A knowledge representation framework for managing Leonardo Da Vinci's Mona Lisa: case study of the hidden painting

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Abstract

This paper explores the use of Artificial Intelligence/Knowledge Representation methods for digitally modeling the cultural heritage items. It fully complies with the concept of "Cultural Heritage Digital Twin", which is characterized by a "physical" component of the cultural entity, concerning style, dimension, name of the artist, execution time, etc., and by an "immaterial" component representing, among other things, the emotional and intangible messages transmitted by the entity. The "Narrative Knowledge Representation Language" (NKRL) is then been adopted for digitally representing the two components of the twin and its immaterial component in particular, due to its ability to represent in a simple but rigorous and efficient way complex situations and events, behaviors, attitudes, etc. An experiment concerning the "hidden painting" that lies beneath the Mona Lisa ("La Gioconda") image on the same poplar panel has been then realized, showing that NKRL is able, in fact, to successfully provide a suitable representation of at least some of the intangible elements of the "visual narrative" represented by this still largely undeciphered portrait.

Keywords

Cultural Heritage Digital Twin, Knowledge Representation, NKRL, Mona Lisa.

1. Introduction

In recent years, knowledge representation and querying/inferencing proved to be important topics to be dealt with in the cultural heritage domain, which raised attention by the European Commission. More specifically, considering the recent Horizon 2020 Programme, and with respect in particular to the specific 2020 challenges related to the topic "DT-TRANSFORMATIONS-12-2018-2020: Curation of digital assets and advanced digitization", the Commission expressed the need to create *a comprehensive representation of the studied assets*, which includes not only the visual and structural information, but also experiences and narratives stored in language data, together with their cultural and socio-historical context, as well as their evolution over time [1].

This implies that *more advanced methodologies* should be introduced to describe and represent not only the "*physical*" aspects of the cultural heritage items, including all those features usually employed for characterizing the items, i.e., support, style, dimensions, name of the artist, execution technique, information about the owner, location and collections the item is or was in the past, etc., but also the *"message" and the emotional states* that these items express according to their cultural, historic and social background. Recently, the term "Cultural Heritage Digital Twin" has been introduced, which merges the concept of Digital Twin well-known in the context of Artificial Intelligence [2] and that of Cultural Heritage, in order to provide a complete digital modeling and characterization of every Cultural

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Heritage item. The twin should be characterized by the presence of *two components*, the first one regarding the aforementioned *physical* description of the item, and the second one to be used for representing the *intangible (immaterial) and emotional messages* transmitted by the item.

In this paper, we make use of this new concept by focusing, in particular, on the improvement of the digital modeling techniques to be used for those "*iconographic entities*" (paintings, drawings, frescoes, mosaics, sculptures, murals etc.) that represent a particularly important component – both numerically and culturally – of the whole Cultural Heritage domain. In this framework, an experiment has been conducted in the context of a project concerning an advanced digital representation of the Mona Lisa ("La Gioconda") painting by Leonardo Da Vinci, taking into account in particular the "hidden painting" that lies beneath Mona Lisa's portrait on the same poplar panel. This work conforms to the aforementioned concept of Cultural Heritage Digital Twin by emphasizing, in particular, *the importance of the "immaterial" and "emotional" components of this concept*; in spite, in fact, of the current literature where various works have been proposed for pattern extraction and exploration from a "visual computing" perspective [3], this research direction is still little explored. Accordingly, it seems there are no really suitable computer-usable descriptions of these emotional elements that can be considered as sufficiently exhaustive (and interoperable) for the scope. To overcome this limitation, the "Narrative Knowledge Representation Language", NKRL [4] has been selected for digitally modeling the whole Mona Lisa's Cultural Heritage Digital Twin, due to the NKRL's ability to represent in a simple but rigorous and efficient way complex situations and events, behaviors, attitudes, etc., see also our previous work in this context described in [5].

The paper is organized as follows. Section 1 provides the general background and motivation of this work. Section 2 presents in some details the experiment about the digital modeling of the hidden painting's "narrative". Eventually, Section 3 draws conclusions about the described experiment.

