Knowledge Management at Multiple Decision Levels: a Use Case about COVID-19 Pandemic

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Abstract Many organisations, including state administrations, define rules involving spatial knowledge. However, these rules are mainly specified and managed by hand using natural language. Advances in Geographic Information Systems (GIS) and computer science in Knowledge Management may improve such rule handling. Knowledge has to be built on recent, accurate, consistent and complete information – when possible – to allow decision-makers to take relevant actions. However, in many contexts such as urban planning or emergency response support, information and rules are available from multiple stakeholders, which belong to different decision levels such as national, regional and local, thus highlighting several challenges. A first issue deals with modelling the rules by considering the hierarchy of decision levels, timeline of rules, etc. Next, acquiring knowledge from these stakeholders may lead to errors (*e.g.*, partial rule extracted from a textual document, misinterpretation), inconsistencies or incompleteness (*e.g.*, cases not covered by rules). Thus a crucial step deals with the detection of relationships between rules (*e.g.*, equivalence, causality) to facilitate the application of all rules. Lastly, integrating heterogeneous data, on which rules can be applied, is a well-studied problem which becomes more complex due to data provided at different levels of details. In this article, we study how GIS cope with these challenges to manage rule-based knowledge at different levels, and we illustrate them on the COVID-19 pandemic.

Keywords: geographic information systems, knowledge management, rule extraction, data integration, geographic rule.

1 Introduction

Geographic information systems (GIS) have become essential tools in our daily lives. Many application domains such as transportation, points of interest search or emergency response systems, include spatial concepts as part of their basic knowledge. For example, events (*e.g.*, concert, moon landing or nuclear disaster) are typically represented using time and location concepts. Rubenstein *et al.* defines knowledge as *"information that has been organized and transformed into something understandable and applicable to problem solving and decision making"* [Rubenstein-Montano, 2000]. To build a reliable knowledge base, it is necessary to combine information from different levels [Grillitsch and Trippl, 2014]. Besides, such knowledge has to be built on recent, accurate, consistent and complete information – when possible – to allow decision-makers to take relevant actions and is mainly supported by domain rules.

In this paper, we focus on knowledge management at different levels of decision, as in the context of urban planning or emergency response support [Fischer, 1994]. Although the latter implies quick decisions with possible significant impact, both domain applications share similar characteristics and goals, namely the detection of conflicting situations and the recommendation of actions. As an example, many urban rules are defined and applied to lead and constrain the development of territories such as the Right to Build [Brasebin et al, 2016]. These rules are produced at different levels, for instance national and local (city). Besides they are usually scattered into numerous textual documents (*e.g.*, *PLU-H* in France, which stands for Urban Local Plan), thus making them difficult to use for non-experts. Finally, rules are in relationship with each other and these links have an impact on the application of the rules. For instance, equivalent rules should not be all triggered as it decreases performance, and conflicting rules should be disambiguated to enable decision-making.

Gathering and formalizing domain knowledge from multiple decision levels could have many benefits such as an enhanced planning with global standardization and simplification of rules, automatic checking and recommendations, reuse and sharing of rules, better transparency for citizens, an improved understanding of the past or a comparison between territories through spatial analysis. Thus we study the life cycle of multi-levels rules (from production to application) with a focus on their relationships. In this paper, we first present related work dealing with spatial knowledge (Section 2). Then we explore the challenges related to knowledge management at different decision levels (Section 3). We illustrate these challenges by presenting a use case about the recent worldwide disaster, the COVID-19 pandemics (Section 4). We finally conclude and outline perspectives (Section 5).

2 Related work

In this section, we describe works that are based on different spatial levels or papers discussing spatial knowledge.

Kuipers and Tversky both describe the levels and structure of spatial knowledge from a cognitive point of view [Kuipers, 1978; Tverksy, 2018]. Although the main objective is to navigate (human or robot), knowledge about the mental representation of an external environment should be available at high level (overview) and at a lower scale (views, *e.g.*, for determining a direction at each turn). Similarly, in the cartography domain, different levels are used, but they typically refer to the level of detail, *i.e.*, the amount of visible information shown at a given zoom level. These various levels are source of inconsistencies, especially in volunteered geographic datasets [Touya and Brando-Escobar, 2013].

In Germany, Herrmann *et al.* discuss landscape protection and use according to rules at different geographic levels (European to local) [Herrmann and Osinski, 1999]. The studied case deals with rural planning following the consequences of intensive agriculture. Federal and national levels provide guidelines for the development of landscapes (*e.g.*, ecological targets) while the regional level measures effects of the applied measures regarding ecology and economics. The local level is for applying the planned measures, evaluating their social impact and transferring scientific information to other levels. Among the achieved results, authors underline the importance of similar cartographic unit among actors at the same level (*e.g.*, 50 meters grid for regional actors), as well as the active implication of planners and politicians and scientists using interdisciplinary methods. In this context, decisions can be seen as complementary and refined for deeper levels.

In disaster risk management, urgent decisions need a comprehensive and reliable knowledge base, as illustrated in France by the 2010 Xinthia storm which was followed by a deadly flood [Weichselgartner and Pigeon, 2015]. As noted by the authors, the local knowledge is not taken into account to support scientific knowledge (established at a national level in this case) and therefore decisions do not rely on complete and qualitative knowledge. Gaillard *et al.* confirms the importance of combining these forms of knowledge by bridging the gap between them [Gaillard and Mercer, 2013]. Indeed, local communities tend to develop their own way of addressing a risk, which could, after assessment, directly benefit to risk reduction policies. To succeed, there is a need to overcome several obstacles such as the absence of dialogue, the limited trust between actors, or the tools needed to make communities participate. More recently, a study demonstrated the complementary between local and national levels for flash floods [Bucherie et al, 2021]. Indeed, continental scale flood forecasting systems are not sufficiently efficient to predict these floods, while local communities have gathered knowledge (*e.g.*, events at night, specific rain and wind conditions) to protect themselves. Researchers show that using such knowledge enables a better prediction accuracy.

When acquiring knowledge from multiple actors, inconsistencies may arise in the knowledge base [Adrian et al, 2013]. Various strategies enable to cope with these issues: ignorance (with the risk of errors when querying), rejection (conflicting rules are discarded) or resolution (cleaning or rewriting of certain rules). In the literature, different types of inconsistencies have been identified, such as contradiction or paraconsistency, as well as measures to evaluate inconsistency in a knowledge base [Thimm, 2019]. Inconsistencies spanning from multiple levels of decision is a specific case of inconsistency management, and dedicated solutions need to be proposed.

The research field of (spatial) data integration has been largely studied [Wiemann and Bernard, 2016; Berjawi et al, 2014; Deng et al, 2019], and it can be affected by the geographic level which produces data (*e.g.*, representation accuracy, quality or freshness). Gupta *et al.* note that in the multiple departments of the same municipality, a spatial object can be represented differently in terms of measurement, quantity and quality of its attributes, structure of metadata, etc. [Gupta et al, 2002]. They propose a mediation system to cope with such heterogeneity, based on spatial data interchange and transformation functions. However, information reconciliation, especially when involving other geographic levels, is not described. The combination of knowledge from diverse actors and at different levels is still an emerging topic.

