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Ontology-based knowledge representation for traditional martial arts

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Abstract

Traditional martial arts are treasures of humanity's knowledge and critical carriers of sociocultural memories throughout history. However, such treasured practices have encountered various challenges in knowledge transmission and now feature many entries on the UNESCO list of intangible cultural heritage. In tackling the urgency of knowledge preservation through digital means, this project employs an ontology-based approach to model the conceptual realm of traditional martial arts. Accordingly, it creates the Martial Art Ontology **(MAon)**, a comprehensive domain ontology with an annotated data resource incorporating entities and relations from embodied, epistemic, and sociocultural facets. MAon underlines the significance of embodied qualities and addresses relevant dimensions, such as kinesthetics, techniques, mnemonics, and tactics, along with stylistic, interpretative, and ideological components. It features scholarly terminology developed through literature analysis, interviews with masters, and expert validations. The instantiation of MAon is realized through annotating three archetypal Southern Chinese styles, offering exhaustive descriptions concerning techniques, forms, principles, and form sets, amongst others. In summary, the reported approach encodes the manifold of martial arts into a structured vocabulary and an interlinked data resource, accessible to both human-reading and machine-operating applications. By applying it to manifest a range of knowledge concepts, we demonstrate the potential of ontology-based *datafication* to create coherent representations for intangible cultural entities and to enable an interoperable data infrastructure across multimodal cultural archives.

Keywords: ontology design; datafication; knowledge representation; traditional martial arts; intangible cultural heritage; embodied knowledge; digital humanities.

1. Introduction

Traditional martial arts are treasures of humanity's knowledge. Originating from the need for combat and sustained through the (re)creations of diverse ethnic groups, martial arts capture the evolution of interactions between individuals and communities over time. The practices have developed into various schools and styles, each holding a unique set of philosophies, concepts, techniques, and training systems (Ma 2009). Historical and contemporary understandings of martial arts converge on the concept of embodiment, wherein the body becomes an embodied vessel for social-cultural discourses, and a complex knowledge system that encompasses physical, perceptual, social, and ideational evolvements (Chao et al. 2018; Jaquet 2023). This perspective resonates with the fundamental attributes of intangible cultural heritage (ICH), where the body acts as the medium that inherits and enacts cultural vernaculars through time (Wulf 2020). Hence, we approach traditional martial arts as an instance of ICH, a reservoir of embodied knowledge requiring effective preservation and transmission methods.

Describing knowledge in traditional martial arts entails addressing multiple dimensions: the techniques and movement principles in a martial arts system; tactical awareness conveyed through mnemonics and codified sequences; the practical and ideological pursuits of body manipulations; and the encounters between individuals, styles, lineages, or clans through physical interactions. In addition, a comprehensive understanding of the cultural realm necessitates an illustration of how the concepts and dimensions are interrelated. Recent advances in semantic technologies have provided a methodical ground promising to address the challenges. A typical path involves ontology design, which displays a subject area by formally defining the elements and elucidating their interrelations (Hou et al. 2022).

In this light, the CROSSINGS project has set out to formalize the concepts and relations underpinning the

domain of traditional martial arts.[1] Building on the initial inspections of structural considerations in modeling foundational aspects of martial arts (Adamou et al. 2021), two parallel efforts have been carried out. On the one hand, we investigated an inference-based practice employing the initial modular ontology to extract data knowledge from archival materials and detect potential traits of cultural contact in Southern Chinese martial arts (SCMA; Adamou et al. 2023).[2] On the other hand, this research adopted a more epistemic focus, drilling down to transform the embodied (technical and kinaesthetic), stylistic, epistemic, and sociocultural facets of martial art knowledge into a structured ontology-based vocabulary. This article presents the Martial Art Ontology (**MAon**), an ontological resource warranting a culturally meaningful domain terminology developed from selected scholarly materials. Utilizing MAon, instantiation has been made based on annotating three archetypal styles in SCMA—White Crane, Hung Kuen, and Choy Lit Fut, each exemplifying a short-, middle-, and long-range fighting style. Our method encodes the manifold of intangible knowledge into a linked RDF-based data asset operable by computational tools. By applying MAon to represent different dimensions in martial art knowledge, we demonstrate the potential of ontology-based *datafication* in offering new pathways for browsing, learning, and interpreting knowledge, with a further potential to integrate with diverse data modalities.

2. Research context

2.1 The living heritage of traditional martial arts

Martial arts originated as combat techniques to resolve disputes, display valor, and acquire honor, and have developed in the course of sustained interactions between individuals, communities, ethnicities, and states. The practices in time become embodied systems of knowledge, comprising complex physical techniques with cultural, technical, material, and metaphysical dimensions that influence "how one [practitioner] thinks, perceives, and reacts" (Allen 2015; Chao 2023). Apart from demonstrating information on an individual level, martial arts also exhibit an avenue to express cultural identity through social enactment. In nations like China and Japan, certain martial arts systems have been declared and preserved through a top-down mechanism, arguably serving both as a nation-building device and "technologies of the self" promoting health and self-identity (Farrer and Whalen-Bridge 2011; Ma 2012). Nonetheless, many traditional forms have faced a declining public interest, now at an increasing risk of being lost with many registrations on the UNESCO list of ICH.

Specifically, the transmission of traditional Chinese martial arts has encountered multiple obstacles, such as the historical lack of knowledge documentation due to secret teaching and learning within one's own community, loss of treatises and martial manuals in contemporary wars and political movements, the scarce innovation in knowledge transfer, the extensive physical demands of training, and critically, the dwindling number of elder masters. Efforts to mitigate the situation are underway.[3] Taking a living heritage approach, the *Hong Kong Martial Arts Living Archive* (HKMALA) leverages state-of-the-art technologies to digitally capture the full-body sequence performances (known as *Taolu*) in collaboration with distinguished masters, who behold the knowledge chiefly passed down through generations otherwise re-enacted from ancient books (Chao et al. 2018). Another ongoing effort is the "Lingnan Martial Arts Elite Training" program, which seeks to renew pedagogical means for martial arts by integrating theoretical knowledge with regular practical training. In practice, the program recruited a group of young dancers and martial arts trainees to engage in a comprehensive learning experience encompassing individual techniques and forms, sparring techniques, empty-hand and sparring sets cross styles (ICMS 2022). These establishments have paved the ground upon which we endeavor to investigate a systemic approach to organizing and conveying martial knowledge to broader audiences. Therefore, joining hands with the HKMALA and the training program, we propose to explore the potential of *datafication* methods in facilitating knowledge representation for traditional martial arts.

2.2 Representing cultural heritage materials

The surge in digitization and documentation of cultural heritage (CH) materials has posed plural theoretical and technological challenges for archaeologists, technologists, artists, scientists, and various stakeholders. One significant challenge lies in compiling content from heterogeneous sources that pertain to the same or related themes and accessing it coherently (Bikakis et al. 2021). To this end, Semantic Web technologies, notably ontologies and linked data standards, have shown that through compliant modeling, operating, and interoperating, entities can acquire identity and expressivity. Accordingly, these tools can aid in organizing data content based on their cultural coordinates (Noardo 2018). Researchers have established a thriving ecosystem of ontological models applicable to the organization of CH data, such as the CIDOC Conceptual Reference Model (CIDOC-CRM; Doerr 2003), Europeana Data Model (EDM; Doerr et al. 2010), and International Image Interoperability Framework (IIIF; Snydman, Sanderson, and Cramer 2015). These foundations have enabled

various practical applications, respectively ensuring a curated scope of resource types, properties, and relational operations within their specific material or immaterial cultural domain. For example, grounded on the CIDOC-CRM entities, Carboni and De Luca (2019) introduced an iconographical representation relating tangible and intangible elements to describe a cultural object. Bartalesi et al. (2022) employed CIDOC-CRM and Functional Requirements for Bibliographic Records object-oriented as reference models to create the Hypermedia Dante Network ontology, representing the primary sources of *Dante's Comedy* for knowledge expression and exploration.

Moreover, with the integration of linked open data (LOD), the WarSampo Knowledge Graph furnished a shared semantic infrastructure for publishing data about the Second World War, making it possible to harmonize and exchange information between different sources (Koho et al. 2021). Mościcka and Zwirowicz-Rutkowska (2020) incorporated EDM elements into the metadata profiles of ancient maps to facilitate access to cartographic collections. Machidon et al. (2020) connected an intelligent conversational agent with Europeana APIs to improve searchability in digital records. Utilizing multiple open standards, including the Linked Art Data Model and IIIF-based digital services, the PHAROS project assembled various components into a united platform for photo archives (Caraffa et al. 2020; Delmas-Glass and Sanderson 2020). Likewise, the ArCo knowledge graph made available a LOD network involving over 800 thousand Italian CH entities (Carriero et al. 2019). These examples showcase a fraction of the establishments, more projects analyzed by Davis and Heravi (2021) and Ziku (2020) .