2. Experiment

A problem that has troubled Mona Lisa' specialists for a long-time concerns the identification of the woman represented in the "*hidden painting*", i.e., the portrait, visible to us only in x-rays, indubitably painted by Leonardo and that lies beneath Mona Lisa on the same poplar panel see, e.g., [3]. According, e.g., to Lillian Feldmann Schwartz [6], *this woman has nothing to do with Mona Lisa* and represents probably Isabella d'Aragona, wife of the Duke of Milan Gian Galeazzo Sforza – end of 15th century, Leonardo had worked for the Sforza family. Feldmann Schwartz's hypothesis is based, essentially, on the *lack of correspondence* between the facial characteristics of the hidden painting woman and Mona Lisa. More exactly, eyes, mouth, nose tips, hairlines and chins do not match between Mona Lisa and the unknown woman. A correspondence exists, on the contrary, between this last woman and the woman represented on a Leonardo's cartoon, a (very retouched) preparatory study for a portrait of Isabella d'Aragona. Specifically, the eyes of the hidden painting woman were, in L.F. Schwartz's words, "lined up with the eyes on the cartoon, the hairlines fell into place and overlapped exactly". Table 1 below reproduces the NKRL narrative, gio3, see [4], which formalizes (at least partly) the hidden painting issue.

Table 1

NKRL representation of the "hidden painting" issue

gio3.c1: (COORD gio3.c2 gio3.c3 #gio3.c4 gio3.c5)

The formal representation of the "hidden painting" topic is structured in three parts. gio3.c2 *informs us that a hidden painting exists, that it has been realized by Leonardo, and lists some of its characteristics.* gio3.c3 *and the associated* #gio3.c4 *occurrence (completive construction) explains why Lillian Feldmann Schwartz rejects the identification of the hidden woman with La Gioconda and suggests, instead, that the hidden portrait could represent Isabella d'Aragona. The last predicative occurrence,* gio3.c5, *points out that several art historians agree with Ms. Feldmann Schwartz about her "Isabella d'Aragona hypothesis".*

gio3.c2: (COORD gio3.c6 gio3.c7)

The first component of the representation consists of two predicative occurrences.

```
gio3.c6: PRODUCE:
         SUBJ: LEONARDO_DA_VINCI
         OBJ: PAINTING_2
         TOPIC: (SPECIF portrait_ UNKNOWN_WOMAN_1)
```

date-1: 1/1/1497, 31/12/1503
date-2:

Produce:Entity (6.2)

A painting (conventionally: PAINTING_2) *concerning the portrait of a woman (conventionally:* UNKNOWN_WOMAN_1*) has been produced by Leonardo da Vinci within the temporal interval 1497-1503.*

gio3.c7: OWN:
SUBJ: PAINTING_2
OBJ: property_
TOPIC: (COORD1 (SPECIF painted_on POPLAR_PLANK_1 (SPECIF under_ PAINTING_1)) (SPECIF labelled_as HIDDEN_PAINTING) (SPECIF visible_ x_ray_analysis))
{ obs }
date-1: today_
date-2:

Own:CompoundProperty (5.42)

We can remark today (modulator obs*(erve)) that i)* PAINTING_2 *has been painted on the same poplar plank of* PAINTING_1 *(conventionally, Mona Lisa's portrait), ii) it is located under* PAINTING_1*, iii) it is known as the* HIDDEN_PAINTING *and, iv) it is visible only under x-ray analysis.*

gio3.c3: MOVE:
SUBJ: LILLIAN_FELDMANN_SCHWARTZ
OBJ: #gio3.c4
MODAL: (SPECIF SCIENTIFIC_PAPER_2 (SPECIF published_on THE_VISUAL_COMPUTER_JOURNAL))
date-1: 1/1/1988, 31/1/1988
date-2:

Move:GenericInformation (4.41)

In January 1988, Lillian Feldmann Schwartz has circulated the information described in gio3.c4 *by means of a scientific paper published in 1988 on "The Visual Computer" Journal.*

gio3.c4: (COORD gio3.c8 gio3.c9)

The information spread by Lillian Feldmann Schwartz via her paper is formed of two parts.

gio3.c8: (CAUSE gio3.c10 gio3.c11)

The first part of the disseminated information consists in stating that what is described in gio3.c10 *is originated by the events collected in* gio3.c11.

gio3.c10: BEHAVE:
SUBJ: (SPECIF UNKNOWN_WOMAN_1 (SPECIF identified_with MONA_LISA))
{ obs, negv }
date-1: 1/1/1988, 31/1/1988
date-2:

Behave:HumanProperty (1.1)

The elementary event represented by occurrence gio3.c10 *is a "negated event" (modulator* negv*), i.e.,* UNKNOWN_WOMAN_1 *is not* MONA_LISA.

gio3.c11: (COORD gio3.c12 gio3.c13)

The reasons for failing to identify UNKNOWN_WOMAN_1 *with* MONA_LISA *are (partially, see below) collected in* gio3.c11.

