Large-scale Reasoning with a Complex Cultural Heritage Ontology (CIDOC CRM)

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Nov 2013

ResearchSpace (RS) Project

- Funded by Mellon Foundation, run by the British Museum
  - Stage 3 (Working Prototype): developed between Nov 2011 and Apr 2013.
  - Stage 4: to start in 2013, with more development and more museums/galleries
- Support collaborative research projects for CH scholars
  - Data conversion and aggregation (LIDO/CDWA/similar to CIDOC CRM)
  - Semantic search based on Fundamental Relations
  - Collaboration tools, such as forums, tags, data baskets, sharing, dashboards
  - Research tools , e.g. Image Annotation, Image Compare, Timeline, Geo-Mapping
  - Web Publication
- RDF engine is at the core of RS, providing effective data integration across different organizations and projects

RS Semantic Search

- Allows a users unfamiliar with CRM or the British Museum's data to perform intuitive searches
- Features:
  - Intuitive "sentence-based" UI
  - Auto-completion across all searchable thesauri. Available search relations and appropriate Thesauri are coordinated
  - Search across datasets. E.g. once the entity "Rembrandt" is co-referenced between the BM People and RKD Artists thesauri, paintings by Rembrandt can be found across the BM and RKD datasets
  - Faceting of search results

RS Search: Example 1

Dashboard | Forum | London England and paper

Find all objects ☐ with images | from | London England | and | made of | paper

29 Results

List | Thumbnails | Timeline

Object Type
- 1 box
- 1 broadside
- 7 calligraphy
- 1 document
- 4 invitation
- 3 leaflet

Creator
- 6 Middle East and North Africa Modern Art
- 1 Mughal Style
- 1 Osman Waqialla
- 1 Syed Tajammul Hussain
- 6 The British Museum
- 1 Thomas Arne

Places
- 1 Asia
  - 1 South Asia
    - 1 India pre-1947
- 28 Europe
  - 28 British Isles
    - 28 England

Created
- 1 (missing this field)
- 1 1627-1658 ::
- 1 1659 ::

sorted by: Title; then by...

RFM1619 Calligraphic composition. Silkscreen print...
calligraphy; print: RFM1619 Calligraphic composition. Silkscreen print...; **Created**: Ahmed Moustafa; Middle East and North Africa Modern Art. London England; **Material**: paper; **Technique**: screenprint

RFM1620 Print. Calligraphy. Silkscreen print.
calligraphy; print: RFM1620 Print. Calligraphy. Silkscreen print.; **Created**: Ahmed Moustafa; Middle East and North Africa Modern Art. London England, 1977 ::; **Material**: paper; **Technique**: screenprint

RFM1621 Print. Calligraphy. Silkscreen print.
calligraphy; print: RFM1621 Print. Calligraphy. Silkscreen print.; **Created**: Ahmed Moustafa; Middle East and North Africa Modern Art. London England, 1978 ::; **Material**: paper; **Technique**: screenprint

RFM1622 Print. Calligraphy. Silkscreen print.
calligraphy; print: RFM1622 Print. Calligraphy. Silkscreen print.; **Created**: Ahmed Moustafa; Middle East and North Africa Modern Art. London England, 1983 ::; **Material**: paper; **Technique**: screenprint

RFM2064 Arabic calligraphy; ink and gold on vellum...
calligraphy: RFM2064 Arabic calligraphy; ink and gold on vellum...; **Created**: Osman Waqialla; Middle East and North Africa Modern Art. London England, 1980 ::; **Material**: paper

RS Search: Example 2

Find all objects with images | created/modified by | Rembrandt
and | is/has/about | drawing
and | is/has/about | mammal