2.3 Ontology design for intangible heritage

While models capturing material-based qualities have seen significant advancements, modeling intangible and ephemeral aspects of ICH remains underaddressed. These elements, which are often bodily, performative, expressive, symbolic, and non-instrumental, require new methods for encoding and representing so that the knowledge can be unfolded and presented in a meaningful context (Kenderdine and Shaw 2017; Hou et al. 2022). A critical medium where many cultural expressions occur is the body, manifested primarily through body movement (e.g. traditional practices, rituals, and performances). Through the perception of the body, physical qualities acquire significance in presenting a culture or offering a means for transmission. This forms our rationales to inspect the conceptual realms of a body movement.

Ontology-based approaches have been used to model the nuanced movements in performing arts like dances mostly in combination with the established notation systems, such as Labanotation (Hutchinson, Guest, and Hutchinson 1977) and Benesh Movement Notation (Benesh and Benesh 1983). For instance, El Raheb and Ioannidis (2013) transferred the concepts of dance choreography into a DanceOWL dataset, drawing from the structure of notation scores to produce a machine-operable vocabulary. This ontology was then applied to annotate videos of classical ballet performances, which allows movement search via domain concepts (El Raheb et al. 2016). In a more CH-focused effort, Mallik, Chaudhury, and Ghosh (2011) devised an ontology for Indian classical dances, providing knowledge-level descriptors about specific hand gestures, facial expressions, and body postures applicable to enrich a multimedia heritage data system. On the other hand, storytelling is another locus where ontology modeling has been applied. Drammar is one such resource that transforms multilayer dramatic qualities into ontological datasets (Lombardo, Damiano, and Pizzo 2018). Similarly, the Mingei Crafts Ontology seeks to encode the knowledge and artifacts in craft heritage through temporal, causal, and inclusion relations (Meghini et al. 2020).

In summary, existing ontologies chiefly reply on notational or sequential structures, which does not readily apply to describing practical traditions such as martial arts. Nevertheless, these existing frameworks propound a conceptual foundation from which the conceptualization of martial arts can adapt and expand.

3. Methodology

An explicit ontology should be able to identify a core set of terms with standard norms to describe the domain concepts (Uschold 1998). On this notion, we base the model on a standard terminology valid for martial art knowledge description. The terminology is extracted from the corpus in a range of scholar-selected materials, including:

- Foundational martial manuals and books of masters' interpretations (Ting 2000; Popov 2002; Lee 2011; Lam and Chao 2013, 2014), which are instrumental in our conceptualization and instantiation of classes and properties in the technical module and stylistic module;
- Exhibition texts provide scholarly interpretations of martial cultures and communities from a contemporary perspective (Chao et al. 2016; Chao 2018; Kenderdine et al. 2018), crucial for conceptualizing classes and properties in the social module;

- Narratives by martial arts practitioners in the HKMALA assets, which consolidate our understanding of martial arts techniques, the association between training methods and physical qualities necessary to certain technical aspects, and the use of weapons and training tools. The individual-based storytelling also helps solidify our conceptualization of social attributes concerning masters and institutes.
- Technical notes collected through field interviews with kung fu masters, which are pivotal for instantiating MAon's technical concepts, particularly in annotating and validating the tactics and movement principles associated with specific techniques or forms.

Based on a close study of these materials and comprehension of the core terms and their significance to knowledge transmission, we synthesize a set of considerations that inform the ontology's structure and content design.

3.1 Structural considerations

As analyzed by Adamou et al. (2021), the ontological organization of knowledge in martial arts should be able to identify characteristics of the encoded entities so that conceptual inference is achievable via linkages and relationships. In addition, the schema should serve as an archetype non-exclusive to martial arts, to which models specializing in other ICH domains can attach and apply. In fulfilling the ideals, the model mandates the following prerequisites on the structure level:

- *Modular*. The model should outline the epistemic role of different conceptual modules, while every single module should be self-contained. An effective modular structure can facilitate knowledge organization and the reuse of certain ontological parts (D'Aquin, Sabou, and Motta 2006).
- *General*. The model should generalize the components descriptive of martial arts and provide extension points potential to adapt or partly model other domains featuring embodied knowledge, CH, or performing arts.
- *Inferential*. Both explicit and implicit cultural manifestations should be considered in the ontology design. In many cases, traits of culture will materialize through rule-based reasoning, integrating various entities according to the ontology structure.
- *Referential*. The model should attain an appropriate level of standardization where the entities already specified in a formal upper ontology should be related or referred to with semantic alignments.

3.2 Competency questions

On the content level, the MAon aims to underline entities essential to martial knowledge manifestation and constructive to its transmission. Its focus differs from the model that employs a phenomenal lens to study martial arts as the syntheses of cultural contacts (Adamou et al. 2023), highlighting the significance of embodied learning and technical interpretations. In doing so, we adopt the scenario-based design framework by NeOn Methodology (Suárez-Figueroa, Gómez-Pérez, and Fernandez-Lopez 2015) and ground the ontological development upon a set of competency questions (CQs):

- CQ1. *How to describe a technique, or what elements can be identified in a technique?*
- CQ2. *What techniques are practiced in a form? What other elements can be identified?*
- CQ3. *What principles does a martial arts style or system have? Moreover, how to describe a principle?*
- CQ4. *Which techniques or forms represent a typical principle of a martial arts style?*
- CQ5. *Are there any explicit and implicit links between techniques or forms?*
- CQ6. *Which techniques, forms, or styles are simulating or symbolized by a creature or living thing?*
- CQ7. *What type of weapons, if any, are used in a martial arts style?*
- CQ8. *In what social units is a certain martial art taught (e.g. clans, schools*, and *sports federations)?*

A critical consideration behind the CQs is to enable explicit assertions and connotations of the concepts of semantic relevance. With appropriate modularization, users of the ontology can form interpretations with the means to trace meaningful clues. Specifically, CQ1 and CQ2 guide the technical module to represent hierarchical organizations of technical components within concepts identified as techniques or forms. Particularly, CQ2 informs the establishment of relationships between different elements in completing the conceptual representation of a martial art form. Examples of classes created based on these considerations include *MA_form*, *MA_technique*, and the latter's subclasses, such as *Handwork*, *Footwork*, etc., and the relational properties such as *trains* and *employs* connecting them. CQ3 and CQ4 are instrumental in the creation of classes and properties that reflect the principles and their embodiments in techniques or forms. For instance, classes of *MA_tactic* and *MA_principle*, along with properties like *represents* and *has principle*, capture the ideological and stylistic essence while bridging

technical and stylistic attributes. CQ5 necessitates properties that reflect both explicit and implicit connections between techniques or forms, such as *similar to* and *similar form to*, enabling the ontology to infer more complex relational knowledge. CQ6 is addressed by associating techniques, forms, or styles with the creatures or living things they *imitate* or *symbolize*, for instance, through their relation to classes like *symbolic_animal*. Moving on to social aspects, CQ7 informs the inclusion of weaponry as a key element to capture the materials and objects used by practitioners of diverse martial arts styles, for example, by introducing the property *uses* to connect *Training_method* and *Armament* or *Training_Tool*. CQ8 shapes the social context by linking martial arts styles to their contexts of transmission, such as clans or sports federations—entities of the class *MA_institute*, with relations to *MA_master* and *MA_syllabus*, among others.

Additionally, in light of the *General* and *Referential* requirements, we relate MAon's adjacent concepts to CIDOC-CRM entities, that is, the notions of *E21 Person*, *E22 Human-Made Object*, *E52 Time-Span*, *E53 Place*, and *E31 Document*.[4] In such a manner, we provide a semantic pathway for martial art terminology toward both material and immaterial conceptualizations as defined by the existing CH ontology systems.

4. MAon: the martial art ontology

The state of mastery in traditional martial arts is believed to arise from cycles of theoretical learning, practical exercises, and moving to play ("*andare a gioco*"), ultimately fostering automatic bodily responses and creative mind to outmaneuver the opponent (Gotti 2023). This understanding implies that the conceptualization of martial arts necessarily involves a multilayer network addressing various components. Kinaesthetic qualities, for instance, not only specify a technique's choreographic arrangement and combinational manipulations but may also distinguish a martial arts style or system. Pedagogical means, such as mnemonics and codified form sets are critical as they delineate a technique's characteristics and explain its sequential or combinational application in different contexts. Furthermore, stylistic, tactical, symbolic, ideological, and sociocultural interpretations serve a vital role in enriching and completing the conceptual elaboration of body movement.