3 Challenges of level-based knowledge management

To enable the transition towards knowledge management at different levels, several challenges need to be tackled. We first describe challenges for modelling rules, then for extracting rules and determining their possible relationships and we finally highlight challenges related to data integration and quality.

3.1 Modelling rules

First, a generic model has to be established for representing rules [Ferreira et al, 2014; Laurini, 2019; Servigne et al, 2016], which takes into account the hierarchy (*e.g.*, rule inheritance from the top-level) and exemptions at lower levels. Exchanges between domain experts (urbanists, computer scientists, decision-makers, etc.) and agreements on the concepts definition are crucial for a successful data representation. Besides, such representation is different according to the actors' level. For example, when projecting to build an industrial facility, security rules are not applied on the same spatial objects: regional decision makers think about seismology while local decision makers are interested in distances to surrounding residences.

Based on Laurini's formalism [Laurini, 2019, 2021], a rule can be expressed with the following components[1]:

- Context, which sets up the typed variables used in the rest of the rule;
- Conditions, or the antecedent of the rule, which have to be satisfied (evaluated as true) to assert the consequents. Conditions are usually represented as conjunctions of boolean expressions;
- Consequents, which stand for the resulting part of the rule (*e.g.*, actions, assertions). They are usually composed of a set of expressions.

Using these components, the formal and high-level notation of a rule is written in formula 1. Please refer to [Laurini, 2019] for a more detailed description of the formalism inside components.

$$\text{context} : \text{condition} \Rightarrow \text{consequents} \tag{1}$$

A simple example of rule deals with a road crossing a river. Its notation is given in 2. We first declare variables ro and ri in the context component. In the conditions part, we compute the intersection area of both geometries, and if not empty, then a bridge b should exist to enable the crossing above the river. Note that a rule has a square bracket on the right so as to facilitate reading, especially when several rules are mentioned altogether.

$$\left.\begin{array}{l} \forall ro \in Roads, \forall ri \in Rivers \\ : Intersection(Geometry(ro), Geometry(ri)) \neq \emptyset \\ \Rightarrow \exists b \in Bridges; MeansOfCrossing(b, ri, ro) \end{array}\right] \tag{2}$$

This generic model enables to represent rules, but we also need to define relationships between them to effectively manage a knowledge base.

3.2 Rule extraction

As previously stated, rules are currently stored in documents. Besides, some rules are not formally written (*e.g.*, mimicry between close cities, best practices, oral expertise). Extraction of rules can be performed manually or auto-

[1] Note that for simplicity reasons, we omit the component *type of implication*, which accepts three values (logical implication, best practice, associative rule from data mining or fuzzy implication [Bordogna, 2021]), and we only consider logical implication (⇒).

matically. In the former method, domain experts at different decision levels need to exchange and confront their points of view to agree on the modelling and definition of the rules. This work also involves computer scientists and practitioners to tackle technical and usage issues. Interviews and focus groups are traditional methods for collecting qualitative knowledge from experts [Sabherwal and Becerra-Fernandez, 2005]. However, such manual process is more difficult to set up for large scale domain or with multiple actors at different decision levels, which is an experience feedback also highlighted in the Towntology project [Teller et al, 2007].

Using an automatic method requires a process for extracting rules from textual documents or from data. Natural language processing or pattern recognition with a strong analysis on spatial concepts enables rule extraction from documents [Aggarwal and Zhai, 2012]. Many works on spatial data and text mining have also been conducted for extracting knowledge from data [Atluri et al, 2018; Galton et al, 2015]. Evaluation of generated rules is a challenge since both techniques do not guarantee a perfect quality, and a human validation is required (*e.g.*, inconsistency between rules). Automatic extraction of rules is out of scope of this paper, and we focus on a related challenge, the detection of relationships between rules.

3.3 Relationship detection

Whatever method is used for collecting rules and also due to real cases, there is a high probability that several rules are redundant, complementary or contradictory, especially when dealing with multiple decision levels. Detecting relationships between rules is consequently crucial to maintain the knowledge base in the cleanest possible state. Besides, it enables to improve performance when applying rules (*i.e.*, less rules to process). Some rules enable to detect and correct states or behaviours while others enable decision-makers to analyze links between rules (*e.g.*, causality). We propose a list of relevant relationships in the context of knowledge management at different decision levels, inspired from work in reasoning and relationships between events [Keet and Artale, 2008; Ning et al, 2019; Wu, 2020]. Table 1 provides an overview of identified relationships. The first column presents four main categories. They are divided into eight more specific types of relationships, which are labelled in the second column. In the third column, we provide a formal notation for each type of relationship between two rules A and B. The next column stands for the definition of this type of relationship. And the last one indicates whether this type of relationship can bear mereological aspects or not, *i.e.*, a rule includes at least one component or object which is subsumed to the corresponding one in the other rule. Mereology can be found at the generalization/specialization point of view (e.g., shop and a drugstore which is a shop) and at the geometric point of view (e.g., the city of Lyon included in the Auvergne-Rhône-Alpes region). This mereology aspect is transversal to several relationships, and we note *yes* (respectively *no*) when a type of relationship accepts (respectively cannot have) mereological situations. This column also provides references to rule examples which are detailed thereafter. Two rules may be linked with several types of relationships.

Category	**Relation**	**Notation**	**Definition**	**Mereology (example)**
Redundancy	Equivalence	$A \equiv B$	Rules A and B exactly convey the same meaning	no (ex. 3)
	Inclusion	$A \subset B$	Rule B is included in rule A	yes (ex. 4)
Ambivalence	Full contradiction	$A \nRightarrow\!\!\nLeftarrow B$	Rules A and B are totally contradictory (opposite consequents)	yes (ex. 5) no (ex. 6)
	Partial contradiction	$A \rightarrow\!\!\!\!\times\!\!\!\!\leftarrow B$	Rules A and B have opposite consequents and overlapping objects	yes (ex. 7)
	Exception	$A \oslash B$	Rules A and B are ambivalent, but B is an exemption to A	yes (ex. 8)
Discordance	Ambiguity	A ‽ B	Rules A and B are ambiguous when applied on specific data	no (ex. 9)
	Illogical rules	$A \circ\!\vert\!\circ B$	Rules A and B are consistent but illogical	no (ex. 10)
Causality	Subsequence	$A > B$	Rule A causes another rule B	yes (ex. 11)

Table 1 Types of relationships between rules at different levels

We now provide simple examples for each relationship. Note that not only components of the rule need to be checked, but also (spatial) entities (or objects) that are involved in the rules.

