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ARTICLE

Exploring the applicability of the Semantic Web for discovering and navigating Australian Indigenous knowledge resources

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ABSTRACT

Semantic Web ontology files can be flexibly programmed to delineate metadata relationships in *machine-readable* formats to create relational pathways for discovering resources both on and off the Internet. There is a global community of Semantic Web developers and users across a broad multi-disciplinary range of interests who create and share extensible open-source ontologies. In this article, the author will explore the functionality of Semantic Web techniques for representing the *ontologies of relatedness* through kinship that typically underpin Australian Indigenous knowledge systems, and investigate their potentials for meeting persistent demands among leading Australian Indigenous collections creators and users to be able to search and discover their hereditary knowledge resources in ways that reflect and reinforce their enduring cultural values, ways of knowing and rights-management concerns.

KEYWORDS

Semantic Web; ontology metadata; Indigenous knowledges; Australia; knowledge organisation

Introduction

In 1990, Tim Berners-Lee, the computer scientist who invented the World Wide Web, first envisioned the Semantic Web as an open-source metadata framework for managing information in which all links between content and data on the Internet would 'be handled by machines talking to machines'.[1] His vision for the Semantic Web was to provide an underlying relational metadata structure for the Web that would be *machine-readable*. The Web is a sprawling network of individual links among more than one trillion unique addresses or Universal Resource Locators (URLs).[2] Links among these myriad URLs are inherently fragile because they are only *human-readable*. A standard webpage displays what it is programmed to display on a surface level that is readable only by humans, yet the operating system that generates this display cannot itself interpret this content or its links to other resources on the Internet. When a hyperlink coded into a standard webpage breaks, all evidence of its relatedness to its intended target resource can disappear forever.

Semantic Web techniques seek to address this problem by allowing for the creation and machine-readable chaining of Uniform Resource Identifiers (URIs), which are unique

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strings of characters that can be authored to identify and link all kinds of *information resources* that are native to the Internet, as well as practical and conceptual *non-information resources* such as real-world people, places, things and ideas. While this original vision for the Semantic Web has not (yet) been fully realised, it nonetheless catalysed the development of open-source metadata techniques that are highly applicable to the resource-discovery and rights-management needs of Indigenous Australian heritage collections.

This article is based on a paper that I presented at the Information Technologies and Indigenous Communities (ITIC) Symposium, which was convened by Lyndon Ormond-Parker at the University of Melbourne on 27–28 September 2017.[3] In it, I will demonstrate how kinship protocols within the regional Indigenous knowledge systems of the Yolŋu of northeast Arnhem Land and the Warlpiri of the Tanami Desert constitute foundational non-hierarchical *ontologies of relatedness* that can be authored and represented in machine-readable Semantic Web metadata code.[4] Such code can be of great use to localised collections of Yolŋu and Warlpiri heritage such as those of the Mulka Project at Yirrkala in Arnhem Land and PAW Media at Yuendumu in the Tanami Desert.[5] I will exemplify this process through my discussion of three Web Ontology Language (OWL) ontology datasets that I authored and published online in Protégé,[6] which is presently the most accessible and user-friendly application for coding and managing Semantic Web ontologies.[7]

The two OWL ontology datasets that I will discuss first, 'gurrkurr.owl' and 'Baripuy_manikay.owl',[8] were informed by my research into the Yolŋu *gurruṯu* (kinship) system with the Yolŋu elder and intellectual, Joseph Neparrŋa Gumbula,[9] while the final dataset to be discussed, 'walaltja.owl',[10] was informed by my research into the Warlpiri *walaltja* (kinship) system with my Warlpiri colleague, Steven Wantarri 'Wanta' Jampijinpa Pawu-Kurlpurlurnu Patrick.[11] Ultimately, I hope to show and promote further discussion into how these approaches to coding relational information via Semantic Web techniques can contribute to meeting demand among Indigenous Australians for interfaces that enable them to search and navigate collections of their own heritage in ways that reflect and strengthen their cultural values, ways of knowing and rights-management protocols.

The medium is the message

In his seminal book on media theory, *Understanding Media: The Extensions of Man*, the philosopher Marshall McLuhan coined the axiom the 'medium is the message',[12] thereby drawing attention to the reality that content cannot exist in a dissociated state of neutrality from the media through which it is served and experienced. The media through which content is served, indeed, frames audience understandings of it, and this is as true of collections content as it is for all other kinds of media content.[13] The interfaces available to end-users for discovering and managing Australian Indigenous heritage in collections are also not neutral,[14] and their underlying structures can indeed be optimised to reinforce and perpetuate attendant cultural values and ways of knowing.

The Indigenous Australian educationalist Martin Nakata has warned that it is 'important to understand what happens when Indigenous knowledge is documented in ways that disembodies it from the people who are its agents; … to consider what disintegrations and transformations occur when it is redistributed across Western

categories of classification'.[15] Internationally standardised metadata schemes, such as MAchine-Readable Cataloging (MARC) 21 for libraries, ISO 23081 for records and General International Standard Archival Description (ISAD(G)) for archives,[16] have largely been developed through Western ways of knowing and organising knowledge, and now inform national archiving standards such as in Australia.[17]

These schemes are generally good at allowing for keyword and faceted browsing of collection catalogues, and at fulfilling basic end-user resource-discovery needs in ways that align with Western frames of knowledge in instances where suitable keywords and facet restraints are known by users. They are not necessary good, however, at representing parallel knowledge traditions or framing resource-discovery experiences in ways that enable Indigenous users, whose own knowledge traditions have often been compromised by intergenerational colonial destabilisation, to strengthen and revitalise their traditional knowledges.