Figure 1 presents an overview of the MAon components, where the classes are represented in oval shapes and grouped into conceptual modules. The classes are interconnected via properties depicted as lines. In the following sections, we aim to outline the principal classes and properties (or addressed as relations) within each module succinctly. Complete documentation of the ontology and annotated individuals is publicly available at https://purl.org/maont/techCorpus.

Colored rectangles represent the MAon-specified classes, while grey rectangles denote the CIDOC-CRM external classes. Dashed lines indicate a subclass, and solid directed lines indicate properties.

4.1 Technical module

This module describes how technical qualities, including kinaesthetic attributes and movement perception, cumulate to acquire the identity of a martial art technique or form. In certain circumstances, this can involve procedural body manipulations and the use of weapons. Multilayer conceptualization is possible when a technique or form is interpreted as a synthesis (frequently called a combo) of multiple techniques. The module also encompasses entities related to weaponry, relating it to the broader conceptual realm of material technologies and craft techniques.

4.1.1 *Principal classes and properties*

The class ***Technique*** is designed to function as a connector between different modules, establishing connections between general kinetic elements, technical interpretations, stylistic expressions, and methods of training, application, teaching, and documentation. Furthermore, our model drills down into this class and expands four major categorical subclasses: ***Handwork***, ***Footwork***, ***Bodywork***, and ***Bridge***. These subclasses aim to provide an embodied understanding of the techniques' structure. Accordingly, most instances of ***Technique*** are subsumed under one of the three principal categories given which anatomical part is substantially involved.

In cases where applicable, these categories can retain subclasses at further granularities. For example, as shown in Figure 2, our model extends the class ***Handwork*** to encompass specific types of ***Palm_Tech***, ***Fist_Tech***, ***Claw_Tech***, ***Elbow_Tech***, and ***Gesture***. Similarly, the class ***Footwork*** includes subclasses of static ***Stance*** or dynamic ***Leg_Tech***. The rationale behind this structure lies in the major focus of our instantiation on traditional SCMA. These styles have been extensively developed for close-range and empty-hand fighting. In contrast to northern Chinese martial styles that may employ more sophisticated footwork with wide-step movements, southern styles prioritize hand conditioning and hence feature a broader array of handwork techniques, incorporating tactical muscle manipulation in the palm, fist, claw gestures, and sometimes the elbow.

This difference also results in an emphasis on bodywork and bridge techniques. The former, represented through the class ***Bodywork***, signifies the nimble application of the body and accentuates a

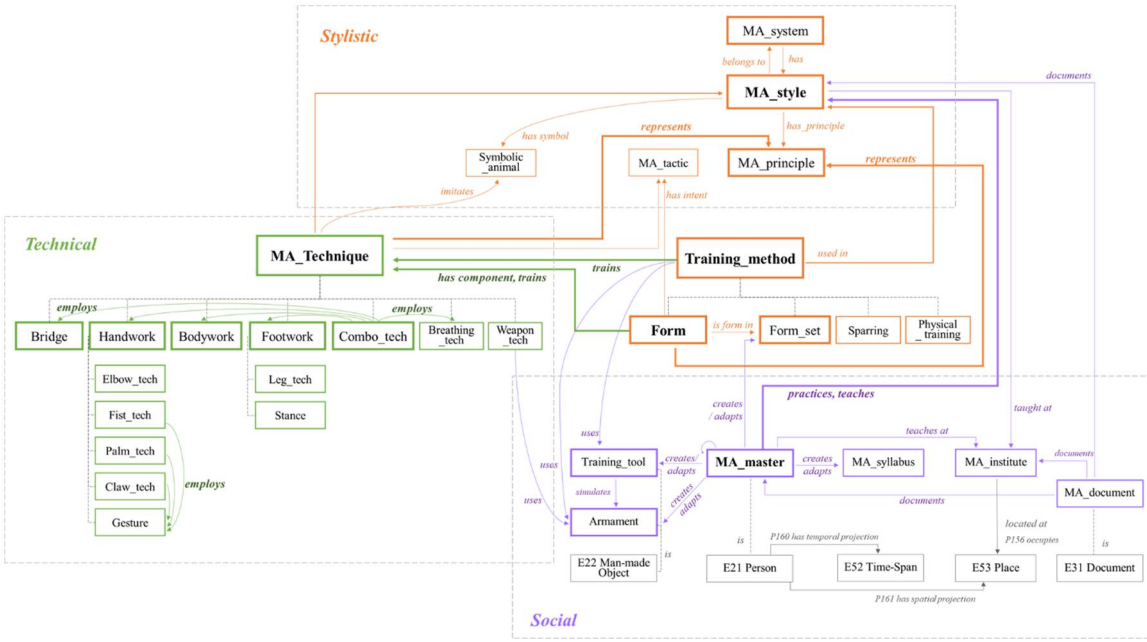

Figure 1. Overview of MAon components synthetically organized into conceptual modules.

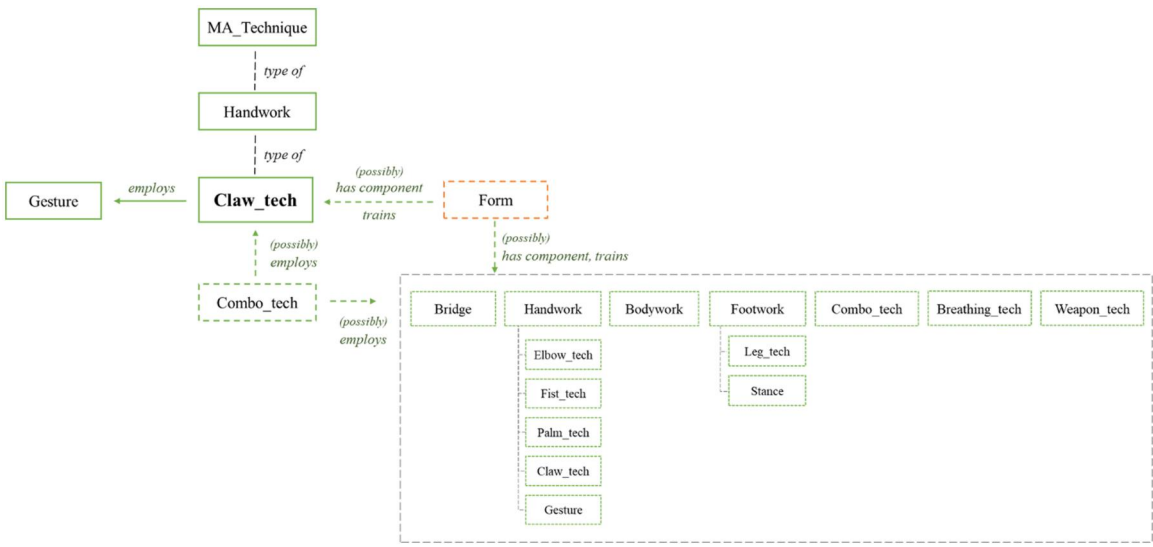

Figure 2. The pattern for a claw technique within the technical module in MAon, with possible relations depicted in dashed lines.

coherent yet flexible use of the waist and upper-body muscles. The term "bridge," sometimes referred to as "bridge hand(s)" is a uniquely critical concept in traditional Chinese martial arts. This concept is represented as the class ***Bridge*** within our model. It implies a body structure established through the forearms with systematic manipulation of whole-body muscles, forming a connection between the practitioner and the external world, be it the environment or the opponent.

In addition, three supplementary classes used to describe a technique are ***Combo_tech***, ***Weapon_tech***, and ***Breathing_method***. The class ***Combo_tech*** denotes a technique that is a combination of multiple others, typically involving movements in different body segments. Instances of such techniques acquire

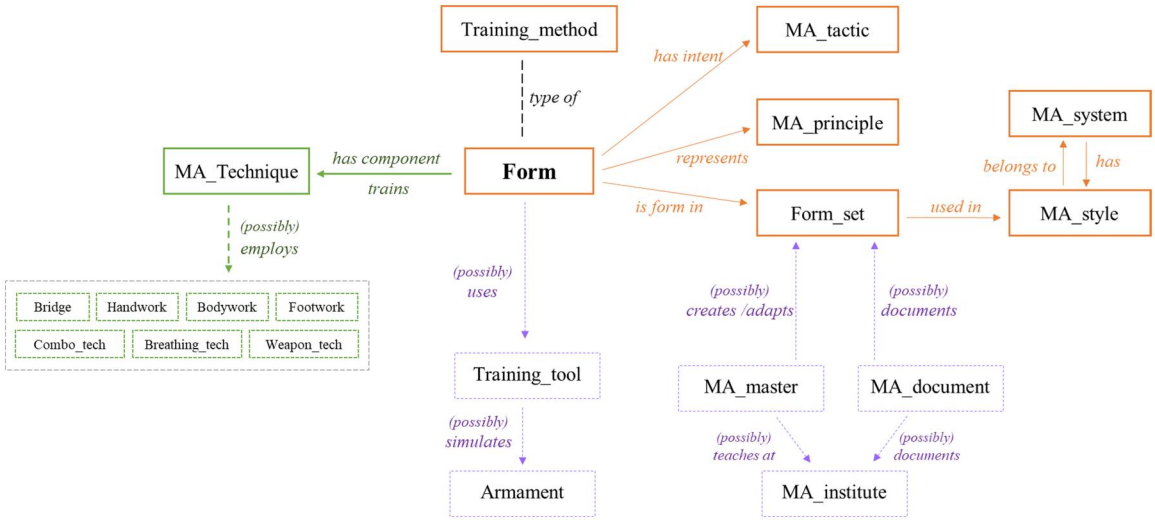

Figure 3. The pattern for a form with possible relations to technical, stylistic, and social components in MAon.

