A Category Theory Approach to Interoperability

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Abstract

In this article, we propose a Category Theory approach to (syntactic) interoperability between linguistic tools. The resulting category consists of textual documents, including any linguistic annotations, NLP tools that analyze texts and add additional linguistic information, and format converters. Format converters are necessary to make the tools both able to read and to produce different output formats, which is the key to interoperability. The idea behind this document is the parallelism between the concepts of composition and associativity in Category Theory with the NLP pipelines. We show how pipelines of linguistic tools can be modeled into the conceptual framework of Category Theory and we successfully apply this method to two real-life examples.

1 Motivation and plan of the paper

This article does not pretend to rewrite the approach to syntactic interoperability within the chains of linguistic tools. The concepts behind NLP suites or platforms such as those described in Appendices, already consider the idea of an exchange format in which to read and write textual data (and linguistic annotations) an essential one. Independently from the design of such suites, they work in a sort of “cathedra mea, regulae meae”-perspective: they provide plugins, of course, but suggest to use what they provide.

In the field of Social Sciences and Humanities, however, there are many legacy tools or tools that are used to visualize data and it gets hard to integrate such tools into NLP suites or platforms.

This paper, instead, looks at the exchange format and the format converters (that play the role of the plugins) from an abstract perspective: it shows that syntactic interoperability can be modeled with a Category Theory approach.

Readers unfamiliar with the world of Language Resource and Technologies can find a small summary in Appendices A, B, and C.

Appendix A describes Language Resources, Language Technologies, and introduces Natural Language Processing (NLP) tools, while Appendix B delineates
the issues of interoperability as they are addressed by International projects and Research Infrastructures.

2 Introduction

The entire idea of interoperability relies on both composition and associativity. Generally speaking, let’s suppose we have a system with 3 agents, call them $a_0, a_1, a_2$, which act on a bunch of data $d_0$ to produce $d_3$ as a result.

Let’s suppose again that the agent $a_i$ acts on some $d_i$ to produce $d_j$. We can simply formalize the process $d_0 \rightarrow d_3$ as $d_0 \xrightarrow{a_0} d_1$ then $d_1 \xrightarrow{a_1} d_2$ finally $d_2' \xrightarrow{a_2} d_3$. We explicitly put a prime sign $'$ to suggest that the case when the output of an agent is the exact input for another is infrequent. Indeed, we can apply $a_1$ after $a_0$ if and only if the data $d_1'$ on which $a_1$ acts is compatible, to some extent, with the data $d_1$ created by $a_0$. In other words, $a_1$ and $a_0$ speak the same language in terms of some characteristics of $d_i$ such as formats, interchanged data and their meaning. We say that when two agents $a_i, a_j$ speak the same language they are compatible with. So, if $a_1$ and $a_0$ are compatible, we can create a new agent, $a_3$, simply putting together (i.e. composing) $a_1$ with $a_0$: $d_0 \xrightarrow{a_3} d_2$. Also, if $a_2$ and $a_1$ behave as $a_1$ and $a_0$ do, that’s to say they are compatible, we can compose $a_2$ with $a_1$: the new agent $a_4$ acts on $d_1$ to produce $d_3$, $d_1 \xrightarrow{a_4} d_3$. At this point, we have 5 compatible agents $a_0, a_1, a_2, a_3, a_4$ that we can associate in different ways: either $d_0 \xrightarrow{a_2 \text{ after } a_3} d_3$ or $d_0 \xrightarrow{a_4 \text{ after } a_0} d_3$.

If we substitute the term agent with function, a bunch of data with elements of a Set and the phrase “speak the same language in terms ...” with “restriction on domain and codomain” we obtain the theory of functions in Sets.

Well, Category Theory uses the same model. Instead of elements of a Set or a bunch of data, there are objects, instead of functions or agents there are arrows (morphisms) between objects. Moreover, in Category Theory, composition and associativity are key concepts as they are in interoperability. And if we look at the theory of functions in Sets, agents acting on data and at objects and morphisms in Category Theory, we see that they are very similar. All these similarities form the idea that is behind the paper.

3 Background

Interoperability is a general concept, commonly related to systems (in their broadest sense) able to work together without restrictions. As explained in the dedicated website, [http://interoperability-definition.info/en/](http://interoperability-definition.info/en/) interoperability goes beyond the concept of compatibility between systems, since it is based on agreed structures and open standards. In this way each system is compatible with the others limiting, or even avoiding, the preponderance of one system over the others.

Interoperability is widely used in many disciplines, from healthcare to the medical industry; from services for citizens to emergency management; from
computer science to proper software interoperability. For example, the European Interoperability Framework (EIF) identifies 5 levels of interoperability: from technical to legal, while the Healthcare Information and Management Systems Society, Inc. (HIMSS) refers to 4: from foundational to organizational. These two subjects cover very different areas: EIF covers public services, HIMSS healthcare, but both of them underline syntactic and semantic interoperability.

Not surprisingly, when we come to formalize the concept of interoperability within computer systems, these two terms frequently emerge. Syntactic interoperability is a prerequisite for semantic interoperability and concerns data formats, communication protocols and everything that can be labeled as structural. Formats such as XML, SQL dumps, JSON... are the prototypical examples of agreed data structures and form the structural backbone for syntactic interoperability.

Semantic interoperability focuses on the agreement of the meaning of data exchanged. And this is the place where available standards begin to play a key role. This is especially true for Language Resources (LRs). Many efforts have been directed toward documenting the LRs that, although different, could be mapped in some way. Hence the idea of establishing maps between metadata systems and the use of data categories and controlled vocabularies. In the realm of Language Resources software integration platforms such as GATE, UIMA, European projects, and Research Infrastructures (RIs), such as CLARIN and DARIAH (see Appendices A and B) massively use the concepts of syntactic and semantic interoperability for the (linguistic) services they offer to users.