Example 3 (equivalence). The following rules ensure that if a plane flies over the city of Paris, it must be above 2,000 meters high. Despite their different condition, they are equivalent since both entities refer to the same point of interest (Paris, using its name or its Wikidata identifier). Note that we do not deal with multilingual equivalence.

$$\left.\begin{array}{l}\forall p \in Planes, \exists c \in Cities \\ : c.name = 'Paris' \\ \Rightarrow p.height > 2,000\end{array}\right] \qquad \left.\begin{array}{l}\forall p \in Planes, \exists c \in Cities \\ : c.wikidata = 'Q90' \\ \Rightarrow p.height > 2,000\end{array}\right] \tag{3}$$

Example 4 (inclusion). This example deals with land planning. The top rule states that if a development project is located in a natural area, the project must include a plan for protecting wildlife. The bottom rule, which could be defined at a lower decision level, is very similar to the previous one but it protects a more specific target (insects). Thus the second rule is included in the first one.

$$\left.\begin{array}{l}\forall pr \in Projects, \forall na \in NaturalAreas \\ : Contains(Geometry(pr), Geometry(na)) \\ \Rightarrow \exists pl \in Plans; pl.target := 'wildlife'; Includes(pr, pl)\end{array}\right] \qquad \left.\begin{array}{l}\forall pr \in Projects, \forall na \in NaturalAreas \\ : Contains(Geometry(pr), Geometry(na)) \\ \Rightarrow \exists pl \in Plans; pl.target := 'insects'; Includes(pr, pl)\end{array}\right] \tag{4}$$

Example 5 (full contradiction, with mereology). In the following rules, France forbids hunting in all natural areas while a region of France (Bretagne) authorizes hunting in its territory. Objects involved in both rules share a mereological relationship (Bretagne is included in France) so both rules are totally in contradiction.

$$\left.\begin{array}{l}\forall na \in NaturalAreas, \exists c \in Countries \\ : c.name =' France' \wedge Contains(Geometry(c), Geometry(na)) \\ \Rightarrow na.hunting := 'forbidden'\end{array}\right] \\ \left.\begin{array}{l}\forall na \in NaturalAreas, \exists r \in Regions \\ : r.name =' Bretagne' \wedge Contains(Geometry(r), Geometry(na)) \\ \Rightarrow na.hunting := 'authorized'\end{array}\right] \tag{5}$$

Example 6 (full contradiction, without mereology). The following rules hold a full contradiction relationship, but without mereology. Indeed, the first one means that vehicles drive on the left side while the latter authorize them to drive on the right side.

$$\left.\begin{array}{l}\forall v \in Vehicles \\ : \\ \Rightarrow v.driving := 'left'\end{array}\right] \\ \left.\begin{array}{l}\forall v \in Vehicles \\ : \\ \Rightarrow v.driving := 'right'\end{array}\right] \tag{6}$$

Example 7 (partial contradiction). The following rules illustrate a partial contradiction in which mereology is involved. First, there is a permission for hunting and fishing in forests, but the second rule forbids these activities in seas. Although both rules are clear, one could ask whether hunting and fishing are allowed or not in swamps or in mangroves, which can be both seen as part of *sea* and part of *forest*.

$$\left.\begin{array}{l}\forall a \in Areas \\ : a.type =' forest' \\ \Rightarrow a.hunting := 'allowed'; a.fishing := 'allowed'\end{array}\right] \\ \left.\begin{array}{l}\forall a \in Areas \\ : a.type =' sea' \\ \Rightarrow a.hunting := 'forbidden'; a.fishing := 'forbidden'\end{array}\right] \tag{7}$$

Example 8 (exception). A first rule states that areas which are included in *Areas50* have a 50 km/h speed limit. Similar rules may be available, for instance for *Areas25*. The second rule means that (parts of) roads inside a city are limited to 50 km/h speed. Cities have the possibility to increase (*e.g.*, main road in a village) or decrease (*e.g.*, close to schools) this limitation. The last rule, defined at the local level, constrains the speed limit to 25 km/h close to schools (*i.e.*, belongs to *Areas25*). To express such limitation, the consequent of this rule computes a 200 meters limited zone on the road centred around the overlapping area between the road and the school. The first impression when studying these three rules is an ambivalent situation, and resolving the conflict enables to determine that an exception relationship holds between the last two rules.

$$\begin{bmatrix} \forall a \in Areas50 \\ : \\ \Rightarrow a.speed\_limit := 50 \end{bmatrix}$$
$$\begin{bmatrix} \forall ro \in Roads, \forall c \in Cities \\ : Intersection(Geometry(ro), Geometry(c)) \neq \emptyset \\ \Rightarrow Intersection(Geometry(ro), Geometry(c)) \in Areas50 \end{bmatrix} \quad (8)$$
$$\begin{bmatrix} \forall ro \in Roads, \exists s \in Schools \\ : Touches(Geometry(ro), Geometry(s)) \\ \Rightarrow Intersection(Geometry(ro), Buffer(Intersection(\\ \quad Geometry(ro), Geometry(c)), 200)) \in Areas25 \end{bmatrix}$$

Example 9 (ambiguity). The following case leads to an unclear situation. In France, several rules state that cycling lanes are dedicated to cycles only, roads are for registered vehicles (with a numberplate) or for bikes, and pavements for pedestrians. With the recent emergence of electric scooters, there was an ambiguity regarding the place where these new vehicles could drive. Existing rules were consistent, but there was confusion due to new data (new type of vehicle). The clarification of this situation took several years in countries like France where a new law for these electric scooters was finally voted.

$$\begin{bmatrix} \forall v \in Vehicles, \forall cl \in CyclingLanes \\ : v.type =' bike' \\ \Rightarrow Drives(v, cl) \end{bmatrix}$$
$$\begin{bmatrix} \forall v \in Vehicles, \forall r \in Roads \\ : v.registered = true \quad \vee \quad v.type =' bike' \\ \Rightarrow Drives(v, r) \end{bmatrix} \quad (9)$$

Example 10 (illogical rules). In the following example, both rules are consistent, but they are not logical. In the French Isère region, there is a pollution in the Rhône river, so fishing is prohibited. In the neighbouring (downstream) region Drôme, the rule still authorizes fishing in the Rhône river. This case relates to border continuity issues, which is typical in multi-levels knowledge systems.

$$\left.\begin{array}{l}\forall ri \in Rivers, \exists re \in Regions \\ : ri.name =' Rhone' \quad \wedge \quad re.name =' Isere' \\ \quad \wedge \quad Contains(Geometry(re), Geometry(ri)) \\ \Rightarrow ri.fishing :=' forbidden' \end{array}\right] \\ \left.\begin{array}{l}\forall ri \in Rivers, \exists re \in Regions \\ : ri.name =' Rhone' \quad \wedge \quad re.name =' Drome' \\ \quad \wedge \quad Contains(Geometry(re), Geometry(ri)) \\ \Rightarrow ri.fishing :=' authorized' \end{array}\right] \tag{10}$$

Example 11 (subsequence). The following rules have a causal relationship: a tunnel is present when a road is located below a watering area, and vehicles driving in tunnels should have their lights on. This kind of rules may be useful to prevent road accidents for instance. It is possible to collect and analyse device traces from connected cars to check the parts of roads with the most issues. If the system detects that most cars do not use their lights in tunnels, it can provide recommendations to decision-makers about this problem.

$$\left.\begin{array}{l}\forall r \in Roads, \forall w \in WaterAreas \\ : Intersection(Geometry(r), Geometry(w)) \neq \emptyset \\ \quad \wedge r.elevation < w.elevation \\ \Rightarrow \exists t \in Tunnels; MeansOfCrossing(t, w, r) \end{array}\right] \\ \left.\begin{array}{l}\forall v \in Vehicles, \forall t \in Tunnels \\ : Drives(v, t) \\ \Rightarrow v.lights :=' on' \end{array}\right] \tag{11}$$

We have described the different types of relationships, and we now detail the problems that may occur in a multi-level knowledge management system. Table 2 provides, for each type of relationship, the main problem and dedicated solution(s). Redundant rules mainly produce a problem of performance while ambivalent rules typically generate confusion when applying rules. Discordant rules are more difficult to detect due to missing information or absence of conflict between rule or data. For causal rules, an efficient reasoning system should be able to sort rules prior to execution so as to execute all induced rules. In most cases, expert intervention is needed to solve and clean the knowledge base.