the identity of a combo technique with a collective impact of its technical components. To capture these characteristics, we use the ***employs*** property to indicate that a more complex instance of ***Technique*** is fulfilled by employing another or several other basic ones. On the other hand, the class ***Weapon_tech*** addresses situations where a technique involves using a specific ***Armament***(s) in actual combat or an alternative ***Training_tool***(s), which generally affects body conditioning and the movement of body parts. The class ***Breathing_method*** is linked to the mythical concept of *qi* (or *chi*). Often interpreted as a flow of energy through the body, *qi* is fundamentally the effect of well-managed breaths, as elucidated by Master Lee Kong (Lee 2011). Correct breathing methods are vital for generating power while maintaining a sound internal environment and can be consciously trained through specific techniques, forms, and form sets.

The class ***Training_method*** encompasses methods created or adapted by a teaching master for learners to practice specific techniques while developing necessary physical qualities and comprehending the movement principles embedded. Instances of this class may feature a unitary exercise—a ***Form***, or a series of exercises constituting a set—an instance of ***Form_set***. While forms and form sets can vary significantly across styles and systems, they all serve training purposes. Another two categories of training methods crucial for developing martial arts skills are ***Physical_training*** and ***Sparring***, both not codified. In either situation, the ***trains*** property is established to connect an instance of ***Training_method*** to one or more of ***Technique*** if the former contributes to the development of the latter.

The ***similar to*** property represents a conceptual similarity between instances of ***Technique***. In specific situations, particularly across stylistic systems, this relationship may also exist between instances of ***Technique*** and ***Form***. An example is the connection between the form in the Hung Gar system and the technique in the Choy Lit Fut. This relationship is established when techniques or forms demonstrate substantial overlap in technical structure according to masters' interpretations. The related concepts may belong to different martial arts styles, such as the Bow Stance in Hung Gar and San-chin Stance in White Crane, or involve distinct combative formats, such as the empty-hand technique Chopping Palm and the Chopping technique using a weapon like a sword. For similar forms within the same stylistic system, a more specific property ***similar form to*** is employed to imply the range and domain of such relationships. This "similar to" schema is designed to capture nuanced relationships where techniques or forms share significant elements, principles, or characteristics. It provides a pathway for analyzing potential influences across styles based on semantic similarity, particularly focused on technical and embodied attributes.

4.2 Stylistic module

This module incorporates both epistemic and symbolic elements, illustrating how a combination of techniques forms the methodological identity of a martial arts style. These elements are often associated with the concept of styles or systems—the latter denoting a group of styles, and typically emerge from human experiences and reflect a view of nature and humanism. A

common example is the mimesis of five animals—the tiger, crane, snake, leopard, and dragon or monkey, and five phases—fire, water, wood, metal, and earth, found in many traditional styles.

In addition, certain entities within the module encode the style's ideological aspects helpful for knowledge transmission. For instance, the *Twelve Bridges* in Hung Kuen and the principle of *Dynamic Sphere* in Italian fencing convey an essence of the philosophical pursuit, respectively. Some elements may act as the vehicle of collective memory, such as the facing-the-sun palm commonly seen in various Southern styles like Hung Kuen, White Crane, and Choy Lit Fut. This gesture is widely received as a symbolization of ideals of uprightness and the spirit of liberty during the feudal era (Leung 2000; Yin 2015).

4.2.1 *Principal classes and properties*

The class ***MA_style*** conceptualizes the individual stylistic genre of martial art. Each instance holds an umbrella term representing the style's name, typically denoting a group of martial arts styles sharing similar kinaesthetic qualities, norms, and principles. Certain styles may associate themselves with one or multiple creatures or living things as symbols, indicated by the property ***has_symbol*** pointing to an instance of ***Symbolic_animal***. It is widely held that many martial arts styles draw inspiration from the habits and moves of specific creatures like animals in designing their movement and tactical patterns. For example, the various Praying Mantis styles are inspired by the mantis (insect), and the White Crane kung fu imitates the crane (bird).

The class ***MA_system*** pertains to an upper-level systemic grouping of different styles and represents the concept of martial arts systems. Styles within a system typically share a consistent methodological framework and principles, and sometimes have identical geographic origins or parent styles.

The class ***Form*** encapsulates the concept of individual training forms—a fundamental aspect of technical and stylistic training in traditional martial arts. Examples of this class include *zhaoshi* (or *shi*) in Chinese terminology and its Japanese equivalent, *kata*. A form, whether static or dynamic, is a choreographed pattern of movement comprising a unitary sequence of basic **techniques**. Hence, the conventional interpretation is that a form has several technical components while simultaneously serving as a training tool for those techniques and the qualities relevant to fulfilling them. The property ***has component*** is used; it is designed to inherit the CIDOC-CRM declaration of *P148 has component* and to indicate the relationship between a form and the technique(s) trained within. The class ***Form_set*** addresses the concept of form sets—the sequential arrangement of forms. Commonly known as the Chinese term *taolu*, an instance of ***Form_set*** features a set routine of multiple instances of ***Form*** in sequential order. While most form sets are designed for individual practice, some also serve as interactive sparring exercises, represented through the *class* ***Sparring_set.***

In addition to technical elements, the execution of a form, occasionally a technique alone, represents certain tactical intents or guiding principles underlying the movement rationale of a martial arts style. The class ***MA_Tactic*** addresses the former case, in combination with the property ***has_intent*** to describe an instance of ***Form*** or ***Technique*** that embodies the intent to achieve specific tactics, such as attacking, defending, deflecting, controlling distance, or complex maneuvers. In the latter case, the property ***represents*** is used to connect an instance of ***Form*** to one of ***MA_principle***, indicating that the technical movements follow a specific guiding principle or a combination of several.[5]

4.3 Social module

This module encapsulates elements related to the transmission of martial arts and describes how martial arts disciplines are taught, learned, assessed, and disseminated. It involves a range of social agents (e.g. masters and clans), organizations (e.g. martial arts schools and federations), and pedagogical means (e.g. manuals and codified form sets). While the module focuses on addressing critical concepts within the martial arts domain, axioms from external ontologies, such as the Drammar (Lombardo, Damiano, and Pizzo 2018), ArCo (Carriero et al. 2019), and CBDB (Fuller and Wang 2021), can be integrated using established LOD models. The aim is to provide an extensible schema for representing social agents and intellectual encounters within a comprehensive historical context, while maintaining connections with technical and stylistic concepts, as illustrated in Figure 3.

4.3.1 *Principal classes and properties*

The class ***MA_master*** designates individuals conventionally recognized for their remarkable achievements in martial arts skills and their contributions to the transmission and development of martial knowledge. Instances of this class can include historical martial arts practitioners and legendary figures, with the possibility to annotate or classify further. Considering a master of martial arts should naturally warrant a person's identity in cultural history, this class is designed to incorporate the CIDOC-CRM assertions about *E21 Person and associated properties to bridge with other linked data sources, notably, P160 has temporal projection pointing to E52 Time-Span and P161 has spatial projection pointing to E53 Place*. Moreover, a person's status as a martial arts master is typically established through their experience in practicing and teaching specific martial arts styles.

Therefore, we use the *properties* ***practices*** and ***teaches*** to represent these relationships between instances of ***MA_master*** and ***MA_style***, which can be instantiated through assertion or inference based on a valid source of documentation or narrative.

The class ***MA_institute*** conceptualizes any collective social agent where martial arts teaching, training, assessment, or dissemination occurs, for example, a school, clan, sect, or sports federation. Instances of this class typically have a physical location, represented by the property ***located at*** to relate to a place, accordingly subsuming the CIDOC-CRM assertions about *E53 Place and P156 occupies*. One common criterion to identify a master's relationship with an institution is through teaching activities. Therefore, we establish the property ***teaches at***, linking an instance of ***MA_master*** to an instance of ***MA_institute*** if there is valid evidence implying that the master has conducted teaching activities at that institution.