The transcultural interpretive limitations of Western metadata schemes are well known. For instance, it has been well documented since the 1980s that internationally standardised metadata schemes such as MARC have difficulties in representing and managing concepts and resources in non-European languages such as Arabic.[18] Through their own research into this quandary, Boast, Bravo and Srinivasan have found that, when applying such schemes, Indigenous institutions and communities have often 'sacrificed' specific understandings and values that have developed around their own collections in alignment with their own knowledge systems.[19] When repatriating digitised historical song recordings to Yolŋu communities in northeast Arnhem Land, the anthropologist Peter Toner similarly found that:

> It is obvious that the fundamental categories of metadata schemes like Dublin Core are based on Western systems of knowledge management. As archives work increasingly with Indigenous communities on the repatriation of digitised cultural heritage materials, with a clear aim of local knowledge management, we must expand the categories of metadata to include culturally-significant styles and types of knowledge.[20]

These assertions are supported by the folklorist Coppélie Cocq's observation that folksonomies created via Twitter hashtags by Sámi people indigenous to Sweden and Norway have opened 'new modes for the production of knowledge' that contribute to their 'continuity of expressive culture' and provide valuable metadata that are captured nowhere else.[21] This was also the experience of Wellen and Sieber, who found that pre-existing metadata schemes could not adequately address their needs in developing an ontology dataset for cross-culturally interpreting Cree conceptualisations of hydrography in Canada, which prompted them to use Semantic Web techniques in realising this aim.[22]

By contrast, the Europeana OWL ontology dataset has not been geared to interpret ideas and phenomena transculturally.[23] It has yet to be seen to what extent the Records in Context (RiC) standard for archival description, which is presently being developed through the International Council on Archives and is planned to include its own new OWL ontology dataset,[24] will be coded to accommodate transcultural ideas and phenomena. Even so, Semantic Web tools and techniques nonetheless still afford a high degree of flexibility and customisation. The extensible open-source framework through which OWL ontology datasets are created allows them to represent virtually any knowledge system

imaginable, and offers opportunities for Indigenous knowledge systems to represented alongside internationally standardised metadata schemes in interoperable ways.

In Australia, where non-hierarchical ontologies of relatedness underpin regional Indigenous knowledge systems, the challenge is to explore the applicability of such tools and techniques to building discovery and navigation interfaces that enable Indigenous heritage collections to be explored and understood through the unique logics of their source communities, and that assist in strengthening and revitalising the Indigenous knowledges that they represent in turn. Indigenous Australian leaders in this field have identified the persistent paucity of such collections interfaces as a significant barrier to delivering accessible resource-discovery and rights-management processes for their communities.[25]

Indigenising the Semantic Web

Supported by a thriving international online community of more than 300,000 registered developers and users,[26] Semantic Web tools and techniques allow for the extensible open-source authoring of OWL ontology datasets and plugins. Within Protégé, OWL ontology datasets can be saved in a variety of interoperable syntaxes including Resource Description Framework/Extensible Markup Language (RDF/XML), Terse RDF Triple Language (Turtle), Lamport TeX (LaTeX) and JavaScript Object Notation for Linked Data (JSON-LD), and can be visualised via the onboard OntoGraf plugin to aid verification and editing. Every resource documented within such datasets is ascribed its own unique and persistent URI, which allows for machine-readable links to be programmed among them.

At the core of each OWL ontology dataset lies a string of machine-readable atomic data statements known as *semantic triples*. Following the Resource Description Framework (RDF) metadata data model designed by the World Wide Web Consortium (W3C), semantic triples are expressed in an object–predicate–subject format, and are specifically designed to capture relational information that enables complex non-hierarchical ontologies to be authored. When authored in Protégé, the simple semantic-triple statement 'Aaron Corn [object]–works at [predicate]–The University of Adelaide [subject]' consists of three *entities* (see Figure 1). The first and third, the object and the subject, are authored as unique *individuals* within different *classes* constructed for 'Person' and 'Workplace', while the second, the predicate, is authored as an *object property* that describes the nature of the relationship between the two others.

The semantic-triple statement 'Aaron Corn–works at–The University of Adelaide' may seem insignificant to some today. Yet, in the future, it could well provide a vital machine-readable metadata lead for end-users, Indigenous or otherwise, seeking to locate and explore the substantial Indigenous heritage collections that I have generated throughout my career. For instance, the personal archive that I have been populating at the Mulka Project in Yirrkala since November 2017[27] already contains some 25,000 discrete digital resources that intersect and overlap with other collections I have deposited at the Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS) and the National Library of Australia, and legacy records of my work at various Australian universities.[28] The OntoGraf plugin visualisation of this statement is shown in Figure 2, while its underlying code is shown in RDF/XML in the Appendix.

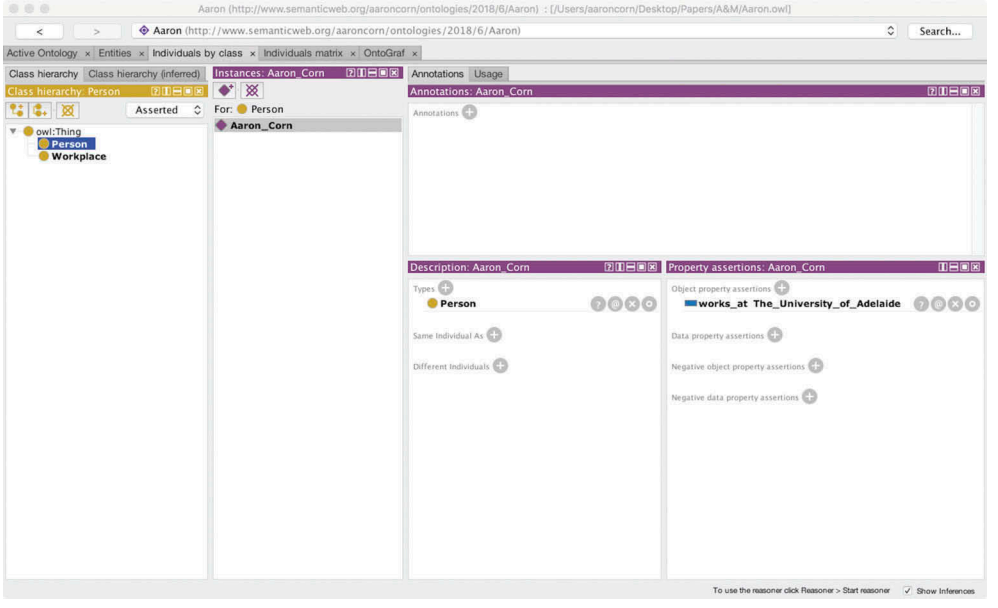

Figure 1. Authoring the triple statement 'Aaron Corn–works at–The University of Adelaide' in Protégé.

