

RDF processing for Bioconductor: *Rredland*

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1 Introduction

Resource Description Framework (RDF) is a graphical model for information. RDF statements are ordered triples of the form (subject, predicate, object). Subjects and objects are viewed as nodes in a directed graph, and predicates are viewed as arcs in the graph. RDF is a key component of current developments towards a semantic web, with considerable work completed on web resource metadata representation and exchange using RDF. A richer metadata model is provided by OWL (Web Ontology Language), but most OWL models are serialized using XML/RDF. Thus, as we will illustrate, various public OWL resources can be processed by this package.

Redland is the name of an open source software project downloadable from librdf.org. Redland is a C language library with bindings provided to a variety of other languages. Redland is highly modular, and allows developers to drop in components to substitute for base functionalities. Because metadata resources can be very voluminous, such flexibility is important. A solution to the problem of persistent storage of indexed metadata is provided through the use of BerkeleyDB serializations of Redland models.

Rredland is an R package that provides interfaces to facilities of Redland. Configuration support is currently limited. You will be able to use Rredland if you do a stock

installation of librdf and BerkeleyDB. If you have these resources in nonstandard locations, you can set the Makevars variables in `src` to reflect your configuration. You may need to set `LD_LIBRARY_PATH`.

2 Illustration

2.1 Simple manipulations with a fragment of GO

Eric Jain of ISB-CH has provided an RDF serialization of the UniProt database and associated annotation resources, including an RDF serialization of GO. A fragment of this serialization is distributed with the *Rredland* package.

```
> library(Rredland)
```

A redland RDF world has been created in package:Rredland as `..GredlWorld`.

```
> gofrag <- system.file("RDF/gopart.rdf", package = "Rredland")
```

Here we dump the first 10 lines of this document as text:

```
> readLines(gofrag, n = 10)
```

```
[1] "<?xml version='1.0' encoding='UTF-8'?>"
[2] "<rdf:RDF xmlns=\"urn:lsid:uniprot.org:ontology:\" xmlns:rdf=\"http://www.w3.org/1
[3] "<rdf:Description rdf:about=\"urn:lsid:uniprot.org:go:0000001\">"
[4] "<rdf:type rdf:resource=\"urn:lsid:uniprot.org:ontology:Concept\"/>"
[5] "<rdfs:label>mitochondrion inheritance</rdfs:label>"
[6] "<rdfs:comment>The distribution of mitochondria, including the mitochondrial genom
[7] "<rdfs:subClassOf rdf:resource=\"urn:lsid:uniprot.org:go:0048308\"/>"
[8] "<rdfs:subClassOf rdf:resource=\"urn:lsid:uniprot.org:go:0048311\"/>"
[9] "</rdf:Description>"
[10] "<rdf:Description rdf:about=\"urn:lsid:uniprot.org:go:0000002\">"
```

This could be processed as an XML document, but let's use Redlands modeling facilities. First we need to set up a URI object for the model source document.

```
> gouri <- makeRedlURI(paste("file:", gofrag, sep = ""))
```

Now we read from this document. We will set the `useCore` option to use in-memory storage.

```
> gof <- readRDF(gouri)
> gof
```

redlModel object, status=open.

We are handed back an S4 object of class *redlModel*.

```
> getClass("redlModel")
```

Slots:

```
Name:          ref storagetype  stateEnv      world
Class: externalptr character environment redlWorld
```

We need to use the `model` accessor to get to the model reference.

We can easily compute the number of statements (also computed with `show()`):

```
> size(gof)
```

```
[1] 69
```

We can also transform to a data frame:

```
> godf <- as(gof, "data.frame")
> godf[1:4, ]
```

```
              subject
1 urn:lsid:uniprot.org:go:0000001
2 urn:lsid:uniprot.org:go:0000001
3 urn:lsid:uniprot.org:go:0000001
4 urn:lsid:uniprot.org:go:0000001
              predicate
1 http://www.w3.org/1999/02/22-rdf-syntax-ns#type
2   http://www.w3.org/2000/01/rdf-schema#label
3   http://www.w3.org/2000/01/rdf-schema#comment
4 http://www.w3.org/2000/01/rdf-schema#subClassOf

1
2
3 "The distribution of mitochondria, including the mitochondrial genome, into daughter
4
```