In CLARIN, WebLicht offers linguistic chains based on an agreed structure which is sent from one tool to the next one, while the Language Resource Switchboard (LRS) connects individual texts with NLP tools. Both of them are based on interoperability.

Interoperability is also important in Computational Philology. In the authors describe how to re-engineer Language Resources and NLP tools as Web Services to address issues of the digital humanists. Interoperability is used to make connections between lexicons, semantic resources, and fine-grained text management.

Category Theory has been applied to different fields from functional programming languages (ML, Haskell...), to physics, logic, chemistry, semantic web, software design, and linguistics. Category Theory and linguistics are in close combination. For example, and use Category Theory and Pregroups to model grammar and interactions among words, while and define and update DisCoCat, a model that provides compositional semantics for the study of the meanings of sentences in natural languages. In the field of semantic web and use concepts from Category Theory and apply them to ontologies: limit,
colimit, pushout, and pullback, are used to define optimal morphisms between ontologies so that they can be enriched and merged. Both works present types of research in the field of semantic interoperability. [21] uses the same concepts for the design of industrial software. They conclude that a formal approach is necessary to create automated software specification, development, and maintenance.

4 Category Theory

Category Theory is a branch of pure mathematics. In some ways, it can be seen as an abstraction of algebraic structures that include a class of objects and a class of arrows that connect the objects.

Category Theory has a “dual approach”: one can learn a good deal on the objects by studying arrows and, conversely, many things can be said about arrows when they are applied to specific objects.

Complete materials on Category Theory and Applied Category Theory can be found here [3], [30], [4], and in [9] and [35] along with their references.

4.1 Definition of a Category

A Category $\mathcal{C}$ is:

- A collection of objects, $\text{Ob}(\mathcal{C})$
- For every pair $X, Y \in \mathcal{C}$, a collection (even empty) of morphisms, arrows, between objects, $\text{Hom}_\mathcal{C}(X, Y)$.
- Additional Axioms:
  - Morphisms (arrows) must be composed: the end of an arrow must be the beginning of another;
  - There must exist an identity arrow which starts and ends on the same object;
  - The composition of arrows must be associative.

**Composition:** $f$ is a morphism from $A$ to $B$, $g$ from $B$ to $C$, $h$ and $k$ are morphisms from $A$ to $C$:

$$A \overset{f}{\rightarrow} B \overset{g}{\rightarrow} C, A \overset{k}{\rightarrow} C$$

But while $k$ can be any arrow between $A$ and $C$, there must exist an $h$ which is the composition of $f$ and $g$ (and usually $h \neq k$):

$$h = f \circ g \quad (1)$$
Identity: The identity morphism is defined as $X \xrightarrow{id_X} X$; when we apply the composition to $f$ as in Figure 2, we obtain

$$f \circ id_A = f = id_B \circ f \quad (2)$$

Associativity: Composition leads to associativity, see Figure 3. In the sense that for $\forall f, g, h$ in $Hom_C(X, Y)$ there must be:

$$h \circ (g \circ f) = (h \circ g) \circ f = h \circ g \circ f \quad (3)$$

5 Interoperability and Category Theory

Composition and associativity are important concepts in Category Theory. Just as they are in interoperability.
The comparison between the composition in Category Theory and interoperability of linguistic tools is quite immediate. When we require two tools to be interoperable we mean exactly that the output of the first tool \((t_1)\) is the input of the second one \((t_2)\). And that these two tools can be grouped to get a more complex, *composite*, tool \((t_2 \circ t_1)\) that provides the same results, as reported in Figure 4.

![Figure 4: Composition of linguistic tools.](image)

Similarly, in the case of more tools, the processing pipeline(s) can proceed in different ways: we can obtain the same results using either atomic or *composite* tools as in Figures 5 and 6.

![Figure 5: Associativity.](image)

\[
(t_2 \circ t_3) = (t_3 \circ t_2)
\]

![Figure 6: Associativity as an equation.](image)

Figures 4 and 5 are the diagrammatic counterpart of Equations 1 and 3 respectively.

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5By atomic tools we mean tools that go directly from *A* to *B*: \(A \xrightarrow{t_1} B\); by composite, tools that need an intermediate *C* to go from *A* to *B*: \(A \xrightarrow{t_1 \circ t_2} B\)
6 Building the Category

It is therefore natural to identify the objects of the category with the textual documents to be analyzed and the morphisms with the linguistic applications between them.

According to Section 4 we can define a category $\mathcal{C}$ as follows:

- The collection of objects, $\text{Ob}(\mathcal{C})$, consists of all documents $(D^i, D^{ii}, D^{iii}, D^{iv}, \ldots)$ that can be processed by a linguistic application;

- The $\text{Hom}_{\mathcal{C}}(D^i, D^j)$, the collection of morphisms, is the set of any linguistic application which consumes $D^i$ and produces $D^j$ as in Figure 7.

The identity morphism is a dummy tool that consumes and returns the same document. These morphisms can be called the “do-nothing” tools in analogy with the identity function in Haskell, $\text{id} :: x \rightarrow x$, that returns its argument unchanged, or with the pass statement in Python. There must be an identity morphism for every document $D^i$, see Figure 8.

Composition and associativity are reported in Figure 9:

A document $D^i$ is processed to obtain $D^m$ in different ways: directly using $t_5$ (the blue dashed line); composing $t_4$ with $t_3$ which is actually $t_2 \circ t_1$; composing $t_6$ and $t_1$ and doing the same with $t_4$, $t_2$, and $t_1$. It seems we are done. Anyway, we are not.