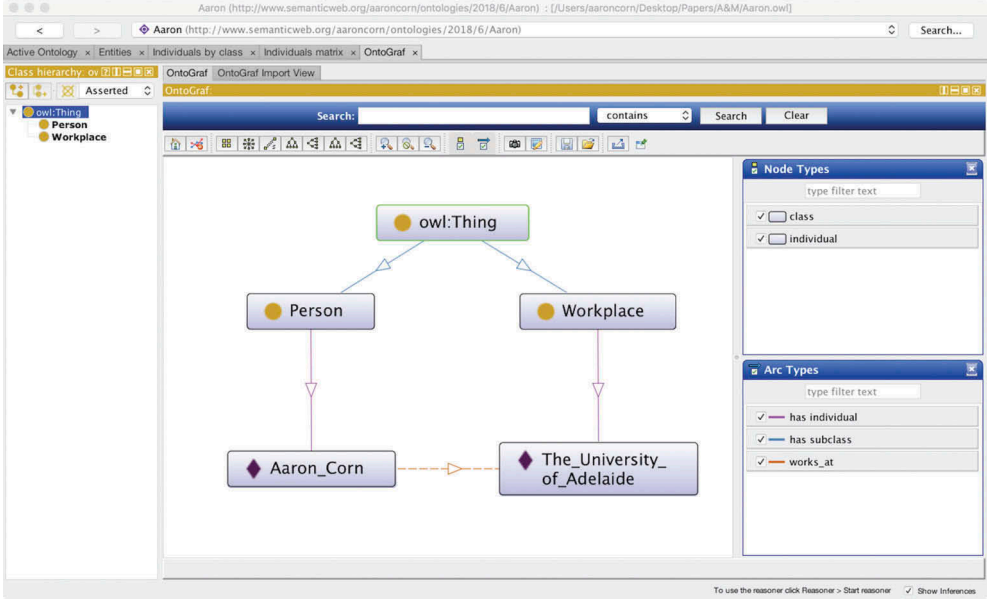

Figure 2. An OntoGraf plugin visualisation of the triple statement 'Aaron Corn–works at–The University of Adelaide' via Protégé.

As shown in Figure 2, the top-tier class of 'Thing' is the basis of all ontologies authored in Protégé. However, nested within this top-tier class, all individuals, properties and classes can be freely customised to address novel end-user requirements. Classes and properties can also be placed in a hierarchy via the optional creation of

sub-classes and sub-properties. It is nonetheless the machine-readable facility of Semantic Web techniques to code and represent an interrelated matrix of entities non-hierarchically, and in a multitude of simultaneous and potentially conflicting ways, that is essential for faithfully capturing and mirroring the multiplistic polysemy that typifies Australian Indigenous knowledge systems. This flexibility extends well beyond the capabilities of Western hierarchical taxonomies such as ISAD(G) as used in archives and Dewey Decimal Classification as used in libraries, and allows for any authored entity to be linked to any other in any conceivable way. The necessity for this flexibility has been explained by the educationalist Michael Christie, through his critique, mid-last decade, of initial attempts to codify Yolŋu knowledge in conventional databases:

> In the Yolŋu world, a word (or phrase) can be a person, a place, the name of a ceremony or object or song, an act, a strategy, a connection, or a label for a particular grouping. One word can stand for a range of these things. So, our only viable alternative is … to rid it [the database] as far as possible of any ontological presumptions. This flattening out of the metadata structure enables the word/phrase (or what the computer recognises as a text string) its maximum connective potential.[29]

Christie was also told by a Yolŋu colleague how, from a Yolŋu ontological perspective, the Yolŋu homelands themselves could be understood to be an ecological database:

> Early in our research, we were working with Yiŋiya Guyula from Milingimbi. While keenly interested in the potential of digital technology for keeping his religious-political knowledge strong into the next generation, he was quite diffident about the potentials of a conventional digital database. He was insistent that the land was his database, and described in detail … how each place spoke of the ancestral acts which gave it its forms and resources. … The land as database tells you who you are, where you have come from and how you must behave.[30]

The ontological complexities exemplified in these quotations underscore some of the challenges in developing metadata datasets that can faithfully mirror Australian Indigenous knowledge systems in ways that are recognisable and useful to source-community end-users, and led Christie to surmise in 2005 that this 'is of course impossible to achieve and in fact unnecessary to attempt'.[31] Even so, due to the proliferation of accessible digital technologies since then, the concerns and needs of Indigenous Australians to improve the discoverability and representation of their knowledge systems within collections have grown significantly, thereby necessitating continued attempts to develop metadata datasets that can faithfully mirror Australian Indigenous knowledge systems.

We know that collections all over the world hold thousands upon thousands of Australian Indigenous heritage resources that Indigenous Australians find persistently difficult to locate and access.[32] We know that in the many regions of Australia, where colonisation destabilised Indigenous societies and knowledge traditions before the twentieth century, there is now a growing hunger to discover ontologically rich historical resources that can assist Indigenous communities in their current cultural revitalisation efforts.[33] We also know that in more remote regions, such as Arnhem Land and the Tanami Desert, which were exposed to colonisation later, Indigenous Australians are hungry for the facility to search and navigate collections of their own heritage in ways that conform to their own localised ways of knowing.