The classes ***Armament*** and ***Training_tool*** are designed to represent the material aspect of martial arts. Respectively, armament serves as the umbrella term for various weaponry and associated equipment used in actual fighting and routine training, given a certain level of mastery. Training tools refer to objects created to simulate a weapon, or part of it, to train a specific technique or physical qualities. The property ***simulates*** is utilized to indicate a possible analogy. Instances of these two classes are generally human-made, thereby incorporating the CIDOC-CRM assertions about *E22 Man-made Object*. This design enables an epistemic pathway to link with additional concepts and properties in the realm of materiality.

The class ***MA_Document*** encompasses a variety of information objects that record aspects of martial arts. These can be either physical or digital and include ancient manuscripts, books, manuals, and audiovisual contents, amongst others. It's important to note that an instance of *MA_Document* may behold identities. We bridge the class with the CIDOC-CRM *E31 Document* to facilitate flexible interoperations and potential acquisition of additional data, and facilitates semantic enrichment of other linked data sources through assertion or inference rules.

5. Instantiation

5.1 MAon-based knowledge representation

5.2.1 *Technical representation of a form*

The following snippet presents an assertive representation of the form "上馬連變側掌打" (translated as "Advancing while delivering a palm strike to the side") using the MAon schema, with a specific focus on technical attributes. In this example, relevant entities and individuals are encoded in bilingual data entries using the Turtle syntax.[6] As the codes imply, the encoded form is in the form set of "Gung Gee Fook Fu Kuen" and is labeled taming_tiger_22, which indicates its position within the sequence. Technically, the form is structured in three layers. The top layer contains the techniques of "Horizontal Palm Strike" and "Turning from Horse Stance to Bow Stance." The latter employs multiple techniques, including Body Twisting, Horse Stance, and Bow Stance. Additionally, the form embodies two fundamental movement principles of Hung Kuen: the Hard Bridge and Pressure Bridge, and its tactical intention is to execute an attacking maneuver. A corresponding visual graph representation is provided in Fig. 4.

```
### http://EncodingActs.github.io/annotated/MAon/taming_tiger_22
mao:taming_tiger_22 rdf:type owl:NamedIndividual ,
      mao:class:MA_form ;
      mao:has_component mao:horizontal_palm_strike ,  mao:horse_to_bow_stance ;
      mao:has_intent mao:attack_int ;
      mao:is_form_in mao:Gung_Gee_Fook_Fu_Kuen ;
      mao:represents mao:hard_bridge ,  mao:pressure_bridge ;
      :name_en "Advancing with the horizontal palm strike" @en ;
      mao:name_zh " 上馬連變側掌打" @zh ;
      rdfs:label "taming_tiger_22" .

### http://EncodingActs.github.io/annotated/MAon/horse_to_bow_stance
mao:horse_to_bow_stance rdf:type owl:NamedIndividual ,
      mao:class:footwork ;
      mao:employs mao: mao:bow_stance ,  mao:horse_stance , mao:body_twisting  ;
      mao:has_intent mao:power_generation ;
      :name_en "Turning from horse stance to bow stance"@en ;
      mao:ontoMA_name_zh "四平馬轉子午馬"@zh ;
      rdfs:label "horse_to_bow_stance" .

### http://EncodingActs.github.io/annotated/MAon/horizontal_palm_strike
mao:horizontal_palm_strike rdf:type owl:NamedIndividual ,
      mao:class:palm_tech ;
      mao:employs mao:horizontal_buddha_palm ;
      mao:name_en "Horizontal palm strike" @en ;
      mao:name_zh " 撐掌" @zh ;
      mao:otherName_zh " 攻橋手" @zh ;
      rdfs:label "horizontal_palm_strike" .
```

5.2 Scale-up: the annotation protocol

A plausible domain ontology should maintain consistent agreements of terms within the discipline. Achieving this requires capturing the breadth of knowledge accumulated in various forms (McDaniel and Storey 2019) and incorporating expert knowledge through an effective annotating process. According to Andrews, Zaihrayeu, and Pane (2012), the design of an annotation protocol involves contextual configurations in structural complexity, vocabulary type, and data collection procedure. Respectively, the complexity of different structural formats, that is, tags, property-value pairs (applicable to relational and descriptive properties), and ontology, impacts the amount of information encoded, how annotations can be displayed, and what end-user services can be enabled. The vocabulary type, particularly the degree of formality, influences the semantic precision of the annotations. Controlled vocabularies generally can alleviate semantic ambiguity and heterogeneity, whereas uncontrolled free-form texts may increase

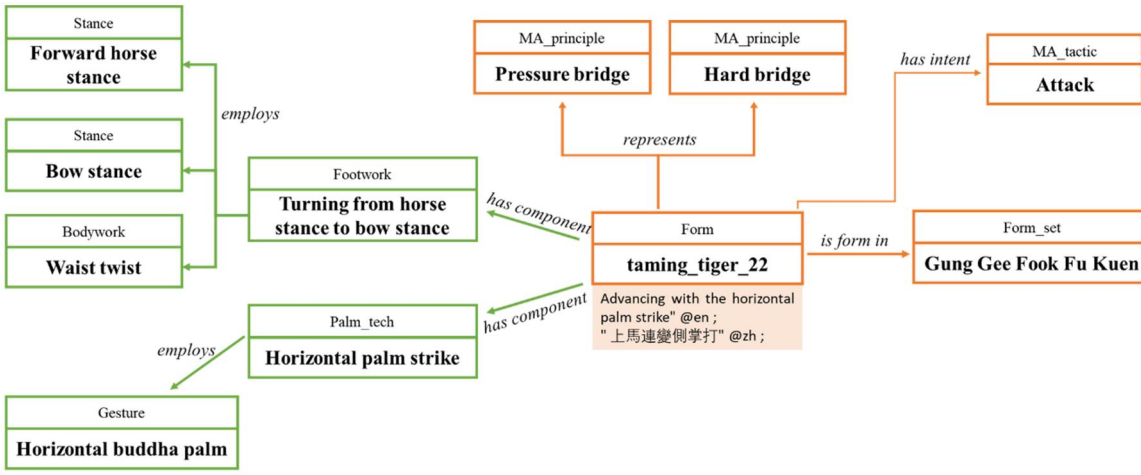

Figure 4. Ontology diagram of the form titled "上馬連變側掌打" (Advancing while delivering a palm strike to the side), as encoded in the snippet above.

informativity. Lastly, the data collection procedure, whether a single-user or collective annotation process, affects the prerequisites for the design choice regarding structure and vocabulary.

The MAon annotation protocol, as outlined in Table 1, has been configured following a thorough assessment of available resources, expert input, and anticipated data applications. The corresponding process unfolds in several stages, as illustrated in Fig. 5.

First, the *Operator* (author) extracts a set of tags and property-value pairs using the constructed terminology. This step is followed by a review and amendment by a *Knowledge Expert*, ensuring the preparation of accurate and standardized annotation terms. Afterward, the *Operator* proceeds to create initial annotations for a specific resource, for example, annotating all the forms in the set of "工字伏虎拳" by referencing scholarly materials and utilizing the standard terms.[7] The preliminary annotations, organized in Excel tables, are then sent to multiple *Knowledge Experts* for validating, correcting, or adding new tags and plain-language descriptions. In the final step, the *Operator* collates all the annotations and uses *Protégé* (Musen 2015) to convert the human-readable annotations into ontological assertions, resulting in RDF-based data material.

Table 1. Configuration of the MAon annotation protocol.

Structural complexity	Vocabulary type	
	Controlled vocabulary	Uncontrolled vocabulary
Tags	collective	–
Property-value pairs	Collective	–
Ontologies	single-user	–
Texts (unstructured)	–	collective

6. Evaluation and application

6.1 Addressing CQs

For assessing the knowledge-level quality of domain ontologies, prototypical queries to encode and answer CQs are recognized as an effective way to evaluate a model's suitability for its intended purposes (McDaniel and Storey 2019). In line with this, we have implemented an interactive MAon graph using Neo4j Bloom, a graph data platform allowing simple question answering via natural language interaction and complex queries via Cypher query language.[8] Below, we present a series of prototypical Cypher queries to answer the CQs in Section 3.1.2, complemented by several visual representation examples to showcase how the visual development of MAon can facilitate more intuitive and accessible analytics. Such a modality can benefit heritage sectors owing to a lower computational barrier.