Category	Relation	Problem	Solution
Redundancy	Equivalence	Decrease performance due to useless rule, possible future contradiction	Delete duplicate rule
	Inclusion	Decrease performance due to useless specific rule, possible future contradiction	Delete or disable specific rule[2]
Ambivalence	Full contradiction	Confusion when applying rules, juridical instability	Delete or disable a rule after revision
	Partial contradiction	Confusion when applying rules, juridical instability	Delete or disable a rule after revision, or modify a rule, or change relation to exception
	Exception	–	–
Discordance	Ambiguity	Missing object or missing rule	Add a rule
	Illogical rules	Inefficient or aberrant application	Modify rules after revision
Causality	Subsequence	Rules may not be triggered	Sort rules

Table 2 Problems and solution for each type of relationship

To conclude this part, we note that there exist other types of relationships between rules (*e.g.*, symmetry when a country replies to a rule decided by another country, political or economical influence, resemblance or imitation for rules adapted from another region). These rules may be useful for decision-makers (*e.g.*, for analysing rules) but they did not seem to be a priority (*a-priori* less significant impact) and thus have been put aside as a research perspective. Identifying relationships between rules is complex and may require experts' feedback, but they are useful for a better management and application of the rules.

3.4 Data integration and quality

Once the rules are linked, another challenge is the data collection and integration, which mainly requires specific development [Doan et al, 2012]. Indeed, data sources are provided by various actors and at different levels, thus causing several issues. One of the most studied problem is heterogeneity: all sources include their own terminology, vocabularies and constraints (schema), and concepts may be represented differently from one stakeholder to another. The same issue occurs for instances and values, which require entity matching or record linkage to detect equivalent entities [Shen et al, 2015]. Heterogeneity also deals with formats (*e.g.*, Relational databases, RDF, PDF documents) and nature of data (*e.g.*, structured, textual, multimedia, maps). Data sources may also be more or less trustworthy, for instance according to quality (*e.g.*, bioinformatics data may be automatically or manually curated). Data availability depends on the provider. Although the Open Data initiative promoted a better availability, especially in large cities, an effort has to be made on data quality (updates, semantics). Besides, many cities are located on a border. Thus, it is necessary to ensure data and rules continuity between adjacent administrative areas.

In our context, the multiple decision levels implies that entities may be represented with various levels of details or described with a different point of view. For instance, the biking trail *véloire* is not available on the French national Geoportail GIS system, but it is shown on a regional tourism map. To solve these issues, solutions such as GeoAlign [Barret et al, 2019] or SLIPO [Athanasiou et al, 2019] enable the detection of conflicting entities and possibly their fusion into a single integrated entity. Rules stored in the knowledge base can finally be applied on collected data, for instance using artificial intelligence techniques such as case-based reasoning [Laurini, 2021; Anthony, 2021].

4 The COVID-19 use case

A typical example of domain application in which spatial knowledge at multiple decision levels is crucial is emergency response scenarios [Hristidis et al, 2010; White et al, 2001]. Thus, we identify and study impact on knowledge management for the current global health crisis (2020-2021, at the time of writing) caused by the Corona virus outbreak from China[3]. This situation implies need for quick changes of rules and also lead to ambivalent rules. Involved decision levels are global (*e.g.*, World Health Organization), national (states), regional (or equivalent, *e.g.*, federal) and local (*e.g.*, cities). Due to

[3] WHO COVID-19 webpage, http://www.who.int/health-topics/coronavirus

the present situation of outbreak, we can observe issues in ruling system because of technical, political and social issues. Experiences have shown that what worked yesterday may not work today. This is especially true for the present situation where rules need to dramatically change and be adapted from one area to another. Current modifications of rules highly impact society to a large extent, for instance in terms of individual liberty, health-care, transport of goods, job and enterprises' rights and organization, taxes system, privatization/nationalization of enterprises, economic model [Shrestha et al, 2020; Bloom et al, 2020; Aday and Aday, 2020; Workie et al, 2020]. They reshape everyday life like during war periods. In the rest of this section, we detail the issues due to the COVID-19 pandemics according to the aforementioned challenges.

4.1 Modelling

Governments provide recommendations or constraints to citizens and companies, that could be translated into rules. Let us provide some examples of rules based on the framework from Laurini *et al.* [Laurini, 2019; Servigne et al, 2016].

In France, when the confinement has been decided, only shops related to food, drugs and gas could be opened. The rule 12 indicates that a point of interest (POI) p which does not belong to the previous categories is closed.

$$\left.\begin{array}{l} \forall p \in POI \\ : p.category \notin \{food, medication, gas\} \\ \Rightarrow p.status := 'closed' \end{array}\right] \tag{12}$$

Open markets (dedicated to food) were also open according to this rule, but the government later decided to close them due to difficulties for limiting contact between people. Thus the previous rule can be updated with a conjunction ($\vee\ p.type = "open\ market"$) in its conditional part. However, in some areas, open markets are essential for obtaining food. For farmers, it can also be the only means of selling their production. Thus, regions could grant opening authorizations to some markets. By establishing a whitelist of regional markets noted $\mathcal{M} = \{market_1, market_2, ..., market_k\}$, rule 13 supersedes the national rule and should be applied afterwards:

$$\left.\begin{aligned} &\forall p \in POI \\ &: p.category \notin \{food, medication, gas\} \\ &\quad \vee\ (p.type = {'}open\ market{'}\ \wedge\ p.name \notin \mathcal{M}) \\ &\Rightarrow p.status := {'}closed{'} \end{aligned}\right] \tag{13}$$

Finally, citizens are allowed to go out one hour per day, and they have to carry a circulation pass form[4] which includes the starting time and place of the move. Besides, walking or running is limited within one kilometre around home. GIS tools such as Geoportail[5] were heavily used to know the allowed area. Rule 14 illustrates this constraint for people moving outside with a circulation pass filled in for sport or walking.

$$\left.\begin{aligned} &\forall m \in Moves, \exists f \in CirculationForm \\ &: f.reason = {'}sport/walk{'} \\ &\quad \wedge\ (Subtract(CurrentTime(), f.departure\_time) > 60 \\ &\quad \vee\ Distance(CurrentLocation(), Coords(f.address)) > 1000) \\ &\Rightarrow GiveFine(f.person\_name) \end{aligned}\right] \tag{14}$$

This rule was quickly created to fit a generic case, but one may notice that the one kilometre distance (as the crow flies) is mostly adapted in big cities, but is probably insufficient in countryside areas. Indeed, a local authority may supersede this rule to allow citizens for a larger distance in rural areas. Finally, note that this rule could be automatically verified by checking geo-locations of citizens through their mobile. This would require careful attention to exceptions (*e.g.*, health workers, shop vendors), and would not be acceptable by citizens (as it is perceived against individual liberties in many countries).