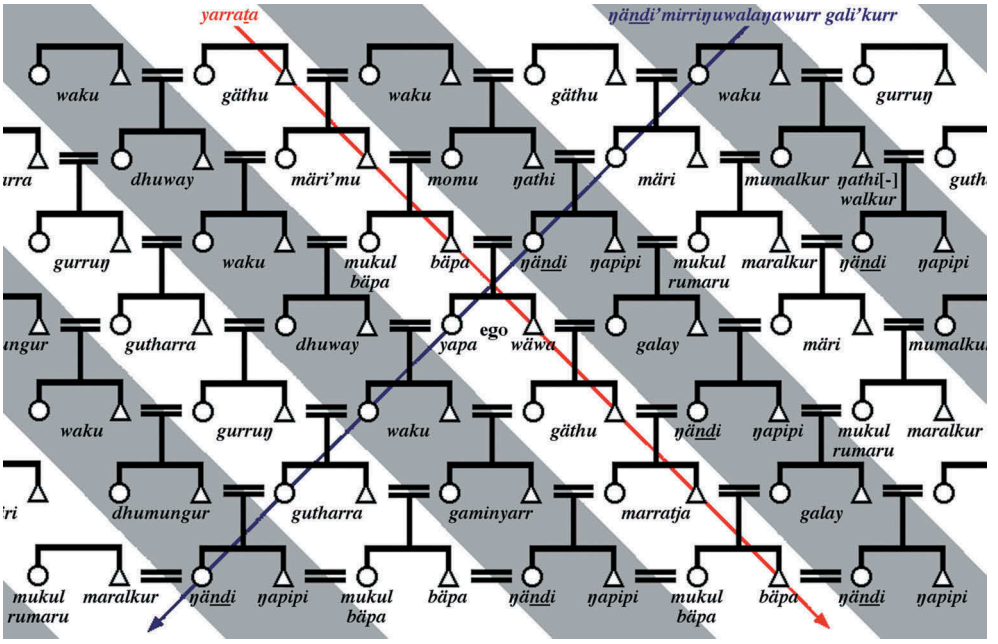

Figure 3. Egocentric projection of the Yolŋu *gurruṯu* schema after Cooke and Zorc.

This latter point was made clearly in the presentation by the Directors of the Mulka Project from Yirrkala, which immediately preceded my own at the 2017 ITIC Symposium.[34] In this presentation, Wukun Wanambi was measured in emphasising how *gurruṯu* (kinship), which is the foundational ontology of relatedness in Yolŋu society that informs human relationships to all people, places, things and ideas (see Figure 3),[35] should be applied as a pivotal organising logic in all efforts to serve and understand all Yolŋu collections content.

Ontologies of relatedness

The Yolŋu elder and intellectual Joseph Neparrŋa Gumbula began working to develop a pilot database of Yolŋu knowledge and heritage for the Galiwin'ku Indigenous Knowledge Centre in 2002. Through this exercise, his initial approach to communicating the complexities of a Yolŋu ontology was to paint a metadata model that detailed traditional access provisions for hereditary knowledge resources through descent and ceremonial seniority (see Figure 4).[36]

Dubbed *The Yolŋu Knowledge Constitution*,[37] the ceremonial-seniority protocols identified in this painting, as indicated by the vertical arrangement of three increasingly restricted green, yellow and red access classes like traffic lights (see Figure 5), were relatively approachable by broader audiences and these were successfully adopted for use in human-readable formats by several significant Yolŋu heritage collections.[38] These included the University of Sydney Archives, which we investigated through our shared Australian Research Council (ARC) grant project as expertly facilitated by the current President of the Australian Society of Archivists (ASA), Julia Mant. This research resulted in Gumbula's

Figure 4. *The Yolŋu Knowledge Constitution* by Gumbula.

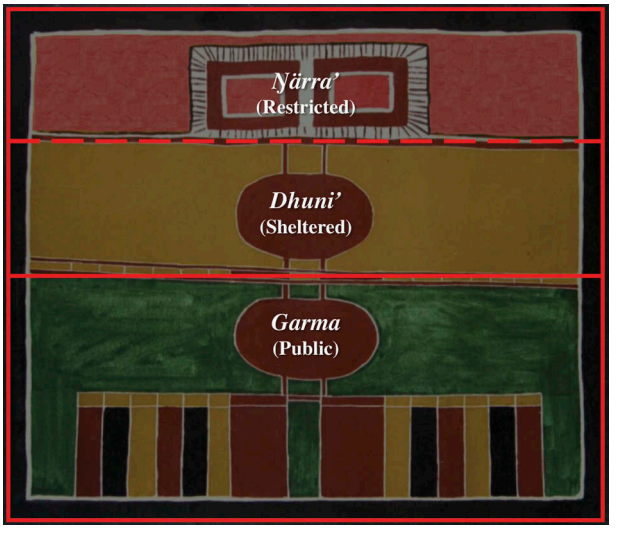

Figure 5. Access classes identified by Gumbula in *The Yolŋu Knowledge Constitution*.

book of historical images from Arnhem Land dating from 1926,[39] for which Gumbula and Mant received an ASA Mander Jones Award in 2012.[40]

The more complex protocols that Gumbula's painting identified for access via descent across multiple matrifilially interrelated clan-groups and the two patrimoieties that constitute Yolŋu society (see Figure 6) were nonetheless far less approachable by broader audiences and were usually lost in translation. This system of exogamous intermarriage ensures that every person in Yolŋu society, through their respective paternal and maternal lineages, is directly descended from clan-groups of both patrimoieties as a means of maintaining this division as a chief means of distributing and balancing executive powers.

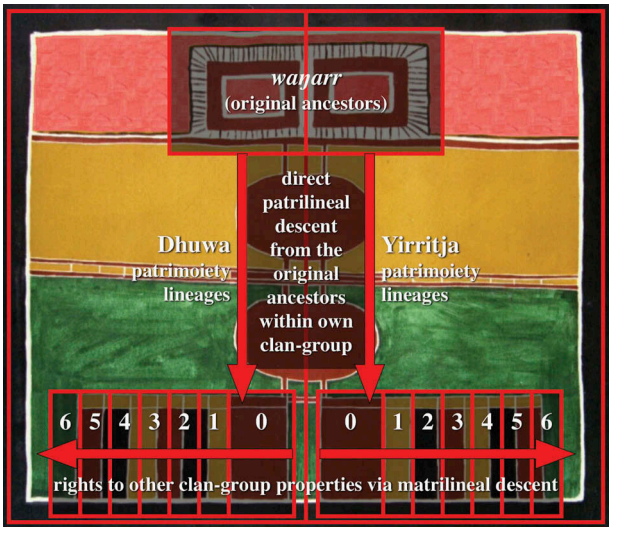

Figure 6. Descent vectors identified by Gumbula in *The Yolŋu Knowledge Constitution* that trace patrilineal descent within one's own (0) *ŋapawanditj* (bone-group), matrilineal descent from one's (1) *ŋändipulu* (mother's group), (2) *märipulu* (mother's mother's group), (3) *wakupulu* (mother's mother's mother's group or 'matrilineal child's group') and (4) *yapapulu* (mother's mother's mother's mother's group or 'sister group'), one's father's matrilineal descent from one's (5) *momupulu* (father's mother's group), and one's patrilineal children's matrilineal descent from one's (6) *milmarapulu* (fraternal wife's mother's group or 'betrothal group').