CQ1. How to describe a technique, or what elements can be identified in a technique?

```
//Q1a: find a technique, e.g. named "willow-leaf palm"
MATCH (t: MA_technique {name_en: 'willow-leaf palm'})
RETURN t
//Q1b: find all elements in composing a technique, e.g. named "Looking-in-the-mirror palm"
MATCH (t: MA_technique {name_en: 'Looking-in-the-mirror palm'})-[re: employs]->(n)
RETURN t, n, re
```

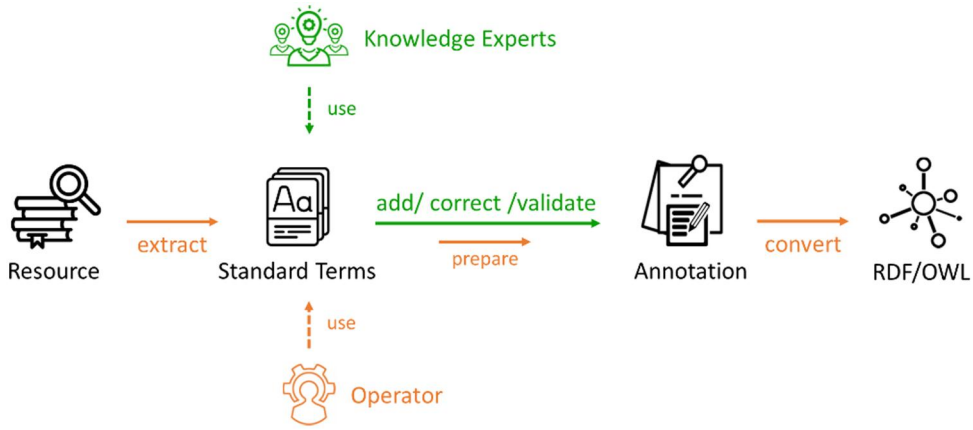

Figure 5. Procedure diagram of how the conceptual entities, such as all concepts in relation to a form, get annotated, formalized, and eventually datafied.

Figure 6 demonstrates an answer to *Q1b* with a two-layer representation of the "Looking-in-the-mirror palm" ("美人照鏡"). This technique, besides being an instance of the class *MA_Technique*, also warrants the characteristics of a *Combo_tech*. It *employs* "Cat stance" ("吊馬"), "Waist twist" ("扭腰"), and "Willow-leaf palm" ("柳葉掌"), with the latter being a *Gesture* and addressing Q1a.

CQ2. What techniques are practiced in a form? What other elements can be identified?

```
//Q2a: find all techniques practiced in a form and expand the elements in combo techniques
MATCH (f: MA_form {rdfs: label: 'taming_tiger_36'})-[rc: has_component]->(t: MA_technique)
WHERE EXISTS {
    MATCH (t: MA_technique)-[re: employs]->(st: MA_technique)
}
RETURN f, t, st, rc, re
//Q2b: find all entities and properties in relation to a form
MATCH (f: MA_form {rdfs: label: 'taming_tiger_36'})-[r]-(n)
RETURN f, n, r
```

Answering the two queries above, Fig. 7 shows an ontological representation of the 36th form in the *Gung Gee Fook Fu Kuen* (工字伏虎拳, or Taming the Tiger) set, titled "照鏡手法爪三勻" ("Reconciling using the looking-in-the-mirror palm followed by double tiger claw strikes to the opponent's face"). The form contains the technique "Looking-in-the-mirror palm" ("美人照鏡"), as seen in the previous example, and follows a sequence with "Serial cat claws" ("雙爪手"), "downward whipping palm" ("冚手") and "Serial cat claws" ("貓兒洗面"). The latter, categorized as an instance of *Combo_tech*, employs the techniques of "Bow stance" ("子午馬"), "Arm-drag claw" ("攦手"), and "Tiger claw" ("虎爪"). Besides technical components, the form represents the principles of "Subduing" ("制"), "Pressure" ("逼"), and "Moving" ("運") —three key concepts among the *Twelve Bridges* in the Hung Kuen system and it delivers intents of subduing and defense via deflecting. Moreover, the properties reveal the form is similar to another titled "貓兒洗面又三勻" ("Striking with the double tiger claws three times again") within the same set.

CQ3. What principles does a martial arts style or system have? Moreover, how to describe a principle?

```
//Q3: find all principles that, e.g. Hung Kuen has
MATCH (sy: MA_system {name_en: 'Hung Kuen'})-[rhp: has_principle]->(p: MA_principle)
RETURN sy, p, rhp
```

CQ4. Which techniques or forms represent a typical principle of a martial arts style?

```
//Q4: find all forms in Gung Gee Fook Fu Kuen that represent, e.g. the "Pressure" principle
MATCH (f: MA_form)-[rp: represents]->(p: MA_principle {name_en: 'Pressure'})
WHERE f-[: is_form_in]-> (:Form_set {name_en: 'Gung Gee Fook Fu Kuen'})
RETURN f, p, rp
```

Figure 8 visually answers Q4, where each node stands for a form within the *Gung Gee Fook Fu Kuen* set that represents the "Pressure" ("逼") principle. The

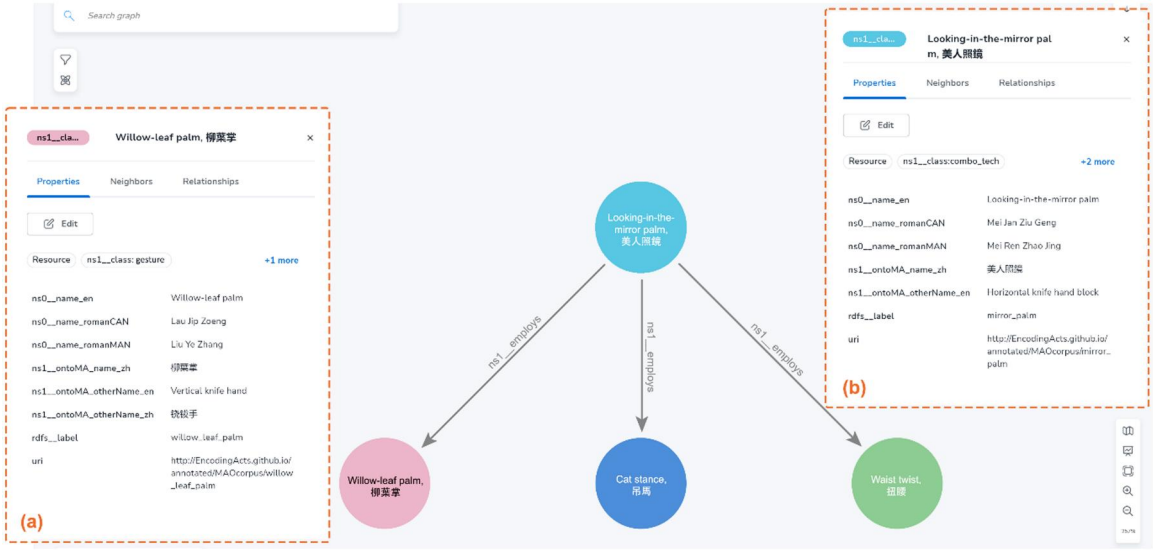

Figure 6. MAon representation of the (a) "Willow-leaf palm" ("柳葉掌") and (b) "Looking-in-the-mirror palm" ("美人照鏡").