\footnote{Henceforth we use document instead of textual document.}
7 More thoughts on texts and NLP tools

What are the NLP tools? Simply put, an NLP tool is a software able to process natural language data and perform linguistic operations on them. Here, by language data we mean any collection of documents. These can be simple documents, written in natural languages, collections of words, annotated documents (e.g. documents which already contain linguistic information), formatted documents (for example in tabbed fields) and so on. Both definitions are not exhaustive (see Appendices A, B, and C for a brief introduction) but, for the scope of the article, we don’t need to formally and exhaustively define NLP tools and documents: it suffices to say that NLP tools perform linguistic operations on documents.

As a consequence, NLP tools are classified according to the linguistic operation(s) they perform on documents: there are part-of-speech taggers, which assign morphological features such as VERB, NOUN...to words, lemmatizers which assign to inflected forms their dictionary entry (e.g. from loves to love), language identifiers, parsers, word sense disambiguators which pick up the right sense of a word (e.g in the sentence “I went to the bank yesterday to get some money”, bank is the financial institution and not the sloping land of a river) and so on.

The most important aspect is that not all documents can be processed by any NLP tool. For example, there could be a lemmatizer (t₁) which reads a list of words (D₁) and assign the lemma to each of them (without considering the structure of the text). But there could be a different lemmatizer (t₂) which reads plain text sentence by sentence (D₂) because its algorithm reads words in context. And there could be a third lemmatizer (t₃) which needs the part of speech of the words (D₃) to assign lemmas.

The fact that a tool needs specific input is not surprising and it is indeed well known, especially in Research Infrastructures (RIs) as [33] reports. In the example above, the tools t₁, t₂, t₃ produce the same result (text with lemmas) starting from three different inputs. If we call D⁴ the text_with_lemmas, the situation goes as in Figure 10.

![Figure 10: Multiple tools producing the same result.](image)

The same example tells us that there are no substantial differences between

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7We provide a generic definition of documents and tools in Section 8.
the documents $D^1$ and $D^2$, apart from their format (list of words vs. plain text), while $D^3$ contains additional information (the part of speech). It is natural to suppose that $D^3$ can be obtained from (for instance) $D^2$ applying a part-of-speech tagger, see Figure 11.

![Figure 11](image)

Figure 11: $D^2$ as source for $D^3$.

8 Tuning the Category

According to 7 the category $C$ sketched in Section 6 is not complete. We have to take into consideration that i) documents with the same linguistic information can have different formats and ii) the final result can be obtained from documents containing different linguistic information.

8.1 Category Objects

In Section 6 we defined the objects, $Ob(C)$, as the documents $(D^i, D^{ii}, D^{iii}, D^{iv}, \ldots)$ that can be processed by linguistic applications. From Section 7 we learned that such documents are more complex than the ones covered by the definition. We define the documents $D^i$ as follows:

$$D \equiv D(c, f, \{a_1 \ldots a_n\})$$  \hspace{1cm} (4)

where $c$ is the content (e.g. the text), $f$ the format and $\{a_1, \ldots, a_n\}$ the set of additional linguistic annotations (if any). From 4 follows the definition for the initial document:

$$D^0 \equiv D(c, f_p, \{\emptyset\})$$  \hspace{1cm} (5)

where $f_p$ is the format corresponding to plain text and $\{\emptyset\}$ means that there is no additional linguistic annotation. In definitions 4 and 5 $f_p$ is how both $c$ and $\{a_1, \ldots, a_n\}$ are serialized in a data structure.

8.2 Category Morphisms

When a document $D^i$ is analyzed with an NLP tool $\tilde{t}_{ij}$, a document $D^j$ is then produced:

$$D^i(c_i, f_i, \{a_i\}) \xrightarrow{\tilde{t}_{ij}} D^j(c_j, f_j, \{a_j\})$$
Depending on the tool \( \tilde{t} \), we expect that \( D^i \) and \( D^j \) may (or may not) differ for the content, the format, and the annotation set. For example, if \( \tilde{t} \) is a named entity extractor and \( D^i \) is the initial text \( D^0 \), \( D^j \) may either have the same content as \( D^0 \) with an additional layer of stand-off annotations consisting of words and named entities or be a simple list of extracted named entities showing no trace of the original content. In addition, the output of \( \tilde{t} \), \( (D^j) \), can be serialized in XML which might not be the original format of \( D^0 \). It seems that \( \tilde{t} \) is “something” acting on the format, “something” on the content and “something” on the annotation set.

Consequently, we can proceed by defining such “something”. We can adopt the following definition of format converters: a format converter is an application which connects two documents and leaves \( c \) and \( \{a_1, \ldots, a_n\} \) unchanged while moving from format \( f_i \) to format \( f_j \).

\[
c_{ij} := D^i(c, f_i, \{a_1 \ldots a_n\}) \rightarrow D^j(c, f_j, \{a_1 \ldots a_n\})
\]

According to the definition of \( \text{Ob}(\mathcal{C}) \), both \( D^i \) and \( D^j \) \( \in \text{Ob}(\mathcal{C}) \) with the additional constraint that \( D^i \neq D^j \). As a consequence, the \( \text{Hom}_\mathcal{C}(D^i, D^j) \) is expanded to add converters as its elements, although they are not proper NLP tools: \( c_{ij} \in \text{Hom}_\mathcal{C}(D^i, D^j) \). Following Appendix A an NLP tool is an application that connects two documents and may change both content \( c \) and annotations \( \{a_1, \ldots, a_n\} \) leaving the format \( f \) unchanged.

\[
t_{ij} := D^i(c_i, f, \{a_1 \ldots a_k\}) \rightarrow D^j(c_j, f, \{a_1 \ldots a_n\})
\]

Definition 7 informs us that NLP tools leave the format \( f \) unchanged. This is a strong position and is openly in contrast with the fact that NLP tools consume specific inputs and produce specific outputs, as reported in Section 7. However, definition 7 is a formal one, without addressing the actual issues related to the implementation of the tools. In fact, it is often the case that a tool does “something” on the format too. But, from a categorical perspective, we prefer to look at such tools as a composition of a tool \( t_{ij} \) and a converter \( c_{ij} \), see Figures 12a and 12b.