Gurruṯu terms are recycled at every fourth generation away from ego, so that everyone in Yolŋu society is identified through this system as a relative, no matter how distantly. For instance, one's mother's mother's mother's mother is called a *yapa* (sister), while one's son's son's son's son is called a *wäwa* (brother).[41]

The OWL ontology dataset, 'gurrkurr.owl' (see Figure 7),[42] shows how this matrix of matrifilial interrelationships displays when authored in Protégé from the perspective of a *gäthu* (patrilineal child) to Gumbula, which is my own adoptive position in the *gurruṯu* system. As with many other people who have been similarly adopted into Indigenous Australian communities, my very placement by Gumbula into this social position back in 1997 not only sealed my initial status as his student from a Yolŋu perspective, but was also an intentional strategy on his part to refocus my learning away from the Western knowledge paradigm through which I had been predominately educated and towards a Yolŋu one.[43]

Through *gurruṯu*, children conventionally inherit full property rights in their own clan-group's homelands and ceremonial law from their father, while also inheriting other kinds of standing complementary rights to homelands and ceremonial law owned by interrelated chains of other clan-groups from whom their father, they themselves and, subsequently, their own *gäthu* respectively trace matrilineal descent. Further complicating this system, as exemplified in Figure 7, is that it is common for a single clan-group to occupy more than one position within a person's matrix of matrilineal relationships via multiple descent vectors.

The specific kind of dataset exemplified here could be used as functional login credentials for a Yolŋu collections portal that could then serve relevant content in

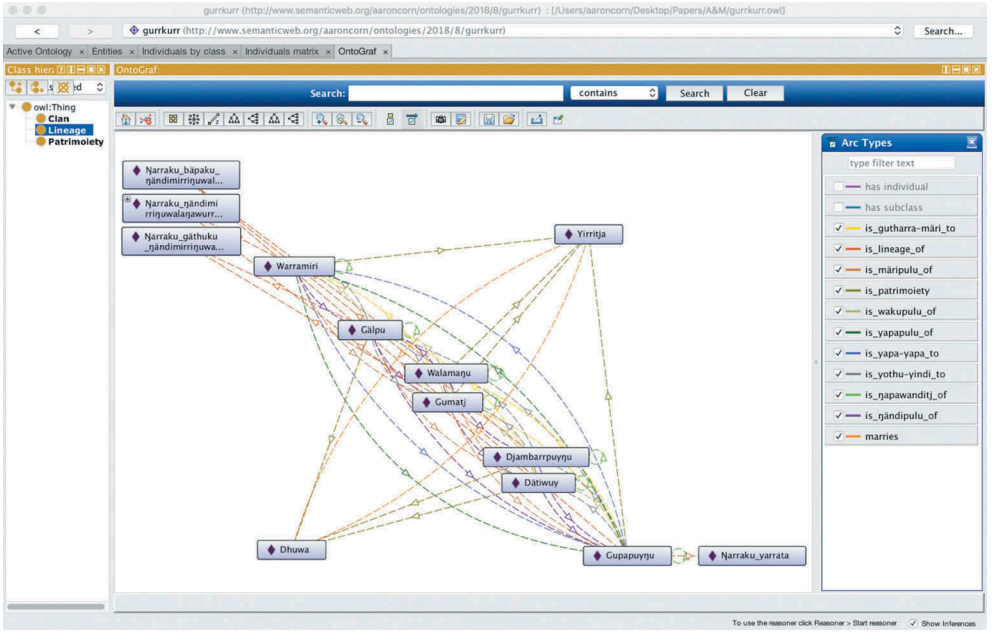

Figure 7. An OntoGraf plugin visualisation of *gurruṯu* interrelationships among Yolŋu clan-groups as coded via Protégé in the Semantic Web metadata file 'gurrkurr.owl'.

response to the nominated matrix of real-world clan-groups to whom an end-user is related. It is unlikely that this complex matrix of interrelationships will be readily interpretable by most people who have not lived their daily lives observing the logic of *gurruṯu*. Yet, the Semantic Web metadata encoded in 'gurrkurr.owl'[44] removes this very need and, by having published this dataset of linked URIs online via Protégé, I have created a machine-readable metadata resource that, like the many thousands of other resources I have collected throughout my career, can now be considered a Yolŋu heritage resource in its own right. It is open source, interoperable and extensible, and as such can be used and customised to inform new interfaces for discovering and navigating any other collected Yolŋu heritage resource with an URI that is native to or catalogued on the Web.

The rich metadata and resource links that this process can capture span the full gamut of ancestrally bestowed properties conventionally passed from generation to generation through Yolŋu clan-groups, including *wäŋa* (homelands), *yäku* (names), *manikay* (songs), *buŋgul* (dances) and *miny'tji* (designs), as well as newer media resources such as photographs, films and websites that document more recent endeavours by Yolŋu communities. Figure 8 shows a Protégé display of the OWL ontology dataset 'Baripuy_manikay.owl',[45] which details the canonical sequencing of song subjects and rhythmic modes in the primary hereditary *manikay* series that Gumbula performed when running public ceremonies.[46] Our 2004 and 2005 recordings of this *manikay* series, in which Gumbula performed with his family, are now held in my personal archive at the Mulka Project in Yirrkala.[47] It is this kind of rich metadata about significant hereditary properties that is now scarce among records of Indigenous