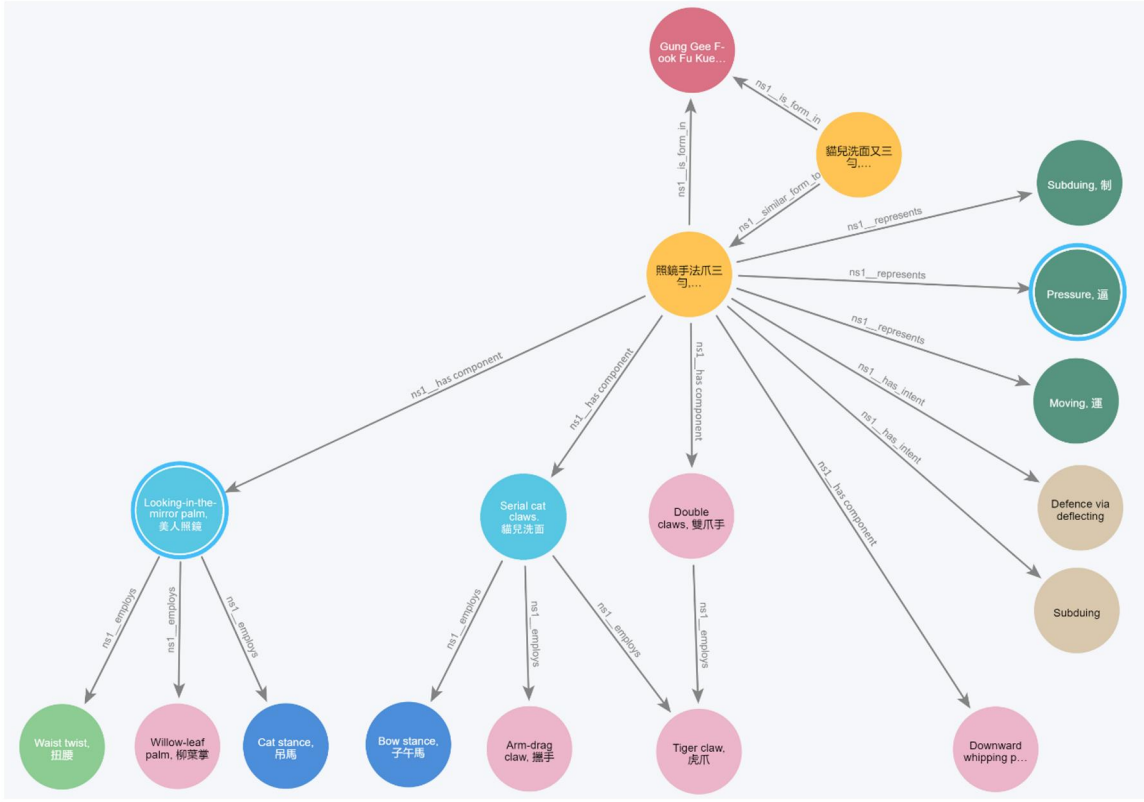

Figure 7. MAon representation of the 36th form in *Gung Gee Fook Fu Kuen*, titled "照鏡手法爪三勻."

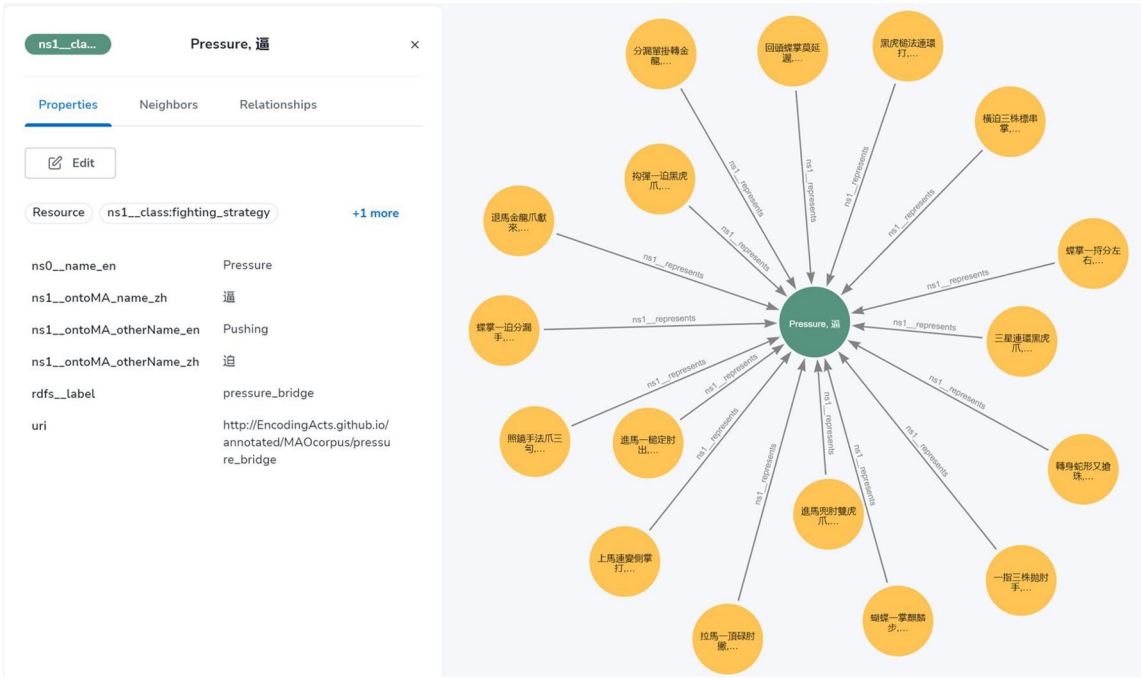

Figure 8. Forms representing the "逼" (Pressure) principle.

network visualization also demonstrates how these forms collectively describe a principle, addressing the second part of CQ3.

CQ5. Are there any explicit and implicit links between techniques or forms?

```
//Q5a: find all similar forms in the knowledge base (explicit, mostly assertive)
MATCH (f1: MA_form)-[sim: similar_form_to]-> (f2: MA_form)
RETURN f1, f2, sim
//Q5b: find all forms, e.g. that employ "Tiger Claw" in Gung Gee Fook Fu Kuen (implicit)
MATCH (f: MA_form)-[re: employs]-> (t: MA_technique {name_en: 'tiger claw})
WHERE f-[: is_form_in]-> (:Form_set {name_en: 'Gung Gee Fook Fu Kuen'})
RETURN f, t, re
```

In alignment with Q5b, Fig. 9 showcases all those forms employing "Tiger Claw" ("虎爪"), with an expanded view of relevant techniques. This illustration differs from explicit links shown in Fig. 5. It highlights implicit relationships, such as the shared employment of specific techniques or representation of a principle, renewing insights into connections between forms and styles to help analyze traits of exchange and contact.

CQ6. Which techniques, forms, or styles are simulating or symbolized by a creature or living thing?

```
//Q6a: find techniques and forms simulating, e.g. a crane
MATCH (f: MA_form)-[rs: imitates]-> (s: symbolic_animal {name_en: 'crane'}))
OR
MATCH (t: MA_technique)-[rs: imitates]-> (s: symbolic_animal {name_en: 'crane'}))
RETURN f, t, s, rs
//Q6b: find styles symbolized by, e.g. a crane
MATCH (st: MA_style)-[sbl: has_symbol]-> (s: symbolic_animal {name_en: 'crane'}))
RETURN st, s, sbl
```

CQ7. What type of weapons, if any, are used in a martial arts style?

```
//Q7: find all weapons used in, e.g. "Hung Kuen" and identify their weapon types
MATCH (w: armament)-[: used_in]-> (:MA_system {name_en: 'Hung Kuen'})
RETURN w.weapon_type
```

CQ8. In what social units is a certain martial art taught?

```
//Q8: find all social units that e.g. "Hung Kuen" is taught
MATCH (:MA_system {name_en: 'Hung Kuen'})-[: taught_at]-> (i: MA_institute)
RETURN i
```

It is also possible to address this question based on inference, such as by finding all martial art institutes that a master who teaches one style teaches at.

```
MATCH (ma: MA_master)-[: teaches_at]-> (i: MA_institute)
WHERE ma-[: teaches]-> (:MA_system {name_en: 'Hung Kuen'})
RETURN i
```

6.2 Association with multimedia content

On an ongoing basis, we have integrated multimodal knowledge representations into the "Lingnan Martial Arts Training" program (in Section 2.1) to enhance martial arts tutorials in a semantic-rich manner. The aim is to attach conceptual knowing to physical learning, thereby fostering a more mindful and comprehensive grasp of knowledge in martial arts.

As illustrated in Fig. 10a, the program has developed a series of short videos featuring demonstrations of fundamental techniques performed by elite masters. These videos were initially created for dissemination on social media platforms and later enriched with dynamic annotations sourced from the MAon datasets, supplemented with additional notes by knowledge experts.[9] This integration exemplifies how computational resources, through a scrutinized extraction and organization from humanities materials, can efficiently aid in content creation and enrichment.

Another running experiment involves iterating an interactive manual that connects the knowledge graph of respective martial arts concepts to their intuitive multimedia manifestations. The resulting interface provides a video-watching experience accompanied by the MAon representations and natural language descriptions of the captured technical components. Users can watch master performances of individual forms within the sequential context of a form set, as captured in the

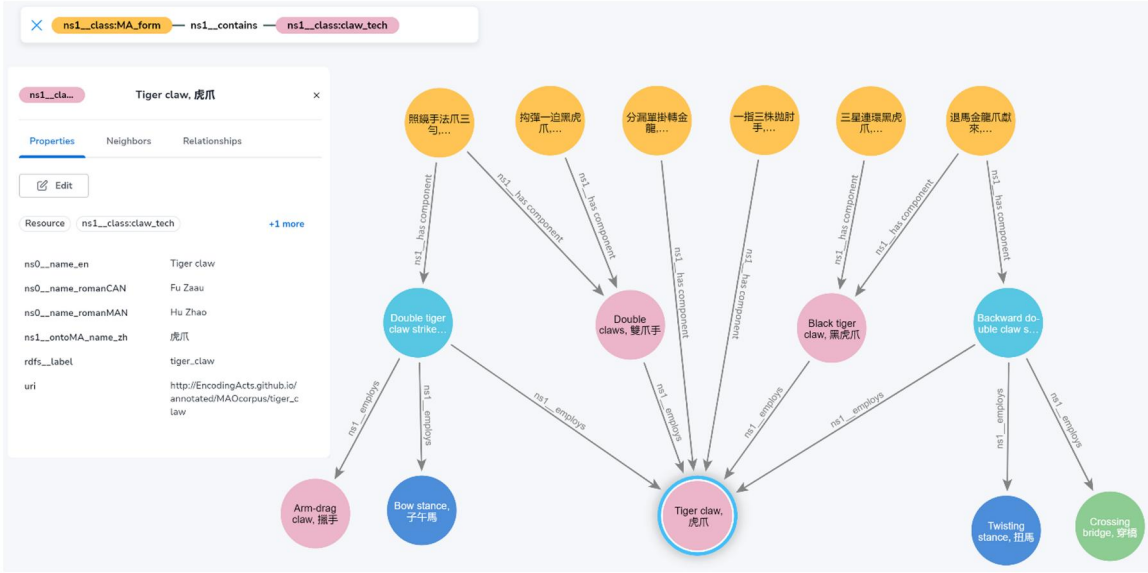

Figure 9. Forms employing the "虎爪" (Tiger Claw) technique.