gio3.c12: OWN:
SUBJ: (SPECIF eye_ (SPECIF cardinality_ 2) UNKNOWN_WOMAN_1)
OBJ: property_
TOPIC: (SPECIF different_from (SPECIF eye_ (SPECIF cardinality_ 2) MONA_LISA))
MODAL: x_ray_analysis
{ obs }
date-1: today_
date-2:

Own:CompoundProperty (5.42)

A dissimilarity exists between the eyes of UNKNOWN_WOMAN_1 *and those of* MONA_LISA.

gio3.c13: OWN:
SUBJ: (SPECIF mouth_ UNKNOWN_WOMAN_1)
OBJ: property_
TOPIC: (SPECIF different_from (SPECIF mouth_ MONA_LISA))
MODAL: x_ray_analysis
{ obs }
date-1: today_
date-2:

Own:CompoundProperty (5.42)

A dissimilarity exists also between the mouths of UNKNOWN_WOMAN_1 *and* MONA_LISA. *In reality, the* COORD *list (binding occurrence)* gio3.c11 *should include three additional predicative occurrences, practically identical to* gio3.c12 *and* gio3.c13, *but including* nose_, chin_ *and* hairline_ *instead of* eye_ *and* mouth_. *To the extent that the insertion of these three additional occurrences would not introduce any substantial improvement with respect to the understanding of the logic of the NKRL coding, they have been suppressed for the sake of clarity.*

gio3.c9: (REFER gio3.c14 gio3.c15)

The second component of L.F. Schwartz's message is represented by a REFER*(ence) – weak causality – binding occurrence.*

In a REFER*(ence) type of relationship, the second argument is needed but not sufficient to explain the first.*

```
gio3.c14:  BEHAVE:
           SUBJ: (SPECIF UNKNOWN_WOMAN_1 (SPECIF identified_with ISABELLA_D_ARAGONA))
           { obs, poss }
           date-1: 1/1/1988, 31/1/1988
           date-2:
```

Behave:HumanProperty (1.1)

It is possible (modal modulator poss*(ible)) that the "unknown woman" corresponds to Isabella d'Aragona.*

```
gio3.c15:  (COORD gio3.c16 gio3.c17 gio3.c18)
```

The reasons for this (possible) identification are given in the three predicative occurrences listed in gio3.c16.

```
gio3.c16:  PRODUCE:
           SUBJ: LEONARDO_DA_VINCI
           OBJ: CARTOON_DRAWING_1
           TOPIC: (SPECIF portrait_ ISABELLA_D_ARAGONA)
           date-1: 1/1/1490, 31/12/1495
           date-2:
```

Produce:Entity (6.2)

In the period 1490-1495, Leonardo da Vinci realized, in the form of a cartoon drawing, the portrait of Isabella d'Aragona.

```
gio3.c17:  OWN:
           SUBJ: (SPECIF eye_ (SPECIF cardinality_ 2) ISABELLA_D_ARAGONA): (CARTOON_DRAWING_1)
           OBJ: property_
           TOPIC: (SPECIF coincident_with (SPECIF eye_ (SPECIF cardinality_ 2) UNKNOWN_WOMAN_1))
           MODAL: x_ray_analysis
           { obs }
           date-1: today_
           date-2:
```

Own:CompoundProperty (5.42)

There is a correspondence between the eyes of Isabella d'Aragona and those of the unknown woman.

```
gio3.c18:  OWN:
           SUBJ: (SPECIF hairline_ ISABELLA_D_ARAGONA): (CARTOON_DRAWING_1)
           OBJ: property_
           TOPIC: (SPECIF coincident_with (SPECIF hairline_ UNKNOWN_WOMAN_1))
           MODAL: x_ray_analysis
           { obs }
           date-1: today_
           date-2:
```

Own:CompoundProperty (5.42)

There is a correspondence between the hairline of UNKNOWN_WOMAN_1 *and the hairline of* WOMAN_54.

```
gio3.c5:   BEHAVE:
           SUBJ: (SPECIF individual_person art_historian (SPECIF cardinality_ several_))
           OBJ: LILLIAN_FELDMANN_SCHWARTZ
           MODAL: endorsement_
           TOPIC: (SPECIF ISABELLA_D_ARAGONA_HYPOTHESIS LILLIAN_FELDMANN_SCHWARTZ)
           { for }
           date-1: 1/1/1988, 31/1/1988
           date-2:  today_
```

Behave:FavourableAttitude (1.311)

Several art historians agree with Lillian Feldmann Schwartz about her Isabella d'Aragona hypothesis.