The timeline and the level of application of rules are crucial in multi-level knowledge management. Indeed, the COVID-19 crisis has seen many local rules that have been quickly removed due to citizen or government pressure (*e.g.*, the possibility to relax only two minutes on benches or the prohibition of alcohol). Figure 1 illustrates the role of space and time for the rule about wearing a mask. At the national level, it was decided that wearing a mask was required in indoor places (rule at time t). Several French cities (*e.g.*, Nice, Sceaux) voted laws to locally enforce mask wearing, including outdoor (rule at time *t+1* for City c). Surprisingly these local decisions were later cancelled by the regions of concerned cities (rule at time *t+2* in the top-left region). We note that rules at time t and *t+1* can be seen as complementary. However, rules produced at time *t+1* at *t+2* lead to an ambivalence, and more precisely a contradiction (not an exception). Solving this case requires

[4] French circulation pass http://www.service-public.fr/particuliers/vosdroits/R55781

[5] Geoportail, http://www.geoportail.gouv.fr/

to analyse the promulgation date and place of application of the rules, and it brings out that the local rule is superseded by the regional rule.

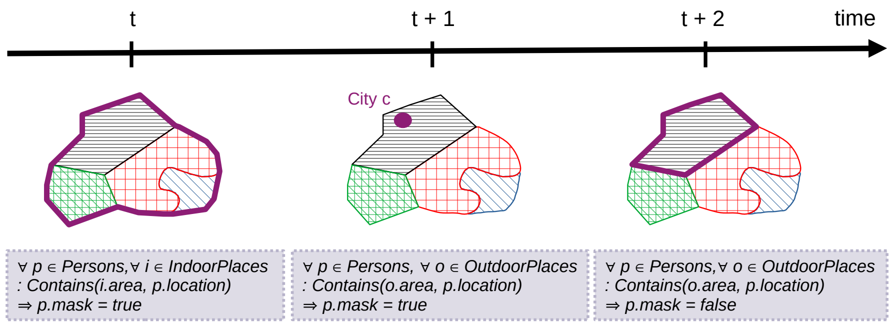

Fig. 1 Importance of timeline and spatial level in rule management

One of the main modelling difficulty is to adopt and use a common framework for writing these rules. For instance, Sutherland *et al.* listed more than 500 societal options for reducing virus transmission [Sutherland et al, 2021]. To build this knowledge base, rules and actions have been proposed by experts, crowdsourced using social media or extracted from literature from various countries. However, these textual-written rules are not directly usable in a GIS.

4.2 Rule extraction

The next challenge is automatic extraction of rules, mostly from textual documents. The COVID-19 outbreak has triggered the production of a large amount of documents from the scientific community, as illustrated by the 300,000 articles in the COVID-19 open research dataset[6]. Various tools have been developed to facilitate search and retrieval of relevant documents[7] or to visualize relationships between biological concepts[8]. Newspapers articles also contain information like the most recent limitations dictated by governments or latest statistics about the pandemic. Extracting rules from such documents first require named entity recognition (NER) or entity linking techniques [Shen et al, 2015]. Wang *et al.* have proposed the identification of relevant concepts on the COVID-19 dataset[9][Wang

[6] COVID-19 open research dataset, http://pages.semanticscholar.org/coronavirus-research

[7] CORD-19 Explorer, http://cord-19.apps.allenai.org/

[8] CoViz, http://coviz.apps.allenai.org/

[9] CORD-NER, http://xuanwang91.github.io/2020-03-20-cord19-ner/

et al, 2020]. For instance, in the sentence `SARS-COV spike proteins have a strong binding affinity to human ACE2`, both terms *"SARS-COV spike proteins"* and *"ACE2"* are identified under the concept *"Gene_or_Genome"*. This detection is a first step towards rule extraction, but finding the type of relationship between concepts is still a challenging issue [Etzioni et al, 2011].

Popular events are typically accompanied with fake news, that even the WHO tries to detect and fight[10]. These fake news may produce bad rules, either irrelevant or contradictory. Let us consider the fact `COVID-19 virus cannot be transmitted in areas with hot and humid climates`, which has been considered as a fake news by WHO. It could generate rule 15 using Köppen–Geiger climate classification system [Kottek et al, 2006]: if a geographic area a is included in a climate zone z which is hot and humid (*Cfa* or *Cwa*), then we cannot find the virus in a. This irrelevant rule may incite people not to respect basic safety recommendations in these areas.

$$\left.\begin{array}{l} \forall a \in Areas, \exists z \in ClimateZones \\ : Contains(z,a) \wedge \ (z.climate = 'Cfa' \ \vee \ z.climate = 'Cwa') \\ \Rightarrow a.covid\_presence := false \end{array}\right] \tag{15}$$

A last issue deals with the multiple levels at which rules may be extracted. How to manage complementary or conflicting rules extracted from different sources? The difficulty also arises because some levels (such as WHO) only formulate recommendations, but not restrictions. On the contrary, countries and regions dictate both constraints (to be respected, *e.g.*with rule 14 about maximum distance and period for going out) and recommendations (*e.g.*, people others than health workers do not need to wear masks). As an example, the French government decided during the first months that wearing masks should not be encouraged. On the contrary, Asian countries have immediately adopted the mask for citizens as a means to limit virus propagation.

To conclude the rule extraction, we note that tomorrow's changes may still not work if the modification process is not fast enough. Rules need flexibility and velocity of adaptation, and automation could improve response times. The recent modifications of national laws required by outbreak situation were extraordinary faster than modification times we used to know. As outbreak came from China approximately two months before reaching Europe, reacting rules of European countries are partly inspired by Asian rules such as lockdown, which is an example of rules' mimic from one region to another.

[10] WHO myth busters about COVID-19, http://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public/myth-busters

4.3 Relationship detection

As previously explained, detecting rules is not sufficient as many rules may be in relationship with each other. We have identified eight types of relationships in Section 3.3 and we provide some ideas to detect them in the use case of the COVID-19 pandemics.

4.3.1 Equivalence

Two equivalent rules must have equivalent components (contexts, conditions and consequents). Except for identical rules, remaining ones may still bear this relationship due to the use of equivalent mentions of the same entities (*e.g.*, EU, European Union and Union européenne). Thus detecting equivalence mainly amounts to perform entity linking or entity matching between objects found in rules. In Figure 2, the bottom-left region produces a rule that authorizes open markets to be open. The top-left area defines a rule which states that points of interest typed as market can be open if they do not have a *building* property[11]. Both rules are therefore equivalent, although the representation of category *open market* differs.