![Figure 12: Combination between tools and converters.](image_url)

Here, we defined \( \tilde{t} \) as either \( c \circ t \) or \( t \circ c \). Since \( c_{ij}, t_{ij} \in \text{Hom}_\mathcal{C}(D^i, D^j) \), we have that \( \tilde{t}_{ij} \in \text{Hom}_\mathcal{C}(D^i, D^j) \).
8.3 Category Axioms

Because of these new definitions, the three axioms, identity, composition and associativity have to be revised.

Identity: identity is still the “do-nothing” tool, but such tool does nothing on content, format and annotation set:

\[ id_{D_j}(c) = c, id_{D_j}(f) = f, id_{D_j}({a_k}) = {a_k} \]

Composition: in Section 7 we explained that a linguistic result can either be obtained from documents with different formats or from documents with different annotation sets, and this is closely correlated to the tool and its input/output restrictions. However, thanks to our definitions of converters \(c_{mj}\) and tools \(t_{im}\), we know how to address this issue. Figure 13 shows a case when a tool \(t_{im}\) consumes \(D^i\) to produce \(D^m\), but \(D^m\) cannot be provided to \(t_{mk}\) to produce \(D^k\).

\[ \begin{array}{ccc}
D^i & \xrightarrow{t_{im}} & D^m \\
\downarrow & & \downarrow \\
D^j & \xrightarrow{t_{jk}} & D^k
\end{array} \]

Figure 13: The tool \(t_{mk}\) can not act on \(D^m\).

If \(D^m\) and \(D^j\) differ for their formats, we can apply a converter \(c_{mj}\) to obtain \(D^j\) and then provide \(D^j\) to \(t_{jm}\) to obtain \(D^k\), see Figure 14a.

Otherwise, If \(D^m\) and \(D^j\) differ for their annotation sets, we can apply a tool \(t_{mj}\) to obtain \(D^j\) and then provide \(D^j\) to \(t_{jm}\) to obtain \(D^k\), see Figure 14b.

In both cases, if \(D^{m'}\) is \(D^m\) transformed, diagrams in Figure 14 are rendered as in Figure 15.

\[ \begin{array}{ccc}
D^i & \xrightarrow{t_{im}} & D^{m'} \\
\downarrow & & \downarrow \\
D^j & \xrightarrow{t_{mk}} & D^k
\end{array} \]

\[ \tilde{t}_{ik} := \tilde{t}_{mk} \circ \tilde{t}_{im} \]

Figure 15: Tools \(\tilde{t}\) ensure composition.

Associativity: it follows from Figure 16.

\[ \text{More realistic cases when the various } D^i \text{ differ for format } \text{and } \text{annotation sets are managed similarly, but are pictorially more complex.} \]
\(D^i \xrightarrow{t_{im}} D^m\)
\[\begin{array}{c}
D^m \\
\downarrow t_{mj}
\end{array}\]
\[\begin{array}{c}
D^j \\
\downarrow t_{jk}
\end{array}\]
\(D^k\)

(a) \(D^m\) and \(D^j\) differ for their formats.

\(D^i \xrightarrow{t_{im}} D^m\)
\[\begin{array}{c}
D^m \\
\downarrow t_{mj}
\end{array}\]
\[\begin{array}{c}
D^j \\
\downarrow t_{jk}
\end{array}\]
\(D^k\)

(b) \(D^m\) and \(D^j\) differ for their annotation sets.

Figure 14: Composition involving converters and tools.

\[\tilde{t}_{mk} := \tilde{t}_{kl} \circ \tilde{t}_{mk}\]
\[\tilde{t}_{im} := \tilde{t}_{mk} \circ \tilde{t}_{im}\]

Figure 16: Tools \(\tilde{t}\) ensure composition.

From Figure 16 we have the usual association rule:

\[(\tilde{t}_{kl} \circ \tilde{t}_{mk}) \circ \tilde{t}_{im} = \tilde{t}_{kl} \circ (\tilde{t}_{mk} \circ \tilde{t}_{im})\]

which makes sense thanks to the fact that \(\tilde{t} \in \text{Hom}_C(D^i, D^j)\) by construction.

9 Real-Life Examples

The authors in [5] described the integration of a set of NLP tools into WebLicht and Language Resource Switchboard and reviewed the encountered interoperability issues. On one hand, WebLicht is a chain of tools, and this implies that NLP tools must accept constraints on their input/output formats to be integrated into WebLicht: namely, they have to consume/produce valid TCF documents. On the other hand, Language Resource Switchboard (LRS) connects documents with NLP tools via their input format\(^9\). When we come to manage the integration of NLP tools into chains such as WebLicht and infrastructural services as LRS, syntactic interoperability emerges. But, at least at the beginning, it can be restricted to conversion issues that are managed with the help of ad-hoc wrappers able to connect one document \(D^i\) to another \(D^j\). We call such wrappers \(W_{ij}\).