It can be interesting to remark how the NKRL representation of a *full (visual or textual) narrative* can always be represented under *tree-shaped format* – as a *knowledge graph*, then, to make use of a now very popular terminology. This possibility represents, among other things, *a simple way to immediately check the logical coherence of a generic digitalized narrative*. Figure 1 shows the representation under tree format of the narrative of Table 1.

We will now comment and explain the above encoding trying, at the same time, to highlight the interest of the NKRL's knowledge representation tools *for symbolizing/managing complex "narrative" contents independently from the type of their support*. That is, independently from the fact that these contents are disclosed to the public through visual-oriented techniques (i.e., making use of paintings, drawings, frescoes, mosaics, sculptures, murals etc.) as in the case examined in the present paper – see also [5, 7] – or through textual-oriented techniques (i.e., via books, papers, articles, news, all sort of written documents, etc.).

2.1 Basic Remarks about the NKRL's Knowledge Representation Structures

From an ontological point of view, *the most interesting characteristic of NKRL concerns the addition of an ontology of elementary events to the usual ontology of concepts*. This last is called HClass (hierarchy of classes) in an NKRL context and allows us to represent the *strictly lexical aspects* of the specific information to be dealt with. HClass presents some interesting, original aspects from an ontological point of view with respect, e.g., to the representation of difficult notions like substances and colors [4: 132-137]. However, HClass' architecture is *relatively traditional*, and its concepts are represented, to a large extent, according to the usual Semantic Web "binary" model.

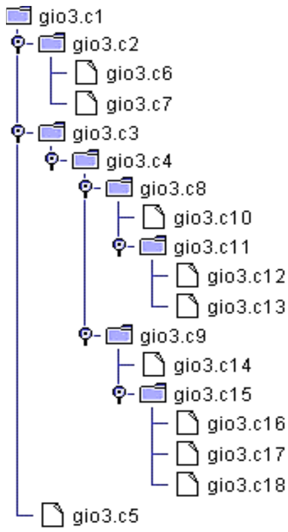

Figure 1: Tree-shaped representation of Table 1 formalism

A pure binary-based approach faces, however, major difficulties when the entities to be represented are not simple notions/concepts that can be defined a priori and inserted then in a graph-shaped static ontology, but denote instead *dynamic situations*. These last are characterized, in fact, by the presence of *complex spatio-temporal information* and of *mutual relationships* among their constituent elements (including, e.g., intentions and behaviors). In specifying then the ontology of elementary events of NKRL, *an augmented n-ary approach has been chosen*. In this approach, *n*-ary means to make use of a formal representation where a given predicate can be associated with *multiple arguments* – representing the *n*-ary purchase relation implies, e.g., associating with a purchase-like predicate several arguments as a seller, a buyer, a good, a price, a timestamp, etc. *Augmented* means that – see in this context the seminal "What's in a Link" paper by William Woods [8] – within *n*-ary representations, the logico-semantics links between the predicate and its arguments *are explicitly represented making use of the notion of functional role* [9]. The NKRL representation of a simple narrative like "Peter gives a book to Mary" will include, then, the indication that Peter plays the role of subject/agent of the action of giving, book is the object of this action and Mary the beneficiary.

In the NKRL ontology of elementary events, the nodes are then represented by *augmented n-ary knowledge patterns called templates* – this ontology is known then as HTemp, the hierarchy of templates. Templates *denote formally general classes of elementary states/situations/actions/episodes etc.* (designated collectively, for simplicity, as elementary events). Examples can be "be present in a place", "experience a given situation", "have a specific attitude", "send/receive messages", etc. Templates' instances – called *predicative occurrences* – describe formally the meaning of specific elementary events pertaining to one of these classes. The general representation of a template is given by Eq. 1.

$$(L_i\ (P_j\ (R_1,\ a_1)\ (R_2,\ a_2)\ \ldots\ (R_n,\ a_n))). \qquad (1)$$

In Eq. 1, L_i is the *symbolic label* identifying a given template. P_j is a *conceptual predicate*. R_k is a *generic functional role*, used to specify the logico-semantic function carried out by its filler a_k, a standard predicate argument, with respect to predicate P_j. We can note that, to avoid the ambiguities of natural language and any possible combinatorial explosion problem, see Zarri [4: 56-61], both the conceptual predicate of Eq. 1 and the associated functional roles are represented as *primitives*.

Predicates P_j belong then to the closed set {BEHAVE, EXIST, EXPERIENCE, MOVE, OWN, PRODUCE, RECEIVE}, and the roles R_k to the set {SUBJ(ect), OBJ(ect), SOURCE, BEN(e)F(iciary), MODAL(ity), TOPIC, CONTEXT}. As a consequence, the HTemp hierarchy is structured into *seven branches*, where each of them includes only the templates created – see Eq. 1 – around one of the seven predicates P_j. HTemp includes presently (September 2022) more than 150 templates, very easy to specialize and customize.