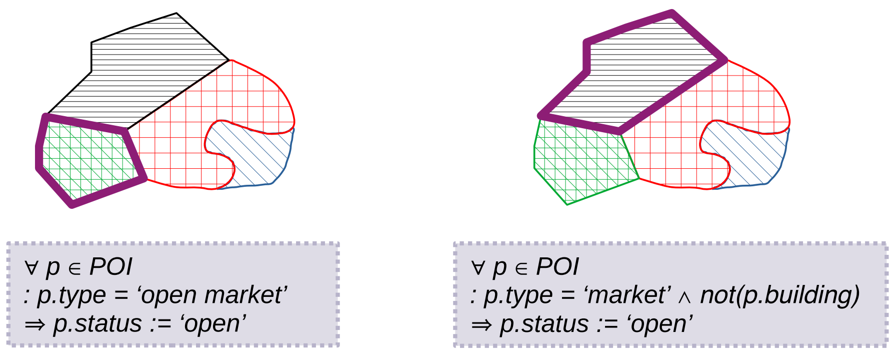

Fig. 2 Example of equivalence between two regional rules

Note that the detection process may be more complex for specific cases. Let us consider a first rule which includes a condition on *average cities*. This notion is clearly ambiguous as it depends on the country. Even in the same country, several definitions may be available. For instance, in France, researchers in social sciences usually describe an average city with a population between 20,000 and 200,000 inhabitants [Santamaria, 2000]. The French

[11] A building property would indicate that the market takes place in a building, as defined by OpenStreetMap tagging practices.

city association[12] represents average cities with 10,000 to 100,000 residents. Finally, the national institute of statistics (INSEE)[13] defines average cities with more than 5,000 jobs, a population lower than 150,000 inhabitants and which is not a prefecture of a region. Such ambiguous concepts should not be used or should specify a more accurate definition. Let us imagine we have a second rule which is similar to the first one except its condition which bear on *cities with a population between 20,000 and 50,000 inhabitants*. Depending on the chosen definition for *average city*, both rules may be equivalent or not.

4.3.2 Inclusion

Given the relationship $A \subset B$, at least one component or object of B is subsumed to the corresponding one in A. Automatically detecting this type of relationship is harder than equivalence. A taxonomy or a GIS system can be used to compare objects, but the verification of a whole component in the rule may require human expertize. In the crisis context, several touristic areas decided to limit incoming visitors during low season, so that the situation gets better for high season. This case is reflected on the left part of Figure 3 with the blue oblique hatched region which forces passengers from high risk countries to be isolated during 10 days. Later, as the situation degrades, the whole state decides to place passengers from any country into quarantine for 14 days (right part). The national rule includes the regional one, as all its components are included in the right rule. We note that the condition component is lacking in the national rule, as it means that the rules applies to any passenger from any country. The detection of the part-whole relationship between these rules implies to verify that each component of the left rule is included in the corresponding right component.

∀ p ∈ Persons, ∀ f ∈ Flights, Passenger(p, f), co = Country(f.departure) : co ∈ HighRiskCountries ⇒ p.status = 'quarantine' ∧ p.isolation_length = 10	∀ p ∈ Persons, ∀ f ∈ Flights, Passenger(p, f) : ⇒ p.status = 'quarantine' ∧ p.isolation_length = 14

Fig. 3 Example of inclusion between a regional and a national rules

[12] French association for cities, https://www.villesdefrance.fr/

[13] French national institute of statistics (INSEE), https://www.insee.fr/

4.3.3 Full and partial contradiction

Rules holding a contradiction should be quickly detected, as they may block the decision process. When rules are provided by different levels of authority, a clear and reliable organization and communication has to be established to avoid ambivalent rules. In a crisis context, a high level authority usually takes decision and ambivalent rules are very rare. Yet, the sudden and unexpected COVID19 situation led to multiple confusion situations due to contradictory rules.

When the vaccine was largely adopted in the country, the French government set up a sanitary pass to only allow vaccinated people to access public buildings. However, universities locally decided that the sanitary pass was optional to access campuses. Figure 4 illustrates this full contradiction, as universities are contained in the higher concept of public buildings. Such conflict can later be considered as an exception after revision. Similarly, wearing a mask was compulsory in all public buildings. But people practising sport activities could avoid wearing the mask. These two rules created a partial contradiction situation, since the intersection of public buildings and sport is not an empty set (e.g., gymnasium).

$\forall\, p \in POI$
$: p \in PublicBuildings$
$\Rightarrow p.sanitary\_pass := true$

$\forall\, p \in POI$
$: p.type = \text{‘university’}$
$\Rightarrow p.sanitary\_pass := false$

Fig. 4 Example of a full contradiction (with mereology)

Another ambivalent example occurred in France when the first confinement has been decided. On the one hand, the government encouraged people to work from home when possible or stay at home for non-essential jobs. But governments are also worried about the economic impact. A few days later, other ministers (from the same government) claim that workers unable to do home activities should therefore go to their workplace (*e.g.*, building labourers). This is illustrated by rules in Figure 5.

$\forall\, p \in Persons, \forall\, w \in Works, Works(p, w)$
$: w \neg\in EssentialWorks$
$\Rightarrow p.workingStatus := \text{‘remote’}$

$\forall\, p \in Persons, \forall\, w \in Works, Works(p, w)$
$: w.canBeRemote = false$
$\Rightarrow p.workingStatus := \text{‘onsite’}$

Fig. 5 Example of a partial contradiction about remote or onsite works

This conflicting relationship can be detected easily in this case as both rules have opposite consequents, and their conditions are not mutually exclusive. But detection may be more complex, especially with many recommendations. For instance, another minister announced that 200,000 unemployed people (due to COVID-19) should go and help farmers for producing food. Such recommendation may create new contamination paths while social distance has become the norm, and it is a contradiction with regards to reduce or avoid human contact. Besides, these people should be able to go to farms (as well as health workers should be able to go to their workplace, etc.), which involves maintaining a high frequency of transportation means. Yet, most low-level decision makers (*e.g.*, cities) have limited public transportation during the confinement. Once again, human expertize is required to detect these conflicting situations.

In order to further reduce the virus propagation, largest areas such as malls and shopping centres were closed when their surface is higher than 20,000 square meters. Given these two rules, as shown in Figure 6, should a large supermarket which sells food be open or closed?

$\forall$ *p* $\in$ *POI* *: p.category* $\neg\in$ *{food, medication, gas}* $\Rightarrow$ *p.status := 'closed'*	$\forall$ *p* $\in$ *POI* *: p.size > 20,000m*^{2} $\Rightarrow$ *p.status := 'closed'*

Fig. 6 Example of a partial contradiction about supermarkets

A last example of possibly conflicting rules is about democracy. This political system goes along with information transparency and individual liberty. Yet, during troubled times, governments communication first trended to minimize or dissimulate danger in order to avoid panic, and then they set rules which restrict liberty such as confinement and geo-tracking. Our societies have to find a trade-off to respect these ambivalent rules, maybe by using uncertainty theories like in the data uncertainty domain [Dubois and Prade, 2009; Bordogna, 2021].

4.3.4 Exception

Due to the high number of possibilities, specific cases may be triggered using dedicated rules which contradicts existing ones (*i.e.*, exception relationship). For instance, a maintenance job in a critical system may be performed remotely most of the time. However, some incidents may require an on-site intervention to check and solve potential issues. As shown in Figure 7, the rule checks the validity of an exemption document which has been granted to a worker (*i.e.*, the working period on the document must include the current day). It is an exemption to the existing left rule from Figure 5, and both are complementary.