Search | Add To Data Basket | Export | Print

13 Results

1

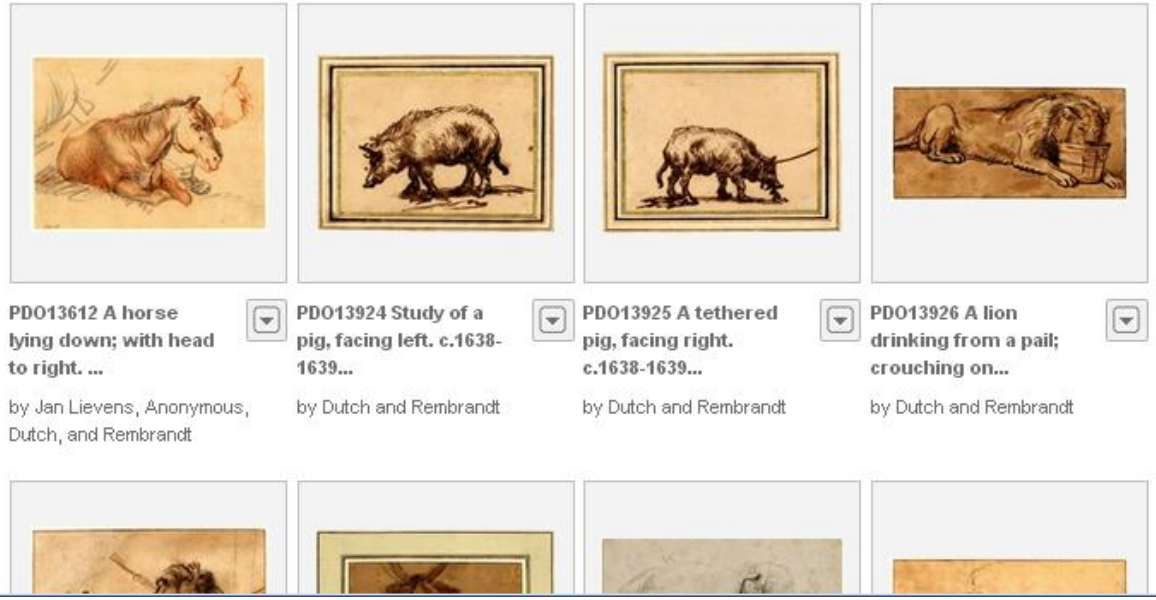
List | Thumbnails | Timeline

Object Type
1 album
13 drawing

Creator
1 Anonymous
13 Dutch
2 Italian
2 Jan Baptist Weenix
1 Jan Lievens

Places
13 (others)

sorted by: Title; then by...



PDO13612 A horse lying down; with head to right. ...
by Jan Lievens, Anonymous, Dutch, and Rembrandt

PDO13924 Study of a pig, facing left. c.1638-1639...
by Dutch and Rembrandt

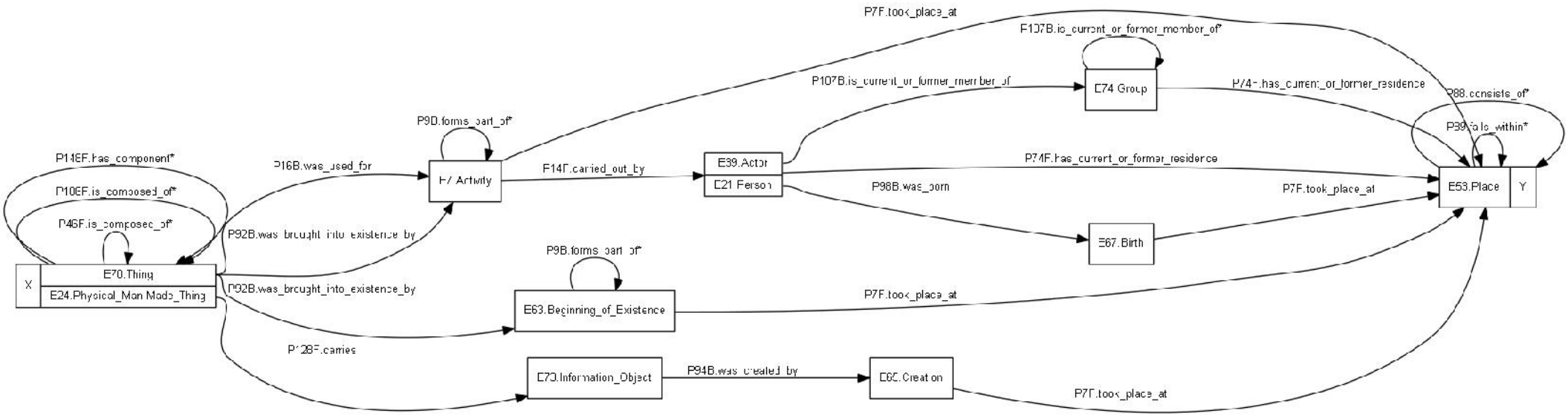
PDO13925 A tethered pig, facing right. c.1638-1639...
by Dutch and Rembrandt