\(W_{ij}\) can be simplified as a box which receives documents in inputs and produces new (annotated) document in output, see Figure 17.

\(^9\)Truth be told, LRS suggests tools according to the mime-type, which is a bit stronger than the format only, of the incoming documents.
9.1 Mapping the process onto Category Theory

In this section, we describe the wrappers from the point of view of Category Theory. According to our formalism, we can model the process as

\[ D^i(c_i, f_i, \{a_i\}) \xrightarrow{\tilde{\iota}_{ij}} D^j(c_j, f_j, \{a_j\}) \]  

(8)

where we identify \( W_{ij} \) with \( \tilde{\iota}_{ij} \) since both format \( f \), content \( c \) and annotation set \( \{a_j\} \) may change during the process, as actually they do. If we look at Figure 19 we see that the native tools \( t_o \) and \( t_p \), including the format converters, are wrapped into a wider box. In Figures 19a and 19b, the incoming format, \( f_i \), takes values from \{kaf, plain, tcf\} while the outgoing, \( f_o \), from \{kaf, tab, tcf\}.

9.1.1 Morphisms

The set of morphisms, i.e. the NLP tools and converters between documents \( D \), \( \text{Hom}_C(D^i, D^j) \), consists of both the original tools \( (t_o, t_p) \) and format converters. Such converters have the task of changing the input formats with those accepted by \( t_o \) and \( t_p \) as well as of transforming the native output formats to one of
\{\text{plain, tab, tcf}\}. To shorten the notation, we will agree on the following: a) \(i\) runs on the set \{kaf, plain, tcf\} while \(j\) on \{kaf, tab, tcf\}; b) if \(i = j\) the the input and the output formats of the converters are the same; c) \(c_{i2j}\) stands from “converting from format \(i\) to format \(j\)”. According to points a), b) and c), input and output converters obey to the following rules:

\[ c_{i2j} = \begin{cases} c_{i2j} & : i \neq j \\ \text{id} & : j = i \end{cases} \tag{9} \]

From Figure 19 we see that there are 12 possible combinations and, thus, 12 converters: 6 of them manage incoming and 6 outgoing formats. But when we consider the input and output restrictions of \(t_o\) and \(t_p\), we reduce the 12 converters in definition 9 to 10: 4 converters for managing input and 6 for output. We keep the 2 identities in input and output\(^{10}\) and the necessary converters, see definitions 10a and 10b.

\[
c_{\text{input}} = \begin{cases} c_0 = \text{id}_{kaf} & ; c_1 = \text{id}_{\text{plain}} \\ c_2 = c_{\text{tcf}2kaf} & ; c_3 = c_{\text{tcf}2\text{plain}} \end{cases} \tag{10a} \]

\[
c_{\text{output}} = \begin{cases} c_4 = c_{\text{ka}2\text{tcf}} & ; c_5 = c_{\text{ka}2\text{tab}} \\ c_6 = c_{\text{tab}2kaf} & ; c_7 = c_{\text{tab}2\text{tcf}} \\ c_8 = \text{id}_{\text{tab}} & ; c_9 = \text{id}_{kaf} \end{cases} \tag{10b} \]

Please note that, thanks to our definition of \(\text{id}\) as the “do-nothing” tool, \(c_9\) in definition \(10b\) is equivalent to \(c_0\) in definition \(10a\) so that the output converters reduce to 5 (9 in total). We build the \(\text{Hom}_C(D_i, D_j)\) as in definition \(11\).

\[
\text{Hom}_C(D^i, D^j) = \{t_o, t_p, \text{id}_{\text{plain}}, \text{id}_{kaf}, \text{id}_{\text{tab}}, c_2, c_3, c_4, c_5, c_6, c_7\} \tag{11}\]

Finally, we have to remember that \(\hat{t}\) is either the composition of a converter \(c\) and a tool \(t\), \(\hat{t} = c \circ t\), or the other way around a tool and a converter, \(\hat{t} = t \circ c\).

This ensure that, for some \(c\) and \(t\), \(\hat{t}\) belongs to \(\text{Hom}_C(D^i, D^j)\) as well. Each process in Figure 19 is identified by a diagram such the one in Figure 20 where \(c_i\) is one of \{\(c_2, c_3\)\} and \(c_j\) one of \{\(c_4, c_5, c_6, c_7\)\}.\(^{10}\) Identities occur when incoming formats are either \text{plain} or \text{kaf}. In such cases, we don’t need to convert such formats. The same happens when the native output of \(t_o\) and \(t_p\) are KAF and tabbed respectively.
Depending of $t$ being either $t_o$ or $t_p$, not all the compositions of $t$ with $c$ are possible. Indeed, $t_o$ is (input-)compatible with $\{c_2, c_3\}$ but only (output-)compatible with $\{c_4, c_5\}$; while $t_p$ with $\{c_3\}$ and $\{c_6, c_7\}$ respectively. Of course, if $c_i = id_i$ and $c_j = id_j$, the diagram in Figure 20 collapses to the one in Figure 21 where $\tilde{t}$ is no longer needed.

9.1.2 Objects

We have to build the collection of objects, $\text{Ob}(\mathcal{C})$. In the process $D^0$ is the initial document:

$$D^0 = D(c, f_i, \emptyset) \text{ with a caveat}$$

with $f_i$ is forced to be $f_p$ which corresponds to plain. While here we assume that $f_i$ can be either kaf or plain. This should not surprise, since, on the one hand, it is related to the input restrictions of $t_o$ which accepts either kaf or plain documents and, on the other hand, it is always possible to constrain $f_i$ to be $f_p$ by adding a converter $c_{kaf/plain}$. Such converter $c_2 = c_{kaf/plain}$ is in $\text{Hom}_\mathcal{C}(D^i, D^j)$.