$\forall\, p \in Persons, \forall\, w \in Works,\, Works(p, w),\, \exists\, e \in Exemption(p, w, period)$
$: period \subseteq CurrentDate()$
$\Rightarrow p.workingStatus := \text{'onsite'}$

Fig. 7 Example of an exception (w.r.t. to the left rule from Figure 5)

4.3.5 Ambiguity

When rules are created at different levels, particularly in a crisis context, it is highly probable that these rules bear ambiguity. For instance, we observe that the rule 12 (in Section 4.1) is ambiguous for some points of interest. Let us imagine we have the two opposite rules which authorize or not points of interest to be open, as shown in Figure 8. Liquor and wine stores do not really fit in the authorized categories (*i.e.*, food, medication, gas), although wine is a typical drink with most meals in France. Besides, people could still buy alcohol in food and general stores, but not anymore in specialized stores, which is not a fair situation. Facing this ambiguity, several alcohol shops decided to open anyway. One can consider that wine stores are a missing object in these rules, which consequently hold an ambiguity relationship. Another possibility is to include wine stores in the food category, thus avoiding any conflict.

$\forall\, p \in POI$
$: p.category \neg\!\in \{food, medication, gas\}$
$\Rightarrow p.status := \text{'closed'}$

$\forall\, p \in POI$
$: p.category \in \{food, medication, gas\}$
$\Rightarrow p.status := \text{'open'}$

Fig. 8 Example of an ambiguity relationship

Note that depending on the system used, this case could be process differently. For instance, in Geonames[14], the category for selling goods, including food, is entitled *store* and it does not allow to distinguish between alcohol and food stores. This lack of precision could become an issue in specific situations. Detecting an ambiguous situation is also very difficult, although it is possible to check all rules that includes an opposition in their consequents component.

Ambiguity also deals with missing rules, which is not obvious to present. In early 2020, when the virus started to spread in Europe, the French government did not recommend to wear a mask, because its utility was not demonstrated. Yet, many Asian countries imposed the mask to their population, and health workers in France also had the obligation to wear a mask. Given existing rules in other countries and for health workers, it would be possible to detect that a rule is missing for the French population.

[14] Geonames feature codes, https://www.geonames.org/export/codes.html

4.3.6 Illogical rules

Another common phenomenon, which is not specific to outbreak situation, is about rules' discontinuity at borders. This occurs when neighbour local authorities emit discontinuous rules. Figure 9 illustrates this kind of situation related to maximum travelling distance. A person needs to go to the south landmark location, which is 2 kilometres as the crow flies, and thus within the 3 kilometres restriction. However, the shortest path goes through an urban area in which the decision-makers have restricted travels up to 1 kilometre. Going around the urban area requires more than the authorized 3 kilometres, and the citizen cannot go to the south landmark location without risking a fine due to rules' discontinuity.

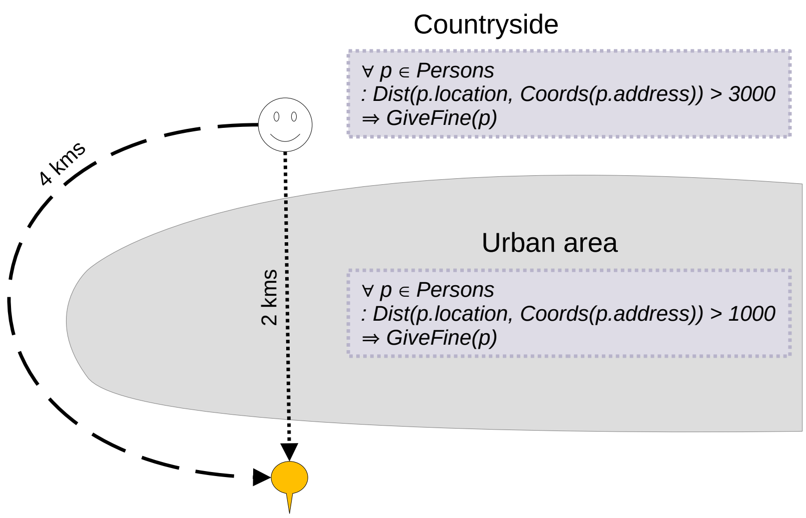

Fig. 9 Example of illogical rules due to discontinuity at borders

Following are two other examples of border discontinuity in France. Some local authorities have taken very restrictive rules (*e.g.*, residents allowed to go out only 10 meters far from their home). Yet, such rule did not apply to neighbours in an adjacent city as they were not subject to this local residential rule. So these neighbours could still visit, do shopping or meet friends in the very restrictive city. To limit propagation, trains could travel from one safer region to another safer region. However, the train could go through a highly contaminated region (without expected stop). What happens if the train has to stop in the middle of such region due to breakdown, problem on the track, sick onboard people?

A consequence of border discontinuities is implication of other rules. If two countries follow different strategies against outbreak, then border trespassing is prohibited or restricted with virus testing. Note that in this situation, a rule is conditioned to the existence of another one ("IF *rule*$_x$ *at neighbour* THEN *local action/fact*", based on format in [Ross, 2011]). Another problem linked to border continuity is that borders are not always "hard" obstacles (*e.g.*, countries in the European Union, states in the US). A country may follow a lock-down strategy against outbreak but a neighbour country may have a strategy to "normally" let outbreak spread out, thus compromising the whole fight against outbreak.

4.3.7 Subsequence

This last type of relationship involves two rules, one of them being triggered by the other. In the simplest case, the consequent of the first rule is equivalent to the condition of the second one. During lock-downs in many countries, several points of interest were closed, such as restaurants, movie theatres or hairdressers. To limit the economic consequences, most states provided financial support to these shops. For instance, Figure 10 depicts a simplified example of this situation. The left rule states that restaurants are closed while the rule on the right side indicates that closed POI are eligible to subsidies. A subsequence relationship between both rules is easily established as the consequent of the left rule is identical to the condition in the right one.

∀ p ∈ POI
: p.type = 'restaurant'
⇒ p.status := 'closed'

∀ p ∈ POI
: p.status = 'closed'
⇒ p.apply_subsidies := true

Fig. 10 Example of simple subsequent rules (consequent ≡ condition)

Yet, the detection may be more complicated, for example due to a condition which partly includes the consequent. The following situation illustrates some barrier gestures which were typically recommended to limit virus propagation. In Figure 11, the left rule forces points of interest to provide a sanitizer when they are open. The right rule recommends that an object which can be manipulated by different persons should be triggered using elbow or foot. A causality relationship between both rules is not obvious, but we could infer that sanitizers should be triggered using an elbow or a foot. The detection of the relationship is complex for an algorithm as there is no equivalent or similar components. Reformulating the rules or the help of an expert may facilitate automatic detection.

$$\begin{array}{l} \forall\, p \in POI \\ :\, p.status = \text{'open'} \\ \Rightarrow ProvideSanitizer(p) \end{array}$$

$$\begin{array}{l} \forall\, p1, p2 \in Persons,\ \forall\, o \in Objects \\ :\, Uses(p1, o) \wedge Uses(p2, o) \\ \Rightarrow o.trigger := \text{'elbow'} \vee o.trigger := \text{'foot'} \end{array}$$

Fig. 11 Example of subsequent rules which are difficult to automatically detect

4.4 Integration of heterogeneous data

To apply extracted rules, experts have to collect and integrate data from multiple sources (*e.g.*, statistics about contaminated people, confinement measures by country). An advantage of the strong focus on COVID-19 is that data producers (governments, organizations at different levels) publish their data in hope that a solution is quickly discovered. WHO provides data for each country, including maps, through its global health observatory[15]. It contains more than 2,260 indicators and provide data as JSON or CSV. Another provider is the Humanitarian Data Exchange platform[16], with tens of datasets provided by different actors. At national levels, agencies also offer datasets that are stored on platforms such as the French `data.gouv.fr` website. For these data, levels range from national to local according to the provider and the degree of precision.