PDO13926 A lion drinking from a pail; crouching on...
by Dutch and Rembrandt

- Finds narrower terms
- RS Video by Dominic Oldman (RS PI and BM IT dev manager) http://www.youtube.com/watch?v=HCnwgq6ebAs

Fundamental Relation (FR) Search

- How does a user search through a large CRM network?
- An answer: Fundamental Relations
  - Aggregate a large number of paths through CRM data
  - Provide a "search index" over the CRM relations
- E.g.: FR "Thing from Place"



- Initial implementation presented at SDA 2012 (TPDL 2012), Sep 2012, Cyprus (CEUR WS Vol.912)

Implemented FRs

N	FR	Description
1	FR92i_created_by	Thing (or part/inscription thereof) was created or modified/repaired by Actor (or group it is member of, e.g. Nationality)
2	FR15_influenced_by	Thing's production was influ-enced/motivated by Actor (or group it is member of). E.g.: Manner/ School/ Style of; or Issuer, Ruler, Magistrate who authorised, patronised, ordered the produc-tion.
3	FR52_current_owner_keeper	Thing has current owner or keeper Actor
4	FR51_former_or_current_owner_keeper	Thing has former or current owner or keeper Actor, or ownership/custody was transferred from/to actor in Acquisition/Transfer of Custody event
5	FR67_about_actor	Thing depicts or refers to Actor, or carries an information object that is about Actor, or bears similarity with a thing that is about Actor
6	FR12_has_met	Thing (or another thing it is part of) has met actor in the same event (or event that is part of it)
7	FR67_about_period	Thing depicts or refers to Event/Period, or carries an information object that is about Event, or bears similarity with a thing that is about Event
8	FR12_was_present_at	Thing was present at Event (eg exhi-bition) or is from Period
9	FR92i_created_in	Thing (or part/inscription thereof) created or modified/repaired at/in place (or a broader containing place)
10	FR55_located_in	Thing has current or permanent location in Place (or a broader containing place)
11	FR12_found_at	Thing was found (discovered, excavated) at Place (or a broader containing place)
12	FR7_from_place	Thing has former, current or permanent location at place, or was created/found at place, or moved to/from place, or changed ownership/custody at place (or a broader containing place)
13	FR67_about_place	Thing depicts or refers to a place or fea-ture located in place, or is similar in features or composed of or carries an infor-mation object that depicts or refers to a place
14	FR2_has_type	Thing is of Type, or has Shape, or is of Kind, or is about or depicts a type (e.g. IconClass or subject heading)
15	FR45_is_made_of	Thing (or part thereof) consists of ma-terial
16	FR32_used_technique	The production of Thing (or part thereof) used general technique
17	luc:myIndex	The full text of the thing's description (including the-saurus terms and textual descriptions) matches the given keyword. FTS using Lucene built into OWLIM.
18	FR108i_82_produced_within	Thing was created within an interval that intersects the given interval or year.
19	FR1_identified_by	Thing (or part thereof) has Identifier. Exact-match string
20	FR138i_has_representation	Thing has at least one image repre-sentation. Used to select objects that have images
21	FR138i_representation	Thing has image representation. Used to fetch all images of an object
22	FR_main_representation	Thing has main image representation. Used to display object thumbnail in search results
23	FR_dataset	Thing belongs to indicated dataset. Used for faceting by dataset