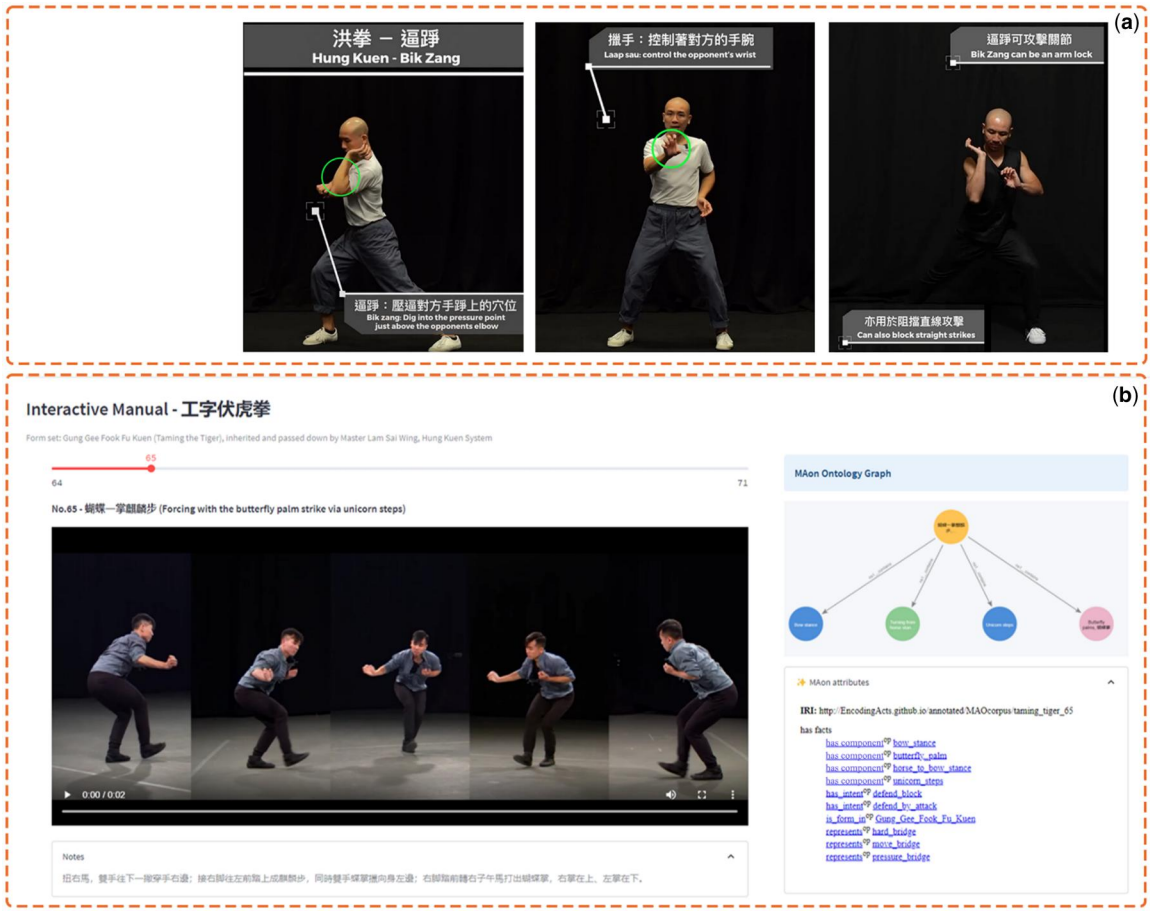

Figure 10. (a) Snapshots from an annotated video demonstrating the "Forcing elbow strike" and "Arm-drag claw" techniques (image courtesy of the Institute of Chinese Martial Studies); (b) A sample of the interactive manual interface manifesting a form using multimodal data.

HKMALA's recordings, while exploring the conceptual realm of embodied knowledge in martial arts (Fig. 10b). As we continue to refine the design of the interactive manual interface, we plan to conduct further user evaluations soliciting feedback from various user groups, including both public audiences and trainees on the program. In particular, the trainees—predominantly dancers who have spent months learning foundational form performances, will offer valuable feedback on how the ontological enhancements can impact martial knowledge learning experiences and guide improvements to the overall design and usability of the interface under development.

7. Conclusion

As computational capabilities increasingly intersect with CH sectors, various tools have emerged to enhance the processing of data materials. While many existing inventions chiefly focus on fine-grained object-based catalogs, there remains a gap in addressing intangible heritage materials. In this setting, this paper introduces the MAon: a comprehensive domain ontology and the first annotated ontological resource dedicated to traditional Chinese martial arts. MAon aims to encode the intangible yet manifold knowledge in traditional martial arts, making it available as a structured vocabulary and accessible to both human-reading and machine-operating scenarios.

Our methodology remedies the gap by emphasizing the embodied dimensions of martial arts, incorporating kinaesthetic, stylistic, and social components to complete the representation of intangible concepts. Through examples of instantiation and application using MAon, we demonstrate a plausible approach for creating coherent knowledge representations through ontology-based datafication. Additionally, we propose the potential of combining ontological approaches, especially LOD, with fine-tuned machine intelligence for interoperating distributed cultural data materials.

At this prospect, our future work has been planned toward integrating a suite of tools, including semantic modeling, automatic movement recognition, and feature-based entity recognition. This integrated infrastructure aims to enable a versatile infrastructure for application in diverse ICH instances, particularly those pertaining to embodied themes.

Author contributions

Yumeng Hou (Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing—original draft, Writing—review & editing) and Sarah Kenderdine (Funding acquisition, Supervision)

Conflict of interest statement. None declared.

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Notes

1. CROSSINGS (Computational Interoperability for Intangible and Tangible Cultural Heritage): https://www.epfl.ch/labs/emplus/projects/crossings/.
2. Cultural contact refers to the changes in artifacts, customs, and beliefs, among others, resulting from the contact of two or multiple cultures. Recent research implies that applying inference rules in semantic technologies can bring about new knowledge about cultural contact from massive data (Granados-García 2020).
3. Different from traditional or Historical European Martial Arts that have primarily survived in written form and entail re-enactment following a master's interpretation, Chinese martial arts have been and continue to be practiced as living art (Chao, 2023).
4. Classes & Properties Declarations of CIDOC-CRM Version 7.1.2: https://www.cidoc-crm.org/html/cidoc_crm_v7.1.2.html.
5. The property *represents* in MAon shares a similar interpretation with the *P138 represents* declared in CIDOC-CRM. However, their domains differ, as observed thus far. The *represents* here establishes connections between two *E89 Propositional Objects*, typically linking one *E89 Propositional Object* with an *E28 Conceptual Object*.
6. The Terse RDF Triple Language (Turtle) syntax allows the expression of RDF graphs in a compact and natural text form with abbreviations for common usage patterns and datatypes. See "RDF 1.1 Turtle": https://www.w3.org/TR/turtle/.
7. The form set of "工字伏虎拳" (Gung Gee Fook Fu Kuen), or Taming the Tiger, is a fundamental training set of Hung Kuen. The form set is regarded as the thesaurus of Hung Kuen techniques and represents typical technical structure across many Southern Chinese styles.
8. Neo4j Bloom is a graph analytic tool that transforms query commands and results into interactive visual elements. Queries in Neo4j are achieved using Cypher, a SQL-like yet intuitive graph query language that lets you retrieve data from the graph. See: https://neo4j.com/product/bloom/and https://neo4j.com/developer/cypher/.
9. The MAon contributions primarily apply to producing short video tutorials of Hung Kuen, which are published by the Institute of Chinese Martial Studies on https://www.facebook.com/lnmartialarts. All rights reserved.

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