We see that long text strings can cause a problem for rendering.

```
> as.character(godf[1:4, 3])
```

```
[1] "urn:lsid:uniprot.org:ontology:Concept"
[2] "\"mitochondrion inheritance\""
[3] "\"The distribution of mitochondria, including the mitochondrial genome, into daughter
[4] "urn:lsid:uniprot.org:go:0048308"
```

The data frame representation is useful for splitting up the statement set.

```
> bypred <- split(godf, as.character(godf$predicate))
> names(bypred)
```

```
[1] "http://www.w3.org/1999/02/22-rdf-syntax-ns#type"
[2] "http://www.w3.org/2000/01/rdf-schema#comment"
[3] "http://www.w3.org/2000/01/rdf-schema#label"
[4] "http://www.w3.org/2000/01/rdf-schema#subClassOf"
[5] "urn:lsid:uniprot.org:ontology:obsolete"
```

```
> sapply(bypred, nrow)
```

```
http://www.w3.org/1999/02/22-rdf-syntax-ns#type
                                     16
  http://www.w3.org/2000/01/rdf-schema#comment
                                     15
    http://www.w3.org/2000/01/rdf-schema#label
                                     19
http://www.w3.org/2000/01/rdf-schema#subClassOf
                                     17
      urn:lsid:uniprot.org:ontology:obsolete
                                     2
```

The subClassOf predicate helps determine the DAG structure:

```
> bypred$"http://www.w3.org/2000/01/rdf-schema#subClassOf"[, -2]
```

	subject	object
4	urn:lsid:uniprot.org:go:0000001	urn:lsid:uniprot.org:go:0048308
5	urn:lsid:uniprot.org:go:0000001	urn:lsid:uniprot.org:go:0048311
9	urn:lsid:uniprot.org:go:0000002	urn:lsid:uniprot.org:go:0007005
14	urn:lsid:uniprot.org:go:0000003	urn:lsid:uniprot.org:go:0008150
18	urn:lsid:uniprot.org:go:0000004	urn:lsid:uniprot.org:go:0008150
26	urn:lsid:uniprot.org:go:0000006	urn:lsid:uniprot.org:go:0005385
29	urn:lsid:uniprot.org:go:0000007	urn:lsid:uniprot.org:go:0005385
38	urn:lsid:uniprot.org:go:0000009	urn:lsid:uniprot.org:go:0000030
42	urn:lsid:uniprot.org:go:0000010	urn:lsid:uniprot.org:go:0016765
46	urn:lsid:uniprot.org:go:0000011	urn:lsid:uniprot.org:go:0007033
47	urn:lsid:uniprot.org:go:0000011	urn:lsid:uniprot.org:go:0048308
51	urn:lsid:uniprot.org:go:0000012	urn:lsid:uniprot.org:go:0006281
55	urn:lsid:uniprot.org:go:0000014	urn:lsid:uniprot.org:go:0004520
60	urn:lsid:uniprot.org:go:0000015	urn:lsid:uniprot.org:go:0005829
61	urn:lsid:uniprot.org:go:0000015	urn:lsid:uniprot.org:go:0043234
65	urn:lsid:uniprot.org:go:0000016	urn:lsid:uniprot.org:go:0004553
69	urn:lsid:uniprot.org:go:0000017	urn:lsid:uniprot.org:go:0042946

2.2 BioPAX Level 1

The BioPAX pathway ontologies are available.

```
> bp1 <- makeRedLURI(paste("file:", system.file("RDF/biopax-level1.owl",
+   package = "Rredland"), sep = ""))
> bp1m <- readRDF(bp1)
> size(bp1m)
```

```
[1] 630
```