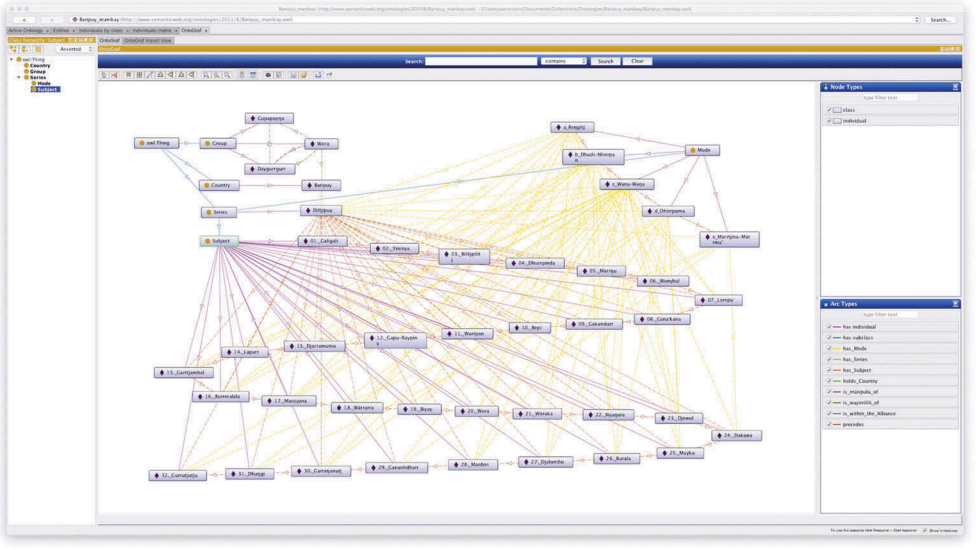

Figure 8. An OntoGraf plugin visualisation of the sequencing of song subjects and rhythmic modes in the Yolŋu public *manikay* series for the Gupapuyŋu homeland of Baripuy as coded via Protégé in the Semantic Web metadata file 'Baripuy_manikay.owl'.

Australian societies and knowledge traditions that were destabilised by colonisation early, and that is now understood to be vital for the ongoing maintenance of Indigenous Australian cultures and ways of knowing into the future.

Using such Semantic Web techniques to link collected Yolŋu heritage resources through the logic of *gurruṯu* in a machine-readable way can ultimately provide better accessibility, rights-management and cultural-strengthening outcomes for Yolŋu end-users, as well as other end-users who seek to understand how Yolŋu society, law, country and culture are framed within Yolŋu knowledge traditions. In another of his writings from back in 2005, Christie asserted that conditions must be created 'whereby Indigenous owner–users can learn to invoke and encode for themselves the multiple connections which constitute Aboriginal knowledge in the context of database use'.[48] Today's Semantic Web tools and techniques now provide us with an increasingly accessible medium through which this can indeed happen.

Reflecting an ecological repository

As mentioned earlier, an important facility that Semantic Web techniques afford for coding and representing Australian Indigenous knowledge systems is their flexibility in non-hierarchically capturing and mirroring a multitude of simultaneous and, potentially, conflicting interrelationships between authored entities. This is exemplified here in the OWL ontology dataset 'walaltja.owl' (Figure 9),[49] which I authored in Protégé through collaboration with my Warlpiri colleague, Steven Wantarri 'Wanta' Jampijinpa Pawu-Kurlpurlurnu Patrick, during our ARC grant project on Warlpiri heritage collections with Stephen A Wild. Like Christie's Yolŋu colleague, Guyula,[50] Patrick was also resolute in emphasising how the Warlpiri homelands of the Tamani

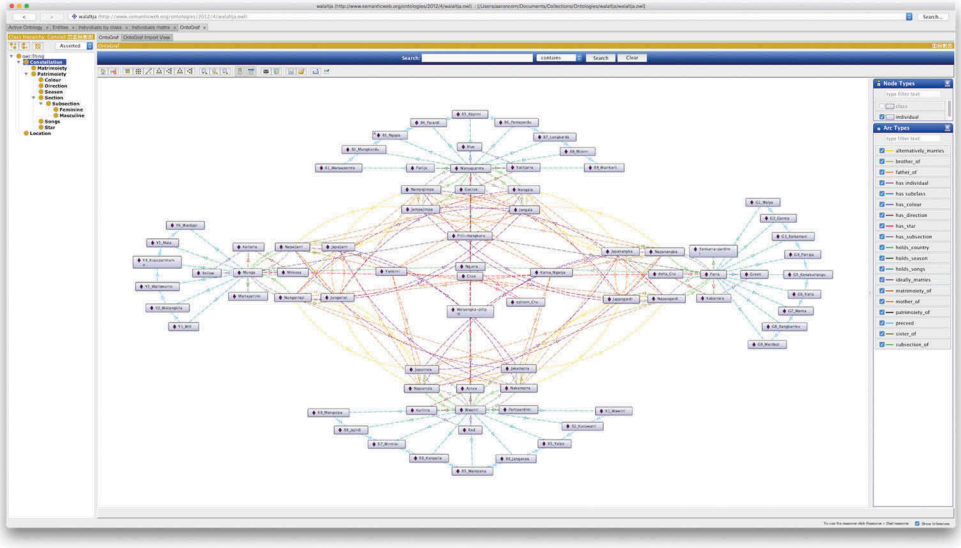

Figure 9. An OntoGraf plugin visualisation of *walaltja* interrelationships and managed rights among Warlpiri group-alliances as coded via Protégé in the Semantic Web metadata file 'walaltja.owl'.

Desert had been provided by his people's original ancestors as an ecological repository for all Warlpiri knowing. Through his related cultural and educational work as Creative Director of the Milpirri Festival in Lajamanu,[51] Patrick coined the captivating maxim, '*Wangkayarla nguruku kapungku nguruju pina wangkami-jarla* [Speak to the land and the land will speak back].'[52]

Just as 'gurrkurr.owl' was coded to reflect the logic of the Yolŋu *gurruṯu* system in response to persistent needs and concerns expressed by my Yolŋu colleagues,[53] 'walaltja.owl' was similarly coded in response to Patrick's concern that Warlpiri collections content should be framed and organised according to the logic of the Warlpiri *walaltja* (kinship) system.[54] This is the foundational ontology of relatedness that informs human relationships to all people, places, things and ideas in Warlpiri society.[55] This exercise not only resulted in the creation and publication via Protégé of a valuable new online Warlpiri heritage resource, but also elicited from Patrick an unexpectedly astonished and affirming response to the representational suitability of Semantic Web techniques in faithfully mirroring Australian Indigenous knowledge systems.