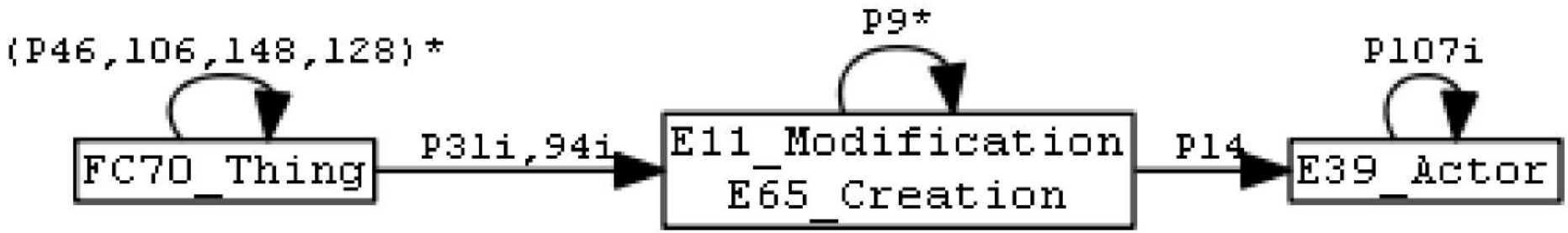
OWLIM Rules

- OWLIM reasoning features:
  - OWLIM's rule-language provides and extension for RDFS-entailment
  - Essentially, simplified DataLog, as found in RDFS and OWL 2 RL specs
  - The predefine rule-sets support: RDFS, OWL Horst, OWL RL and QL
  - Fully-materializing forward-chaining reasoning. Rule consequences are stored in the repository and query answering is very fast

- **120 OWLIM Rules** to implement 23 FRs:
  - 14 rules implement RDFS reasoning, owl:TransitiveProperty, owl:inverseOf (OWL) and ptop:transitiveOver (PROTON)
  - 106 rules implement FRs. Used a method of decomposing an FR to sub-FR : conjunctive (e.g. checking the type of a node), disjunctive (parallel), serial (property path), transitive

Example: FR92i_created_by

- Thing created by Actor
  - Thing (or part/inscription thereof) was created or modified/repaired by Actor (or a group it is a member of)



- Source properties:
  - P46_is_composed_of, P106_is_composed_of, P148_has_component
  - P128_carries: to transition from object to Inscription carried by it
  - P31i_was_modified_by (includes P108i_was_produced_by), P94i_was_created_ by
  - P9_consists_of: navigates event part hierarchy
  - P14_carried_out_by, P107i_is_current_or_former_member_of (agent-groups)
- Sub-FRs
  - FRT_46_106_148_128 := (P46|P106|P148|P128)+
  - FRX92i_created := (FC70_Thing) FRT_46_106_148_128* / (P31i | P94i) / P9*
  - FR92i_created_by := FRX92i_created / P14 / P107i*

Rules for FR92i_created_by

- Use a simple shortcut notation
  - Script translates ";" to newline and "=>" to "---------"
  - Also weaves from wiki
  - Checks variable linearity
  - Generates dependency graph (see next)
- 10 rules for FRT_46_106_148_128
- 7 rules for FR92i_created_by:

```
x <rdf:type> <rso:FC70_Thing>; x <crm:P31i_was_modified_by> y => x <rso:FRX92i_created> y
x <rdf:type> <rso:FC70_Thing>; x <crm:P94i_was_created_by>  y => x <rso:FRX92i_created> y
x <rso:FRT_46_106_148_128> y; y <crm:P31i_was_modified_by> z => x <rso:FRX92i_created> z
x <rso:FRT_46_106_148_128> y; y <crm:P94i_was_created_by>  z => x <rso:FRX92i_created> z
x <rso:FRX92i_created> y; y <crm:P9_consists_of> z => x <rso:FRX92i_created> z
x <rso:FRX92i_created> y; y <crm:P14_carried_out_by> z => x <rso:FR92i_created_by> z
x <rso:FRX92i_created> y; y <crm:P14_carried_out_by> z; z <rso:FRT107i_member_of> t
    => x <rso:FR92i_created_by> t
```