Therefore, we recover definition 5 for the initial document. Not to burden the category with (pretty much) useless morphisms we decided to release definition 5 to 12.

where $c$ is the text to be analyzed, the incoming format $f_i$ is either plain, kaf or tcf, and the annotation set in the empty set. We can apply converters $c_i$ to $D^0$ which leave content and annotation set unchanged:

$$D^0 \xrightarrow{c_i} D^0_i$$

where, as usual, $c_i$ runs in $\{c_2, c_3\}$ and obtain $D^0_2$ and $D^0_3$. Then we can apply $t_o$ to the different $D^0_l$, with $l \in \{0, 2, 3\}$, to add the annotation set obtaining $D^1_o$.

Similarly, if we apply $t_p$ to $D^0_l$ we obtain $D^1_p$. Here we used the shorter notation: $D^1_0 \equiv D^1_o(c, f_{out} = kaf, \{a_1\})$ and $D^1_p \equiv D^1_p(c', f_{out} = tab, \{a_1\})$. Formats $f_{out}$...
We presented a Category Theory approach to syntactic interoperability. This means that also the content $c$ changes.

Finally, we can apply converters $c_j$ to $D_k^i$:

$$D_k^i \xrightarrow{c_j} D_k^j$$

Since $c_j$ runs in $\{c_4, c_5, c_6, c_7\}$ and $k$ runs in $\{a, p\}$, we obtain the following collections:

$$\{D_o^4, D_o^5, D_o^6, D_o^7, D_p^4, D_p^5, D_p^6, D_p^7\}$$

We build the $\text{Ob}(\mathcal{C})$ as in definition $[13]$

$$\text{Ob}(\mathcal{C}) = \{D^0, D^0_2, D^0_3 D_o^4, D_o^5, D_o^6, D_o^7, D_p^4, D_p^5, D_p^6, D_p^7\}$$

### 10 Future Work

A possible research line is to use Category Theory to approach semantic interoperability. In this paper, we assumed that when a converter $c$ is applied to a document $D^i(c_i, f_i, \{a_i\})$ the resulting document is $D^j(c_i, f_j, \{a_i\})$, i.e. the annotation set $\{a_i\}$ is left unchanged. This is not generally true, because there are tools that need documents with different formats and different values in $\{a_i\}$ and we can’t change $\{a_i\}$ with the $c$ and $t$ we have defined in $\text{Hom}_C$. Thus, we have to improve the converters $c$ so that they can act on $\{a_i\}$: $D^i(c_i, f_i, \{a_i\}) \xrightarrow{c} D^j(c_i, f_j, \{a_i\})$. Where the meaning of the values in $\{a_j\}$ might differ from the one in $\{a_j\}$. Adding such converters to $\text{Hom}_C$ allows us to define tools $t'$ which perform the same linguistic operations as $t$ but work on a different set of values in $\{a_i\}$. We can follow the strategy adopted by $[11]$ to model maps between the set of values in $\{a_i\}$ and $\{a_j\}$. In words, such morphisms are applications that maximally preserve the information when moving from $\{a_i\}$ to $\{a_j\}$. The question is are $t'$ and $t$ “the same” tool? Do these maps always exist? If so, are they unique? A different point of view is the following: if $D^i(c_i, f_i, \{a_i\}) \in \text{Ob}(\mathcal{C})$, is $D^j(c_i, f_j, \{a_i\}) \in \text{Ob}(\mathcal{C})$ as well? If we restrict the objects in $\text{Ob}(\mathcal{C})$ to have an annotation set $\{a\}$ with fixed values, the answer is negative. We can either relax this constraint or assume that $D^j(c_i, f_j, \{a_i\}) \in \text{Ob}(\mathcal{C}')$ where $\text{Ob}(\mathcal{C}')$ is a new category. Are $\text{Ob}(\mathcal{C})$ and $\text{Ob}(\mathcal{C}')$ functorially connected?

### 11 Conclusions

We presented a Category Theory approach to syntactic interoperability. This approach allowed us to describe both the composition and associativity, typical issues of a chain of interoperable NLP tools, through a more abstract mathematical formalism. The restrictions of input and output formats of the NLP tools have been modeled as format converters. The resulting category has the NLP

11 This is the case, for example, when a tool $t$ needs `VERB` instead of `V` as part-of-speech.
applications and the format converters as its morphisms, while the documents (with or without linguistic annotations) form its objects. We do not pretend to rewrite the approach to syntactic interoperability within the chains of linguistic tools, but we think that a more abstract approach to syntactic interoperability can help in the actual design and implementation of NLP tools. Certainly, this approach captures the formal requirements of a tool in terms of its input/output specifications and of its linguistic operations providing a guide for software design and implementation. For example, looking at the tools \((\tilde{t})\) as the composition of an NLP tool and a format converter helps software engineers and programmers at keeping core tools (the tools the analyze documents) and format converters logically separated.\(^{12}\) The Category Theory approach takes a step toward the implementation of atomic tools rather than complex ones, which is also in line with \([7]\), but given its abstraction, complex tools are also allowed. Or might be built.

We also proposed further investigations that involve more advanced concepts of Category Theory and that will be addressed in forthcoming papers.

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A Language Resource and Technologies

A Language Resource (LR) is a machine-readable collection of data for written or spoken languages. A collection of texts of Homeric poems, an Italian dictionary, an English-Arabic (bilingual) dictionary, a specific edition of a book, a simple text are Language Resources. But a list of words extracted from a book, the list of most frequent words used by Dante are Language Resources as well.