Unlike the Yolŋu *gurruṯu* system, the Warlpiri *walaltja* system is explicitly modelled on a widely observable natural phenomenon. It is modelled on the five brightest stars in the constellation Crux, also known as the Southern Cross, which can be seen wheeling through the night sky all year round throughout the Warlpiri homelands. This constellation serves as a polysemic template that, in Warlpiri epistemology, binds together the logic of the cosmos and the Warlpiri social order within it, and regulates each person's hereditary rights in the Warlpiri homelands and their incumbent ancestrally bestowed repertoires of names, songs, dances and designs. Forming the shape of a cross, its four brightest outer stars respectively represent the four cardinal directions and the four seasons of the Tanami Desert, and are further linked to four primary colours and

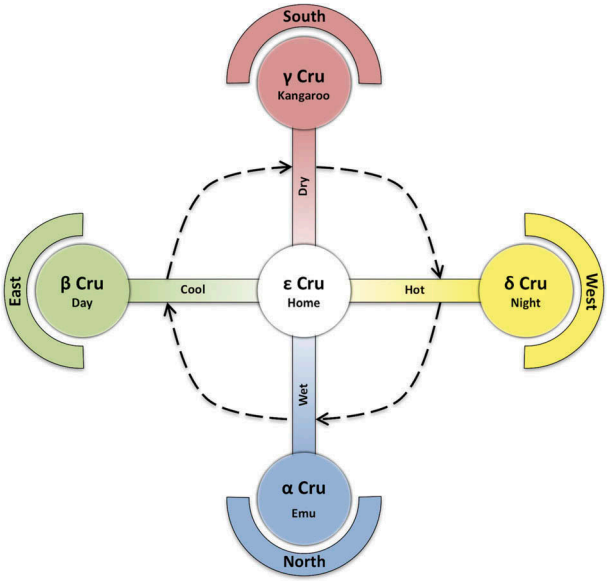

Figure 10. The Southern Cross constellation as a template for Warlpiri *walaltja*.

the four main patrifilial group-alliances that constitute Warlpiri society (see Figure 10).[56]

Exogamous intermarriage among these four group-alliances serves a similar function as in Yolŋu society. This ensures that every person in Warlpiri society, through their respective paternal and maternal lineages, is directly descended from a grandparent of each of the four group-alliances, maintaining this division as a chief means of distributing and balancing executive powers. Children will conventionally inherit the rights in homelands and ceremonial law of their own patrifilial group-alliance from their father, while also inheriting other kinds of standing complementary rights to those the other three group-alliances from whom they trace matrilineal descent. Spanning the vertical and horizontal axes of the Southern Cross, these four group-alliances are organised into two patrimoieties, which each hold chief responsibility for different ceremonial processes and repertories (see Figure 11).[57]

Intermarriage and matrilineal descent among each of these four group-alliances is organised via the known interrelationships among the set of 16 *kuyu* (meat) or skin names, eight for females and eight for males, to which everyone in Warlpiri society is assigned. There is a balanced distribution of four skin names per group-alliance, two for females and two for males, which are internally sorted into two brother–sister pairs that are each considered to sit at either the Left or the Right of their group-alliance. Fixed descent relationships from mother to child perpetually cycle throughout each of the four group-alliances in two counter-directional rotations that form two matrimoieties that are aligned with two constellations either side of the Southern Cross. The Right matrimoiety cycles right or clockwise through the Right skin names in each group-alliance and is aligned with the Pointers, while the Left matrimoiety cycles left or counter-clockwise through the Left skin names in each group-alliance and is aligned with the Magellanic Clouds.[58] Therefore, to explain Patrick's full name, Steven

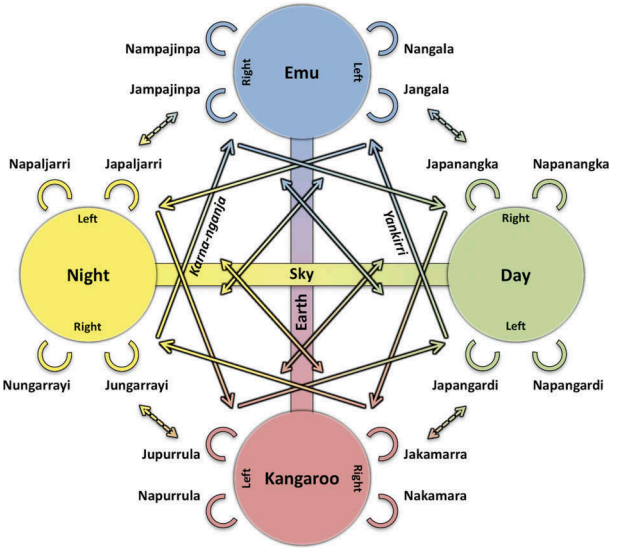

Figure 11. A sociocentric projection showing patrimoiety affiliations (+), matrimoiety affiliations through mother-to-child descent (→), and ideal (↔) and alternative (← →) marriage partner among the four group-alliances (·) and 16 skin names (∩) of the Warlpiri *walaltja* system.

Wantarri 'Wanta' Jampijinpa Pawu-Kurlpurlurnu Patrick, which itself presents a representational challenge for Western metadata schemes, Steven is his English given name, Wantarri is his full Warlpiri given name and 'Wanta' a shortened nickname derived from this, Jampijinpa is his skin name, Pawu and Kurlpurlurnu are homelands in which he holds primary patrilineal ownership rights, and Patrick is his English surname.

Finally, within the outer perimeter formed by Southern Cross's four brightest stars, the fifth-brightest star represents a fixed eternal *ngurra* (home), where Warlpiri ancestors can rest while the natural cycles of the physical world continue to revolve around them. In traditional Warlpiri designs representing the Southern Cross, this fifth star is usually centred to promote the ideal of balance in the Warlpiri social order as a reflection of the underpinning logic of the cosmos. In the night sky, however, it is always seen visibly off-centre and serves the Warlpiri people as a permanent reminder to always strive for balance through observing ancestral law.[59]

The OWL ontology dataset shown previously in Figure 9 exemplifies how the myriad polysemic non-hierarchical associations of the *walaltja* system, as a foundational Warlpiri ontology of relatedness, can be coded and visualised in Protégé via the extensive flexibility that Semantic Web tools and techniques afford. I authored it in direct response to class, individual and object-property entities that Patrick identified as essential for framing and understanding Warlpiri knowledge, and therefore Warlpiri cultural resources and heritage materials of all kinds. Interested to see how hereditary rights in specific resources might display, Patrick asked me to add a sequence of public ceremonial song-and-dance subjects for each of the four group-alliances, which are labelled in 'walaltja.owl'[60] as B1–B9, G1–G9, R1–R9 and Y1–Y6.