crm:P2_has_type
crm:E55_Type
rso:FRX2_has_type
rso:FR2 has type
crm:P127 has broader term
crm:P54_has_current_permanent_location
rso:FR55_located_i
crm:P55_has_current_location
crm:P10_falls_within
crm:P89 falls within
rso:FRT9i 10
crm:P9i forms part of
crm:P128_carries
rso:FRT_46_106_148_128
rso:FR12_was_present_at
rso:FR12 found at
rso:FR92i_created_i
crm:P12i_was_present_at
crm:P7_took_place_at
rso:FRX7_from_plac
bmo:EX Discovery
rso:FR12_found_by
crm:P25i moved by
crm:P30i_custody_transferred_through
rso:FRX24i_25i_30i
rso:FRX24i_30i
crm:P126_employed
rso:FC70_Thing
crm:P24i_changed_ownership_through
crm:P9_consists_of
crm:P45 consists of
rso:FR45 is made o
crm:P106_is_composed_of
rso:FR1 identified by
crm:P148 has component
rso:FRT 46 106 148
crm:E39_Actor
crm:P46_is_composed_of
crm:P3_has_note
crm:P22_transferred_title_to
rso:FR12X
crm:P23_transferred_title_from
rso:FR12 has met
rdfs:label
crm:P28 custody surrendered by
rso:FR51 former or current owner keeper
crm:P1 is identified by
crm:P29_custody_received_by
crm:P12_occurred_in_the_presence_of
crm:P49_has_former_or_current_keeper
crm:P14_carried_out_by
crm:P51 has former or current owner
rso:FRT107i member of
rso:FR92i created b
crm:P107i_is_current_or_former_member_of

Volumetrics

- Museum objects: **2,051,797** (most from the BM)
- Thesaurus entries: **415,509** (skos:Concept)
  - All kinds of "fixed" values that are used for search: object types, materials, techniques, people, places (a total of 90 ConceptSchemes)
- Explicit statements: **195,208,156**
  - 185M are for objects (90 statements/object)
  - 9M are for thesaurus entries (22 statements/term)
- Total statements: **916,735,486**
  - Expansion ratio is 4.7x
  - I.e. for each statement, 3.7 more are inferred
- Nodes (URLs and literals): **53,803,189**

Volumetrics (2)

- Repository size: 42 Gb
  - Object full-text index: 2.5 Gb, thesaurus full-text index (used for search auto-complete): 22Mb.
- Loading time (including all inferencing):
  - 22.2h on RAM drive
  - 32.9h on hard-disks

Complexity: Classes (Type statements)

Class	Statement
owl:Thing	36,485,904
E1_CRM_Entity	36,485,903
E77_Persistent_Item	17,408,450
E70_Thing	17,339,714
E71_Man-Made_Thing	17,216,212
E72_Legal_Object	17,192,518
E28_Conceptual_Object	14,776,488
E90_Symbolic_Object	14,629,292
E2_Temporal_Entity	11,924,877
E4_Period	11,924,877
E5_Event	11,922,986
E7_Activity	11,796,470
E63_Beginning_of_Existence	6,377,421
E11_Modification	6,296,015
E12_Production	6,295,825
rso:FC70_Thing	2,051,797
skos:Concept	415,509
Total	**302,149,587**

Lawyers of the world, rejoice!

museum objects

Terms, people, places, materials, techniques..