We often read sentences like “the lexicon used by author X” or “this word is unusual for author Y” when we go through some essays or criticisms, but also “this concept is closer to the politician A than to B” when we listen to public debates. The first pair of sentences is related to written data, while the second one to vocal data. Both of them, however, originate from information extracted from a LR. Indeed, the lexicon of an author X is the list of distinct words used in the (literary) production of X and these words can be ranked according to their frequencies to obtain most and less frequent words. Or, a very deep analysis of speeches of politician A can extract opinions of A on some topics and so on.

We may ask how such information is extracted from Language Resources. The answer is using Language Technologies. Language Technologies (LT) are the dynamic counterpart of Language Resources. If the latter can be considered “static” in the sense that once created they are stable, the former perform linguistic tasks (in a given time span) to create or modify Language Resources from data or an existent LR respectively.

\[ d \xrightarrow{LT} LR \]
\[ LR \xrightarrow{LT_1} LR' \]

Linguistic tasks may be complex, but the idea is simple. When, at school, in sentences such as “Lysa likes oranges”, we assign the part of speeches (subject, verb, object…) to words: Lysa is a subject, likes is a verb, oranges is the object we are making part-of-speech tagging. If we study the inter-dependency among words we are doing a parsing. Or when we read an email and extract some information we are doing information extraction. Things go more difficult when we try to understand the actual opinion of a person X on a topic Y or to classify some data according to a set of features. But, as humans, we are able to finish the tasks.

Language tasks can also be performed by machines. There is specially designed software to simulate the human ability to perform specific linguistic activities. Tools that process the natural language are part of the Natural Language Processing (NLP) research field.

There are many NLP suites available. In addition to UIMA and GATE, we can cite CoreNLP\[^{14}\][31], the Apache OpeNLP project\[^{15}\][27] or the python-based NLTK\[^{16}\], acronym which stands for Natural Language Tool Kit\[^{19}\].

\[^{13}\]This is not completely true. A LR can be periodically updated, but between updates it is stable.

\[^{14}\]https://stanfordnlp.github.io/CoreNLP/

\[^{15}\]https://opennlp.apache.org/

\[^{16}\]https://www.nltk.org/
On the site of Language Resources, one of the most used, famous and powerful is WordNet\textsuperscript{17}. According to their website:

WordNet\textsuperscript{17} is a large lexical database of English. Nouns, verbs, adjectives and adverbs are grouped into sets of cognitive synonyms (synsets), each expressing a distinct concept. Synsets are interlinked by means of conceptual-semantic and lexical relations.

A.1 Metadating

Metadata are data about data. In other words, metadata describe data. For example, a book tells a story. The story is the data contained in the book. However, the authors and the title bring additional information that is not necessary for the story told but might be useful for the book to be found using search engines. The same happens for Language Resources and Language Technologies. We can describe Language Resource and Technologies (LRT) using metadata to say that “A is a lexicon”, or that “B is a parser” and so on.

Formally, metadata are pairs “key=value” whose meaning is described in a given schema\textsuperscript{18}. The same LR, however, can be described according to different schemas. This situation seems strange, but it’s typical in the field of LRT.

Besides, metadata are not limited to describe what a LRT is but they are also massively used to describe deep features of both LR and LT. For example, metadata are used to specify what an NLP tool accepts as input and produces as output. Unfortunately, given the specificity of the field of LRTs, the possible values that value can assume is an open set. In the case of part-of-speech tagger, a valid pair to specify the output is “pos=V,N,A”. But another part-of-speech tagger could use the alternative “pos=VERB,NOUN,ADJECTIVE”.

B Projects, Research Infrastructures, and Interoperability

From Appendix A\textsuperscript{13} it seems that if we want to run an NLP tool after another, we have only to use one of the available suites. Unfortunately, it is not so easy. And this happens for many reasons. Computational Linguistics, as a discipline, originates between the 1940s and 1950s in the United States as a mechanism to manage automatic translations. In Italy, Father R. Busa firstly applied computational methods to textual analysis. NLP suites started to be available and robust 10 to 20 years ago. In the meantime, researchers in Computational Linguistics all over the world started to develop their proprietary software, using different methods, strategies, formats, and programming languages. When we come to use NLP suites, we find it quite difficult: the offered part-of-speech is not exactly the one we are used to, and when we try to use our proprietary software through such suites, well our tools often are not compliant with the

\textsuperscript{17}https://wordnet.princeton.edu/
\textsuperscript{18}For example the Dublin Core\textsuperscript{TM} schemas at https://www.dublincore.org/schemas/
suite specifications, precisely for interoperability reasons. Also, what if we have a lot of data in our data centers we can’t run NLP tools on?

It is needed, then, to expand the concepts of NLP suites and data centers. Here is where projects and Research Infrastructures come to play.

Platforms such as The Language Application Grid, Lapps, [26], https://www.lappsgrid.org/, in the US, the Language Grid [32], https://langrid.org/en/index.html, in Japan, European Projects such as PANACEA, http://www.panacea-lr.eu/, and OpeNER [1], http://www.opener-project.eu/ are an evolution of NLP suites. Lapps fosters interoperability [36]: the same holds true for OpeNER and PANACEA. Indeed, we see the adoption of Kyoto Annotation Format (KAF) [8] in OpeNER [19] of Graph Annotation Format (GrAF) [20] in PANACEA [20] and Lexical Markup Framework (LMF) [19] in both projects as a clear direction towards interoperability.

But it is with Research Infrastructures that many research communities made further steps. Research Infrastructure [21] are facilities that provide resources and services for research communities to conduct research and foster innovation.