Patrick's initial reaction to seeing this metadata dataset completed was one of astonished delight. It looked precisely like the cruciform arrangement of the *walaltja*

system as he envisioned it in his mind, and he stated how this affirmed his sense of the veracity and relevance of Warlpiri law as an essential way of living and understanding the cosmos not only for Warlpiri people, but potentially for everyone.[61] Such capacity for affirming and reinforcing Australian Indigenous knowledge systems indicates the usefulness of Semantic Web tools and techniques in the creation of future interfaces that can enable Indigenous Australians to search and navigate collections of their own heritage resources in ways that faithfully reflect their cultural values, ways of knowing and rights-management concerns, and can assist them 'to invoke and encode for themselves the multiple connections which constitute Aboriginal knowledge'.[62]

Conclusions

This article has demonstrated how, even using the rudimentary interface of Protégé's onboard OntoGraf plugin, Semantic Web tools and techniques can represent Australian Indigenous knowledge systems in ways that faithfully reflect the cultural values, ways of knowing and rights-management concerns of Indigenous Australian end-users. They provide for an open-source, interoperable and extensible medium that can be applied to develop future search and navigation interfaces for collections that can deliver accessible resource-discovery and rights-management processes for Indigenous Australian communities.

Specifically, I have shown how these tools and techniques hold considerable capacity for non-hierarchically accommodating the polysemic interrelationships that typify ontologies of relatedness through kinship and inform rights-management provisions in Australian Indigenous knowledge systems. Machine-readable OWL datasets that faithfully reflect these ontologies of relatedness constitute valuable online metadata resources in their own right, and can be customised and implemented to serve linked content in response to the needs of specific communities and end-users, no matter what their levels of familiarity are with the encoded knowledge system. Semantic triples are preferred over conventional keyword and faceted browsing methods, because they contain machine-readable object-property statements that describe the nature of relationships between other authored entities in ways that can usefully guide and frame end-user discovery and navigation experiences.

Semantic Web tools and techniques can assist Indigenous Australian leaders in this field to realise their persistent desires for the creation of optimised resource-discovery and rights-management interfaces. This will enable collections of their own heritage resources to be searched and navigated in ways that affirm, reinforce and perpetuate the organising logic of their cultural values, ways of knowing and rights-management protocols not only of their own communities, but indeed for all end-users. As evidenced in Gumbula's painting of *The Yolŋu Knowledge Constitution*,[63] Indigenous Australians have considered such approaches to resource and metadata management for collections of their own heritage essential since their early professional engagements with database technologies. Like other authors from around the world cited in this article, they have long known that the fundamental categories of Western metadata schemes are limited in their capacities to faithfully represent their own knowledge systems, and remain frustrated by the paucity of collections interfaces that enable them to search and

discover their own heritage resources in ways that align with the very knowledge systems that produced them.

Indeed, there has been consistent scepticism from informed Indigenous experts such as Nakata, Guyula, Wanambi, Gumbula and Patrick towards applying Western categories of classification to Indigenous knowledges and even insistence by some that the country itself must be understood as an ecological database or repository from which all Indigenous knowledges stem. Such stances constitute a form of *ontological resistance* against Western categories of classification and their perpetuation of collecting as a colonial enterprise. After all, for Indigenous heritage collections to optimally benefit their source communities, they at least need to be as discoverable and navigable by them as possible. Any vision for an Indigenous collections interface of the future must therefore be one that can serve and frame content in response to end-user queries via the logics of Indigenous knowledge systems and their foundational ontologies of relatedness.

To this end, professional archivists, particularly those caring for Australian Indigenous resources, have an important role to play. Mant, for example, laboured with Joe Gumbula in the University of Sydney Archives last decade to apply access-class protocols that he had identified to its extensive collection of Yolŋu heritage resources in a human-readable format. There is now an immense need for metadata of this kind and, indeed, all kinds discussed in this article to be authored in machine-readable formats that are open source, interoperable and extensible, and linked to Indigenous heritage resources and records throughout the Web and beyond. Semantic Web tools and techniques, in their present and continually developing state, have been demonstrated to afford this possibility and therefore warrant further consideration.

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Steven Wantarri 'Wanta' Jampijinpa Pawu-Kurlpurlurnu Patrick is Creative Director of the Milpirri Festival at Lajamanu. He received an Innovative Curriculum Award from the Australian Curriculum Studies Association in 2007 for his work with the Lajamanu School, and worked at the Australian National University in Canberra with Aaron Corn and Stephen A Wild as a Discovery Indigenous Award Fellow on the ARC grant project, IN120100008.

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Appendix

The underlying code of the triple statement 'Aaron Corn–works at–The University of Adelaide' in RDF/XML.

```
<?xml version="1.0"?>
<rdf:RDF
xmlns="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron#"
xml:base="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron"
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:owl="http://www.w3.org/2002/07/owl#"
   xmlns:xml="http://www.w3.org/XML/1998/namespace"
   xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
   xmlns:untitled-ontology-
59="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/untitled-
ontology-59#"
   xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#">
  <owl:Ontology
rdf:about="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron"
/>

  <!--
///////////////////////////////////////////////////////////////////////
///////////////
  //
  // Object Properties
  //
///////////////////////////////////////////////////////////////////////
///////////////
   -->

  <!--
http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron#works_at --
>

  <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron#
works_at"/>

  <!--
///////////////////////////////////////////////////////////////////////
///////////////
  //
  // Classes
  //
///////////////////////////////////////////////////////////////////////
///////////////
   -->

  <!--
http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron#Person -->

  <owl:Class
rdf:about="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron#
Person"/>

  <!--
http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron#Workplace -
->

  <owl:Class
rdf:about="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron#
Workplace"/>

///////////////////////////////////////////////////////////////////////
///////////////
   -->

  <!--
http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron#Aaron_Corn
-->
```

```
  <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron#
Aaron_Corn">
    <rdf:type
rdf:resource="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aar
on#Person"/>
    <works_at
rdf:resource="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aar
on#The_University_of_Adelaide"/>
  </owl:NamedIndividual>

  <!--
http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron#The_Univers
ity_of_Adelaide -->

  <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aaron#
The_University_of_Adelaide">
    <rdf:type
rdf:resource="http://www.semanticweb.org/aaroncorn/ontologies/2018/6/Aar
on#Workplace"/>
  </owl:NamedIndividual>
</rdf:RDF>

<!-- Generated by the OWL API (version 4.2.8.20170104-2310)
https://github.com/owlcs/owlapi -->
```