A simple example extracted from Table 1 above – a predicative occurrence identified by the symbolic label (L_i) gio3.c16 – will allow us to clarify what the use of Eq. 1 above implies from a concrete point of view.

When the NKRL template Produce:Entity corresponding to the general syntax of Eq. 1, see Table 2, is instantiated to provide the representation of the elementary event, "In the period 1490-1495, Leonardo da Vinci realized, in the form of a cartoon drawing, the portrait of Isabella d'Aragona", we can see from gio3.c16 that the predicate P_j of Eq. 1 (PRODUCE in this case) introduces three arguments a_k, namely LEONARDO_DA_VINCI, CARTOON_DRAWING_1 and (SPECIF portrait_ ISABELLA_D_ARAGONA) via, respectively, the functional roles (R_k) SUBJ(ect), OBJ(ect) and TOPIC. As it appears clearly from Table 2, in the actual representation of all the NKRL's templates, the a_k terms of Eq. 1 are implemented under the form of *variables* var_i associated with *constraints* expressed by HClass terms or combinations of these terms; these constraints must be satisfied when the occurrences are created.

Table 2

The Produce:Entity template

name: Produce:Entity
father: Produce:
position: 6.2
NL description: Creation of Generic Entities, Elements, etc.

PRODUCE:
SUBJ: *var1*: [(*var2*)]
OBJ: *var3*
[SOURCE: *var4*: [(*var5*)]]
[BENF: *var6*: [(*var7*)]]
[MODAL: *var8*]
[TOPIC: *var9*]
[CONTEXT: *var10*]
{ [modulators], ≠abs }

var1: human_being_or_social_body
var3: artefact_, information_content, economic/financial_entity
var4: human_being_or_social_body
var6: human_being_or_social_body
var8: artefact_, activity_, process_, temporal_development
var9: information_content, physical_appearance, situation_
var10: situation_, symbolic_label
var2, *var5, var7*: location_

In our example, the *individual* LEONARDO_DA_VINCI is an *instance* (through intermediate HClass concepts like individual_person) of the *high-level concept* human_being_or_social_body. In NKRL, individuals are denoted using upper-case characters, and concepts are in lower-case. It satisfies then the constraint imposed on *var1* of the Produce:Entity template – and, as a consequence, on all the possible fillers of the SUBJ(ect) roles in all the predicative occurrences derived from this template. Similarly, CARTOON_DRAWING_1 is an *instance* of cartoon_drawing, a specific HClass term included in the branch of the HClass ontology having at the top the (high-level) concept artefact_ and integrating intermediate items like drawing_ and artistic_artefact; it satisfies then the constraint on *var3*, the OBJ(ect) filler of the template. With respect now to the TOPIC filler of gio3.c16, (SPECIF portrait_ ISABELLA_D_ARAGONA), we can note first that main element of this *"structured argument" or "expansion"*, i.e., portrait_, is a *HClass concept instead of an individual as in the previous two cases*. This is in conformity with an important NKRL principle that requires to limit as much as possible any *unnecessary proliferation of individuals* in the context of concrete NKRL applications because of the difficulties of creating and managing in a coherent way large amounts of this sort of entities, see [9] in this context. Anyway, portrait_ is a specific term of image_, a concept pertaining to the information_content subtree of HClass, and the constraint on *var9* of Produce:Entity is then satisfied.

Returning now to the structured arguments/expansions and their syntax, we can note that this particular kinds of a_k arguments take the form of *recursive lists introduced by the four AECS operators*, the alternative operator ALTERN(ative) = A, the distributive operator ENUM(eration) = E, the collective operator COORD(ination) = C and the attributive operator SPECIF(ication) = S. This last operator is widely used in the predicative occurrences of Table 1; in the example of gio3.c16, it is used to *exactly specify* that the portray we are speaking of is the Isabella d'Aragona's portrait. An example of the use of the operator COORD(ination) is given in the gio3.c7 predicative occurrence: in this case, the TOPIC's filler is represented by three SPECIF lists where the first tell us that PAINTING_2 (the hidden painting) is painted on the same poplar plank utilized for the Mona Lisa's portrait and, more precisely, that is located under this portrait, the second that this specific painting is named "the hidden painting", and the third that PAINTING_2 is visible only under x-ray. This particular expansion allows us to introduce also the so-called *priority rule*, see [4: 68-70], which supervises the interweaving of the AECS operators within a structured argument by forbidding, e.g., to use a list of the COORD type within the scope of a list SPECIF. The inverse is obviously admitted, as the structured argument of gio3.c7 demonstrates.