- 238 classes, some of the top are summarizes in the table
- Hierarchy is 10 levels deep : E1>E77>E70>E71>E28>E90>E73>E36>E37>E34
- For each Inscription, 12 type statements are inferred
- Each E12 also repeated as E63_Beginning_of_Existence ; plus 100k Birth and Formation
- Each E7 repeated as E5_Event, which is repeated as E4_Period (plus 19k historic Periods) and E2_Temporal_Entity

Complexity: Properties

Properties	Statements	Percent
rdf:type	302,149,587	37.50%
Objects: CRM, rdfs:label	365,430,152	45.35%
Extensions: BMO, RSO	35,903,831	4.46%
FRs (70M=9%) and sub-FRs (26M=3%)	**96,526,377**	11.98%
Thesauri: BIBO, DC, DCT, FOAF, SKOS, QUDT, VAEM	5,715,250	0.71%
Ontology: RDF, RDFS, OWL	4,159	0.00%
Total	**805,729,356**	**100.00%**
Of which CRM inverses	149,465,596	18.55%

- Total 339 properties, grouped above
- Type statements take 37%: too much (see prev slides)
- Inverses (79) are convenient, but take 18% (duplicates)
- Objects take the majority: 45%
- FRs take only 12%, which doesn't slow OWLIM perceptibly

Comparison to Other Repositories

Repo	Objects	Explicit statements	Expl.st./ Object	Total statements	Expan-sion	Nodes	Density (st/node)	Reasoning
CRM	2.0 1.0	195 1.0	90 1.0	916 1.0	4.7 1.0	54 1.0	17.0 1.0	rdfs+tran+FR
PSNC	3.1 1.5	234 1.2	75 0.83	535 0.58	2.3 0.49	60 1.1	8.9 0.5	rdfs-subClass
EDM	20.3 9.8	998 5.1	50 0.56	3,798 4.1	3.8 0.8	266 4.9	14.3 0.8	owl-horst
FF		1,673 8.6		3,211 3.5	1.9 0.4	456 8.4	7.0 0.4	owl-horst
LLD		6,706 34		10,192 11	1.5 0.3	1554 29	6.6 0.4	rdfs+tran

- **Repositories:**
  - ResearchSpace CRM: http://test.researchspace.org:8081
  - PSNC Polish Digital Library: http://dl.psnc.pl
  - Europeana EDM: http://europeana.ontotext.com
  - FactForge: http://www.factforge.net
  - LinkedLifeData: http://linkedlifedata.com
- **First** column is Million triples, **second** column is ratio to CRM
- **Expansion**=Total statements/Explicit statements: intensity of inference
- **Density**=Statements/Nodes: relative density of the graph

Performance: SPARQL Implementation

- Straight SPARQL 1.1 implementation for "FR92i_created_by rkd-artist:Rembrandt":

```
select distinct ?obj {
  ?obj a rso:FC70_Thing;
    (crm:P46_is_composed_of|crm:P106_is_composed_of|crm:P148_has_component|crm:P128_carries)*/
    (crm:P31i_was_modified_by|crm:P94i_was_created_by) / crm:P9_consists_of* /
     crm:P14_carried_out_by / crm:P107i_is_current_or_former_member_of*
  rkd-artist:Rembrandt
} limit 20
```

- RS endpoint takes over 15 minutes to answer. If you add more FRs, even worse. The reflexive * really kills it
- The query can be optimized a bit by using intermediate variables instead of property paths, but the performance is still untenable

Performance: forward-chaining

- Objects by Rembrandt: sub-second response time:

```
select distinct ?obj {?obj rso:FR92i_created_by rkd-artist:Rembrandt} limit 500
```

- **Drawings** by Rembrandt about **mammals**: still sub-second response time, and the query is simple

```
select distinct ?obj {
    ?obj rso:FR92i_created_by rkd-artist:Rembrandt;
        rso:FR2_has_type thes:x6544, thes:x12965} limit 500
```

- RS search takes 4.5s because after obtaining up to 500 objects, it executes several more queries to fetch their display fields, facets, and images
  - Facets are loaded into the browser using Exhibit, so subsequent facet restrictions are immediate

Summary

- Cultural Heritage is an early adopter of RDF/OWL
- There are number of mature ontologies, e.g. CRM
- Plenty of real-world data available, e.g. in Europeana
- How it is different from Publishing:
  - More static data, more complex and extensive data modeling
  - More in-depth queries and complication relationships
- Reasoning adds value
  - Because doing the same in SPARQL is too expensive
- Understandable
  - Queries and results are easy to make sense of
  - That's not the case, say, with biomedical data

Thanks for listening!

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