical subdivision continues to the block level, and then a temporal order is employed for the apartment number level with a block.

On the other hand, as a perceptual image of locations in reality, people expect addresses to provide procedural knowledge, "which involves identification of locations on a path or landmarks on or near a chosen route segment" ([24], p.163). However, computers expect addresses to be declared in the order that they can be decomposed, interpreted, and matched on the map, which is the question of syntax and has less to do with cognitive issues. As examined, it causes most of the current structured addressing systems to only include absolute addressing concepts (which can be formalized in terms of their type and order), and ignore relative and descriptive concepts (which can be expressed in different ways and free of any formal manner, and thus are not fully compatible with such syntactic viewpoints). It is of interest to see how this issue has supplanted our spatial thinking [45] and how it has influenced the potential of addresses to contribute to configurational spatial knowledge acquisition as well as spatial ability development. In other words, since current addressing systems are developed for machine-based matching purposes, they seem to tend to answer the "You-are-here" question, and thus for a human, it is more like a "learning from map" rather than "learning from travel" experiencing environment, which is provided by spatial relations [46].

Assuming the cognitive map as an *internalized GIS* (Geographic Information System) in which data is symbolized and coded [24], corresponding an address to spatial mental representations is a human-information processing parallel to the machine-based address matching. A major difference is that in GIS, the address matching is a manipulative procedure carried out in a quick and accurate manner. However, a human's internalized GIS performs basically the same manipulative activity, but is prone to inaccuracies and inefficiencies [21] due to the lack of information transmitted by the address as well as personal and societal dependencies [47]. Keeping in mind that addresses may influence aspects

of spatial cognition, an address may also affect other functionalities of a human's internalized GIS (e.g., wayfinding and spatial knowledge acquisition). Assuming that people are increasingly offloading (spatial) thinking to technology [45], it is essential that human spatial experience and cognition are adequately characterized in extended cognitive systems. An extended cognitive system is defined as "an external object that serves to accomplish a function that would otherwise be attained via the action of internal cognitive processes" [35]. In particular, it is interesting to study how ideal addressing systems would consider both computer and human information demands in order to equally develop external and internal geocodings.

7. Conclusions and Future Research

This article introduced the idea of syntax, semantics, and pragmatics of addressing systems: the syntax of an address affects the accuracy of its automated geocoding, while its semantics and pragmatics relate to how much it is interpretable by humans, and how much it corresponds to the elements of their spatial mental representations. In addition, the information provided by an address may influence the growth of humans' spatial knowledge and their spatial activities.

As a first step, this article examined three classes of addressing systems based on their formal definitions as well as the types and relations of their components. Empirical tests are required to verify the results of this pilot research. Moreover, the results need to be further investigated from linguistic, cultural, and cognitive points of view, which may significantly affect the findings. However, it is still unclear as to how to impart the differences in spatial cognition caused by external factors.

Studying different addressing systems can lead to a better understanding of the way different people around the world think about their space. A Japanese person who has been exposed to an addressing system with no names for streets, but (temporally-ordered) codes for blocks and buildings, may perceive the space differently from an Iranian who has interacted with a route description based addressing system full of spatial elements as well as metric and topological relations. We believe that this has a considerable effect on different aspects related to spatial thinking like route planning, verbal and non-verbal spatial communications, etc.

Finally, it would be interesting to study how someone, say Japanese, would react to a new addressing system, say Iranian, and how they would adapt to the new system. Amongst other factors, it seems to be dependent on the semantics and pragmatics of the origin and target addressing systems as well as the user contexts, which triggers another question of how much an addressing system is universally user-friendly for newcomers who are accustomed to other addressing systems.

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