Once a given template has been instantiated in order to obtain a valid *n*-ary predicative occurrence, this last is *reified* by means of a symbolic name like gio3.c16, corresponding then to L_i of Eq. 1 and allowing *the inclusion of this occurrence within wider conceptual structures*, see next subsection. With respect to templates and their instantiation procedures, we can also add that, in Table 2, the elements in square brackets are *facultative*: this means that, for example, in the predicative occurrences derived from the Produce:Entity template, only the SUBJ and OBJ roles and their associated elements are obligatorily present.

When needed, *determiners (attributes)* can be added to templates and predicative occurrences to introduce further details about the *basic core*, "symbolic label – conceptual predicate – functional roles – arguments of the predicate", see Eq. 1, of their formal representation. In the template of Table 2, e.g., the variables *var2*, *var5* and var7 denote, e.g., determiners/attributes of the location type represented, in the corresponding predicative occurrences, by specific terms of the HClass concept location_ or by individuals derived from these terms. *Modulators* represent an important category of determiners/attributes that – unlike the location determiners that can be associated only to the fillers of the SUBJ, OBJ, SOURCE and BENF functional roles – apply to a full, well-formed template or predicative occurrence to *particularize its meaning*. They are classed into three categories, temporal (begin, end, obs(erve)), deontic (oblig(ation), fac(ulty), interd(iction), perm(ission)) and modal (abs(olute), against, for, main, ment(al), poss(ible), wish, etc.), see [4: 71-75]. Several examples of use of the different categories of modulators appear in Table 1. In particular, the temporal modulator obs(erve) is frequently used to denote that, at the specific date associated with the attribute date-1 (see below), the elementary event corresponding to the predicative occurrence we are dealing with (e.g., gio3.c7) is *in progress*, without making any assumptions about the existence of this event before and after the given date. The modal negv (negated event) modulator used in gio3.c10 is particularly important, given that it is used to point out that the elementary event corresponding to the particular predicative occurrence where negv can be found *did not take place*. In the gio3.c7 example, UNKNOWN_WOMAN_1 *has not been recognized* as Mona Lisa.

A last category of attribute/determiners concerns the two operators date-1, date-2. They are necessarily associated with any well-formed NKRL predicative occurrence, see Table 1, and are used in general to materialize the *temporal interval* normally associated with the elementary event corresponding to a particular occurrence. Linking a specific date (full date, uncertain data, reconstructed date etc.) associated with date-1 with one of the three temporal modulators introduced above allows us to denote the *beginning* of a specific event (modulator begin), the *termination* of an event (end) or, as already stated, the fact that a specific event is *in progress* at the date-1 date. A detailed description of the formal system used in NKRL for the representation and management of temporal information can be found, e.g., in [10].

2.2 Second order Conceptual Structures

In the context of accurate, complete and digitally exploitable representations of any sort (pictural, textual etc.) of complex and structured narrative events, it is evident the need for efficient tools able to collect and join together, within a unified and coherent framework, all their possible basic, formalized fragments that could be equated, in some way, to NKRL's predicative occurrences. *NKRL is endowed with several tools capable to satisfy this need*; this represents a further proof of the advantage of NKRL's approach with respect to other proposals committed to the formalization of narrative-like information.

A first, elementary way to associate together predicative occurrences in an NKRL context concerns the possibility of making use of a sort of *co-reference mechanism* allowing us to logically associate two or more predicative occurrences where the same individual(s) appear(s). In Table 1 for example, we have utilized the individual UNKNOWN_WOMAN_1 to denote the unknown personage whose portrait lies beneath Mona Lisa's portrait. The consistent utilization of this artifice allows us, then, to associate together seven predicative occurrences of Table 1 – gio3.c6, gio3.c10, gio3.c12 etc. – and to create then, at lower costs, a (possibly interesting) *thematic cluster*. With respect to the above remark about the practical dangers associated with an unjustified proliferation of individuals, we can note that the creation of the individual UNKNOWN_WOMAN_1 is here *absolutely necessary* and then totally justified. The introduction of a generic unknown_woman concept instead of the individual within the seven predicative occurrences would have made, in fact, the management problems of the HClass terms even worse by forcing the developers to create *useless and expansive inference procedures* to verify, when finding unknown_woman in one of the seven occurrences, that this woman corresponds really to those mentioned in the other ones.