Spatial data are very heterogeneous across all these datasets. For instance, let us study measures taken to limit the pandemic. In a dataset which aggregates measures decided by authorities (social distance, lock-down, etc.[17]), only the country name and one other administrative level (*e.g.*, state, region, province, city) are available. Besides, there is no standardization for values in the administrative level field, thus leading to inconsistencies for future exploitation. The Oxford response tracker dataset[18] only mentions the country name, but more specific locations (e.g, airports, schools) are spread out in textual fields (*e.g.*, in newspaper titles,). Binary fields stand for the category of restrictions (*e.g.*, general, workplace, transport, events, fiscal). Comparing these two datasets require processes with variable quality results (mainly entity extraction, deduplication and entity linking). In the school disclosure dataset[19], spatial data include the country name and an application scale, either national or localized, in which case a note field may provide details (*e.g.*, *"27 of 28 states"*). Finally, the mobility restriction measure

[15] WHO Global Health Observatory, http://www.who.int/data/gho

[16] COVID-19 pandemic locations, http://data.humdata.org/event/covid-19

[17] Government measures dataset, http://data.humdata.org/dataset/acaps-covid19-government-measures-dataset

[18] Oxford response tracker dataset, http://data.humdata.org/dataset/oxford-covid-19-government-response-tracker

[19] Global school closures dataset, http://data.humdata.org/dataset/global-school-closures-covid19

is also described by the International Organization for Migration[20]. In addition to country code and name, points of interest have a location name field, which may specify an airport or port name, a land or sea border point. These values are also formatted differently (*e.g.*, using sporadic or detailed address, including useless country name or location type) and would need to be cleaned during an integration process. To compare COVID-19 contamination cases, locations are represented with four administrative levels and city name (based on Google Geolocation API) in the Metabiota dataset[21] while they are represented as coordinates (latitude and longitude) in the WHO dataset[22].

Integrating data at lower levels is a conventional well-known problem in database interoperability. For instance, consider food services that either are open or deliver during the pandemic. A German dataset is available for Berlin[23] and a French one covers the city of Poitiers[24]. The comparison of schemas require to solve multilingual issues. Besides, data are represented with different structures. For instance, French opening hours may be detailed in a textual field (*specificities*) while the German dataset includes seven fields, one per week day. Both provides food categories, addresses and contact information, but geolocation is only available in the French dataset, which would require geocoding if one plans to present data on a map. Instances also have to tackle multilingual issues, overlapping categories, field merging for address, etc. Note that we have chosen cities of Berlin and Poitiers, but datasets exist for other areas such as Nevers, Corsica, all of them with different schemas. There is even a dataset for the whole territory based on OpenStreetMap[25]. Some metrics (*e.g.*, estimation of completeness) could be useful to select the most relevant datasets and minimize the integration task.

When dealing with integration, it appears that finer levels, which are the most interesting due to their accuracy, are also the most difficult to fusion. Yet, this process is essential to ensure that rule's application produces the most relevant and reliable results.

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[20] Mobility restriction dataset, http://data.humdata.org/dataset/country-point-of-entry-mobility-restriction-covid-19-iom-dtm

[21] COVID-19 cases from Metabiota, http://data.humdata.org/dataset/2019-novel-coronavirus-cases

[22] COVID-19 cases from WHO, http://data.humdata.org/dataset/coronavirus-covid-19-cases-data-for-china-and-the-rest-of-the-world

[23] Berlin Gastronomien dataset, http://www.govdata.de/web/guest/daten/-/details/gastronomien-und-ladengeschafte-mit-liefer-und-abholdiensten

[24] Food shop and producers in Poitiers dataset, http://www.data.gouv.fr/fr/datasets/commerces-alimentaires-et-producteurs-locaux-ouverts-covid19/

[25] Open places in France, https://www.data.gouv.fr/fr/datasets/lieux-ouverts-ou-fermes-pendant-le-confinement-covid-19/

5 Conclusion

Knowledge management at different decision levels is an emerging domain research, especially with the development of smart cities and GIS in regions. Currently, most of this knowledge is described in textual documents or only known by experts. But in case of major crisis such as the COVID-19, there is a strong need for quick decisions and rules' adaptation. Automatically gathering, formalizing and exploiting domain knowledge is therefore crucial to facilitate decision-making, for instance with application to urban planning or emergency response support. Sharing best practices in multi-level knowledge management is also at the heart of scientific questions, as shown by the CORD-19 Kaggle competition[26]. In this paper, we have presented the main challenges related to knowledge management with multiple decision levels: modelling rules, extraction of rules from documents, detection of relationships between rules and integration of relevant data. They have been illustrated on the current COVID-19 pandemic, for which much knowledge and many data sources are released at different levels. We focused on relationships between rules, which has a significant impact when different actors produce rules. We believe that a formal and digital knowledge system of rules would contribute to meet the presented requirements. It would facilitate organization of rules between different levels of governance, make modifications of rules faster, enable the detection of several types of relationships (*e.g.*, equivalence, ambivalence) and possibly infer new knowledge or recommendations. Crisis such as climate change, which are considered as slower events[27], could also benefit from automated knowledge management to take decisions and track obtained results of actions.

Many challenges still need to be solved to head towards automatic knowledge management. Standards or improved interoperability between actors are essential to exchange rules and share information between different decision levels. At the modelling level, one should think about the representation of recommendation. Current GIS engines or reasoners have to be adapted to take into account relationships between rules (*e.g.*, skipping redundant rules, triggering implied causal rules). Multiple strategies for executing rules – possibly including the tuning of parameters – could be developed and tested. Reasoning also needs to be enhanced with fuzziness when answering queries and providing recommendations [Bordogna, 2021]. The current state of the art in rule extraction and relationship detection is not sufficient to ensure a high degree of quality, thus requiring assistance from experts. With the popularity of social networks and the possibility of spreading fake news, another

[26] CORD-19 information sharing task, http://www.kaggle.com/allen-institute-for-ai/CORD-19-research-challenge/tasks?taskId=583

[27] Climate change is a "slow" event w.r.t. human perception, but it is considered fast from a physical geography and climatology point of view.

challenge is to check non-official rules, and the set of relationships is a first step towards an automatic detection. Graphical interfaces would facilitate rule management (adding, modifying or deleting rules or their relationships) for experts. Finally, new application projects involving collaboration between researchers, agencies and companies at various geographic levels should arise to demonstrate the feasibility of automated knowledge management in real-life scenarios.

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