There are Research Infrastructures (RIs) for public service, (high-energy) physics, health ... And for Computational Linguistics and the sub-field of Social Sciences and Humanities (SSH), but entities such as CLARIN, https://www.clarin.eu and DARIAH, https://www.dariah.eu/ are proper Research Infrastructures that “provide resources and services ... to conduct research ...”. According to CLARIN manifesto,

[CLARIN] makes digital language resources available to scholars, researchers, students and citizen-scientists from all disciplines, especially in the Social Sciences and Humanities.

while DARIAH’s states:

The Digital Research Infrastructure for the Arts and Humanities (DARIAH) aims to enhance and support digitally-enabled research and teaching across the arts and humanities...

Both of them foster interoperability, of course. For example, in CLARIN, WebLicht [22] and Language Resource Switchboard (LRS) [37] offer linguistic chains based on an agreed structure, the Tübingen Corpus Format, TCF [23] along with a specific metadata format, the CMDI [10], and a metadata description (in JSON) that provides the relevant information for executing the tools.

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1. https://github.com/opener-project/kaf/wiki/KAF-structure-overview
2. http://www.panacea-lr.eu/system/graﬀ/graﬀ-TU2_documentation_v1.pdf
3. https://ec.europa.eu/info/research-and-innovation/strategy/european-research-infrastructures_en
4. They are ERIC, which stands for European Research Infrastructure Consortia.
5. The TCF format is described at https://weblicht.sfs.uni-tuebingen.de/weblichtwiki/index.php/The_TCF_Format
6. https://www.clarin.eu/content/component-metadata
B.1 Metadating and Interoperability

In Appendix A.1, we enumerated two cases when the same LR or Technology is described with two different metadata schemas and when the same pair "key=value" is applied, but the field value is different.

The former happened, for example, with Metashare\(^25\) and CLARIN\(^26\). Metashare is slightly later than CLARIN, but decided to implement its own metadata schema\(^20\) rather than use CLARIN’s CMDI schema. Then, if the same resource \(R\) is described according to the two schemas, there should be a \textit{syntactic} mapping\(^27\) from one to another:

\[
{R}_{ms} \leftrightarrow {R}_{clarin}
\]

The latter is related to \textit{semantic} interoperability. Given the same schema, a \textit{semantic} mapping\(^28\) from one set to another:

\[
\{V,N,A\} \leftrightarrow \{\text{VERB, NOUN, ADJECTIVE}\}
\]

C Linguistic Annotations

Linguistic annotation is additional information somehow attached to a text, a part of the text, a single word, or a single character. Without pretending to be linguistically rigorous, we provide an example\(^29\). Given the sentence “Lysa likes oranges”, a human or a machine can annotate it as follows:

a) \(<\text{SENTENCE}>\text{Lysa likes oranges}</\text{SENTENCE}>\)

b) \(<\text{SUBJ}>\text{Lysa}</\text{SUBJ}> <\text{VERB}>\text{likes}</\text{VERB}> <\text{OBJ}>\text{oranges}</\text{OBJ}>\)

c) \(<\text{CAP}>L</\text{CAP}>\text{Lysa} <\text{VERB type="3rd singular person" verb="like">\text{likes}</</\text{VERB}> <\text{NAME type="plural" name="orange">\text{oranges}</</\text{NAME}>\)

Figure 22: Some examples of inline tags for linguistic annotations.

Many other annotations are possible. Annotations in Figure 22 are called \textit{inline}, because the tags \(<.../>\) they use are directly inserted in text. If a person reads the annotations, \(s\)he gets from a) that “Lysa likes oranges” is something

\(^25\)http://www.meta-share.org/\(^26\)

Before being an ERIC, CLARIN was a European project. Project in which the technological bases of the future ERIC have been defined.

\(^27\)This does not occur, of course. Indeed, a bijection between two schemas seldom exists.

\(^28\)As for syntactic interoperability, a complete semantic mapping is far from being reached. In Computational Linguistics, there are cases when a value, for instance, \textsc{VERB}, is mapped from two (or even more) different values, for instance, a transitive and an intransitive verb, \(\textsc{VI}\), \(\textsc{VT}\). It is always possible to map from fine to a coarse-grained value, but the vice-versa can not be done. What we can say is that one of the possible (fine-grained) value belongs to the preimage of \textsc{VERB}.

\(^29\)Usually, annotations obey to a schema
called **SENTENCE**; from b) that Lysa has the role of **SUBJ**; from c) that L in Lysa is a capital letter **CAP** ...

Different annotations provide different information. A person, a human agent, can understand the meaning of the various tags: **SENTENCE**, **SUBJ**... However, a machine-based agent, an **NLP**, can be told how to deal with such tags.

In addition to the inline annotations, there are the standoff ones. **Standoff annotation** means that all tags are moved from the text which is left unchanged.

```xml
<TEXT>Lysa likes oranges</TEXT>
...
<word id=1>Lysa</word>
<word id=2>likes</word>
<word id=3>oranges</word>
...
<ROLES>
  <ROLE wid=1 type="SUBJ"/>
  <ROLE wid=2 type="VERB"/>
  <ROLE wid=1 type="OBJ"/>
</ROLES>
```

Figure 23: An example of standoff annotation.

The annotation in Figure 23 replaces annotation b) in Figure 22. It provides the same information as b) does: Lysa has the role of **SUBJ**, likes of **VERB** and so on but using a different format. The original sentence is split by tokens; to each token is assigned a n identifier and additional information is connected to the identifier.

The above mentioned **KAF** and **GrAF** are standoff annotation schemas, while, for example, the **Text Encoding Initiative (TEI)**, [https://tei-c.org/](https://tei-c.org/) is inline.