The most general and interesting way of logically associating single predicative occurrences is, however, to make use of *second order structures* created through the *reification* of the single occurrences. These structures reflect, at the digital formal level, *surface linguistic connectivity phenomena like causality, goal or indirect speech*. "Reification" is intended here, as usual in a Computer Science context, as the possibility of *creating new objects out of already existing entities* and to *say something about them without making reference to the original entities*. In NKRL, reification is implemented using the *symbolic labels* (the L_i terms of Eq. 1) of the predicative occurrences according to two different conceptual mechanisms.

A first solution concerns the possibility of referring to an elementary or complex event as an *argument* of another (elementary) event – a complex event corresponds to a coherent set of elementary events. The (surface) connectivity phenomenon involved here is the indirect speech. An informal example can be that of an elementary event *X* describing someone who speaks about *Y*, where *Y* is itself an elementary/complex event. In NKRL, this mechanism is called *completive construction*, see [4: 87-91]. It is illustrated, e.g., by the association of the occurrences gio3.c3/gio3.c4 in Table 1, where gio3.c4 – a binding occurrence (see below) – is introduced by gio3.c3 as *filler of its OBJ(ect) role*; the # prefix in gio3.c3 indicates that its associated term is not a HClass item but an occurrence label. Some formal restrictions must be respected. For example, only the OBJ, MODAL, TOPIC and CONTEXT functional roles of a predicative occurrence pc_i can accept as filler the symbolic label L_j of a (generic) c_j occurrence: this last can then be, as in the case of the gio3.c3/gio3.c4 association in Table 1, one of those binding occurrences we will introduce below.

The second mechanism allows us to associate together, through several types of connectivity operators, elementary/complex events that, unlike the previous case, *can still be regarded as fully independent entities*. This mechanism – binding occurrences, see [4: 91-98] – is realized under the form of lists formed of a binding operator Bn_i and its L_i arguments, see Eq. 2:

$$(Lb_k \ (Bn_i \ L_1 \ L_2 \ \ldots \ L_n)) \ . \tag{2}$$

Lb_k is the symbolic label identifying the global binding structure: unlike templates and predicative occurrences, *binding occurrences are characterized by the absence of any predicate and functional role*. The Bn_j operators are: ALTERN(ative), COORD(ination), ENUM(eration), CAUSE, REFER(ence), the weak causality operator, GOAL, MOTIV(ation), the weak intentionality operator, COND(ition); their precise logico-semantic definitions can be found in [4: 92]. The binding occurrences bc_i must necessarily conform to a set of *mandatory restrictions*, like the following:

- Each term (argument) L_j that, in a binding list, is associated with one of the above operators denotes exactly a *single predicative or binding occurrence* c_j that is *defined externally to the list*. Therefore, the arguments L_j are always *single terms* and cannot consist of lists of symbolic labels.
- Within binding occurrence of the ALTERN, COORD and ENUM type – see in the previous sub-section the corresponding AECS operators introduced, with the same basic meaning, in a structured arguments/expansions context – *no restrictions are imposed on the cardinality of the list*, i.e., on the possible number of arguments L_j.
- In the binding occurrences labeled with CAUSE, REFER, GOAL, MOTIV and COND *only two arguments* L_m and L_n are admitted. The occurrences labeled with these five operators are then simply of the form, (Lb_k (Bn_i L_m L_n)). In these lists, the arguments L_m and L_n can denote, in general, either a predicative or a binding occurrence: an exception are the COND(ition) binding occurrences, where the first argument, L_m, must necessarily correspond to a predicative occurrence, see [4: 93-95].

Several binding occurrences can be found in Table 1, most of the COORD type, see gio3.c1, gio3.c2, gio3.c4, gio3.c11 etc. gio3.c5, i.e., (CAUSE gio3.c10 gio3.c11), is a binding occurrence of the "causal" type. As explained above, it necessarily includes only *two arguments*, the general meaning being that the event corresponding to its first argument gio3.c10, recognizing that UNKNOWN_WOMAN_1 is not Mona Lisa, is caused by all the incoherencies described by the occurrences included in another binding occurrence gio3.c11. In a context of formal representation of causal situations, it may be worth emphasizing the difference between the conceptual meaning associated with the two binding operators CAUSE and REFER(ence) – the syntax of the corresponding binding occurrences being identical, i.e., (Lb_k (Bn_i L_m L_n)), with Bn_i corresponding to CAUSE or REFER. In the CAUSE case, L_n is both *necessary and sufficient* to explain L_m while, in the REFER case, L_n is *necessary but not sufficient* to explain L_m. This means that, in the interpretation of the Mona Lisa's expert who has inspired the Table 1 coding, and making reference to the REFER occurrence of Table 1, i.e., gio3.c9: (REFER gio3.c14 gio3.c15), all the explications put forward by Lillian Feldmann Schwartz to support her Isabella d'Aragona hypothesis *are necessary but not sufficient to definitely validate this hypothesis*.

To conclude, we can remark that these binding structures are very important in an NKRL context given that, in particular, the *top-level formal structure introducing the NKRL representation of any sort of complex narrative has obligatory the form of a binding occurrence*, see gio3.c1 in Table 1. In this COORD binding occurrence, the three main components of the whole representation are specified: they are introduced, respectively, by gio3.c2, gio3.c3 and gio3.c5. Note that, even if several NKRL representations of full narratives are introduced, as in Table1, by a COORD binding occurrence, *any other sort of binding occurrence can be used to this aim*, e.g., a CAUSE binding occurrence, should the narrative be reduced to the description of a particular event and of its causes. More in general, we can also remark that the (although simplified) description of the second order features of NKRL presented in this subsection should make particularly evident the *advantages of using NKRL to formally describe complex narrative information with respect to possible alternative solutions*, for example those of Semantic Web origin. These features compare favorably, e.g., with the RDF-star initiative [11, 12], the last avatar of the continuous (and largely unsuccessful see, e.g., [13]) efforts made by the SW community to get rid of all the problems generated by a too strict adherence to the "binary RDF" dogma. RDF-star is an extension of the RDF conceptual data model enabling the creation of triples that reference other triples as "subject" and "object" (in the RDF/SW meaning) resources; triples that include a triple as subject or object are denoted as RDF-star triples. Apart from the possible logical incoherencies of this approach derived from the syntactic/semantic limitations associated with its strictly binary framework, and the lack of any real originality giving that these association techniques are in reality very old ones dating back to at least the sixties (see, e.g., [14] in this context), we can note that the resulting RDF-star nested structures are still simply "triples". *In the NKRL case, on the contrary, the entities related through the second-order structures are formalized complex events of any possible degree of sophistication*.

3. Conclusion

In this paper, we have proposed the use of advanced digital techniques to consent a *generalized access* to all the important features, both physical and symbolic/conceptual, of any kind of Cultural Heritage (CH) entities, and to make possible their *global fruition*. According then to the so-called *Digital Cultural Heritage Twin approach* [15], we suggest to conceive the digitalized image of any CH entity as *the association of two terms*, the first describing the *physical* (in the largest leaning of this word) properties of this entity, and the second supplying the formal description of all the *immaterial/symbolic aspects of the same entity*. NKRL, the Narrative Knowledge Representation Language, has been chosen for the implementation, in particular, of the *immaterial component of this approach*, because of its well-known capacity for dealing with important immaterial/symbolic aspects of many different realities.

To demonstrate the viability of this methodology, we have illustrated in some depth the use of NKRL to represent in digital form *complex expressive cultural heritage entities*, with particular reference to those "*iconographic narratives*" entities corresponding to *stories told in visual form* that are conveyed by works of art like paintings, drawings, frescoes, mosaics, sculptures, murals etc. and that represent a particularly important component – *both numerically and culturally* – of the whole Cultural Heritage domain. More specifically, an experiment has been conducted in the context of a project that concerns the digital modeling of the Mona Lisa ("La Gioconda") painting by Leonardo Da Vinci, see also [5] in this context, according to the Digital Cultural Heritage Twin approach: this experiment was devoted to represent in NKRL format the main characteristics of the "*hidden painting*" that lies beneath Mona Lisa on the same poplar panel. As a result of this study, the well-known generality and efficiency properties of NKRL with respect to the *representation and management* of any possible form of "narrative" (both in written and pictorial form) have been confirmed, both from a specific knowledge representation and an inferential point of view – with respect to this last point, not dealt with explicitly in this paper for space limitations see, e.g., [7]. The potential of NKRL overcomes, in fact, *the limitations of simple description under metadata form or knowledge representation tools unsuitable for representing complex situations/events*, allowing us to explore the "immaterial" components (including its emotional factors) associated to any possible Cultural Heritage entities in a *more expressive, complete and meaningful form*. We can also note that the above NKRL's features do not concern merely specific characteristics of the Iconographic Cultural Heritage domain, but represent in general *distinguishing qualities of Human Sciences in their totality*. NKRL could be borne in mind, then, as an attractive possibility for implementing really accurate digitization activities, and interesting applications of the corresponding results, for the whole Human Sciences field.

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