This is a manageable object, so we convert to data frame:

```
> bp1df <- as(bp1m, "data.frame")
> sapply(bp1df[1:5, ], substring, 1, 70)
```

```
      subject
[1,] "http://www.biopax.org/release/biopax-level1.owl"
[2,] "http://www.biopax.org/release/biopax-level1.owl"
[3,] "http://www.biopax.org/release/biopax-level1.owl#physicalEntityParticip"
[4,] "http://www.biopax.org/release/biopax-level1.owl#chemicalStructure"
[5,] "http://www.biopax.org/release/biopax-level1.owl#physicalEntityParticip"
      predicate
[1,] "http://www.w3.org/1999/02/22-rdf-syntax-ns#type"
[2,] "http://www.w3.org/2000/01/rdf-schema#comment"
[3,] "http://www.w3.org/1999/02/22-rdf-syntax-ns#type"
[4,] "http://www.w3.org/1999/02/22-rdf-syntax-ns#type"
[5,] "http://www.w3.org/2002/07/owl#disjointWith"
      object
[1,] "http://www.w3.org/2002/07/owl#Ontology"
[2,] "\"This is version 1.4 of the BioPAX Level 1 ontology.  The goal of the "
[3,] "http://www.w3.org/2002/07/owl#Class"
[4,] "http://www.w3.org/2002/07/owl#Class"
[5,] "http://www.biopax.org/release/biopax-level1.owl#chemicalStructure"
```

The namespace qualifications make the strings difficult to render. A simple approach uses substitution up to the pound sign, preceded by eliminating any XSD postfix information.

```
> strip2pound <- function(x) gsub(".*#", "", cleanXSDT(as.character(x)))
> sapply(bp1df[1:5, ], strip2pound)
```

```
      subject                                predicate
[1,] "http://www.biopax.org/release/biopax-level1.owl" "type"
[2,] "http://www.biopax.org/release/biopax-level1.owl" "comment"
```

```

[3,] "physicalEntityParticipant"      "type"
[4,] "chemicalStructure"             "type"
[5,] "physicalEntityParticipant"      "disjointWith"
      object
[1,] "Ontology"
[2,] "\"This is version 1.4 of the BioPAX Level 1 ontology. The goal of the BioPAX gro
[3,] "Class"
[4,] "Class"
[5,] "chemicalStructure"

```

Working with a data frame, it is easy to filter statements of interest. Suppose we wish to determine all the instances of `owl#Class` in the model.

```

> isTypeOwlClass <- grep("owl#Class", as.character(bp1df[, 3]))
> strip2pound(bp1df[isTypeOwlClass, 1])

```

```

[1] "physicalEntityParticipant"      "chemicalStructure"
[3] "openControlledVocabulary"       "dataSource"
[5] "xref"                            "pathwayStep"
[7] "bioSource"                       "utilityClass"
[9] "rna"                              "physicalEntity"
[11] "smallMolecule"                 "complex"
[13] "protein"                         "relationshipXref"
[15] "unificationXref"                "publicationXref"
[17] "control"                         "conversion"
[19] "interaction"                     "entity"
[21] "complexAssembly"                "biochemicalReaction"
[23] "transport"                       "(r1159910716r13)"
[25] "pathway"                         "modulation"
[27] "catalysis"                       "transportWithBiochemicalReaction"
[29] "(r1159910716r44)"               "(r1159910716r47)"
[31] "(r1159910716r50)"               "(r1159910716r53)"
[33] "(r1159910716r58)"               "(r1159910716r61)"
[35] "(r1159910716r65)"               "(r1159910716r68)"

```

We see a number of decipherable terms, and some tokens of the form (rnnn...). The latter are called blank nodes. These are created to define classes that have no names, but that are implicitly defined in the model. For example, a class that is the union of `entity` and `physicalEntity` is a blank node in this model.

To get the detailed commentary on a class definition, the following function can be used:

```

> getClassComment <- function(term, df, nsPref = "http://www.biopax.org/release/biopa
+   commPred = "http://www.w3.org/2000/01/rdf-schema#comment",

```

```

+   doChop = TRUE, nword = 12) {
+   ind <- which(as.character(df[, 1]) == paste(nsPref, term,
+       sep = "") & as.character(df[, 2]) == commPred)
+   chopLong(cleanXSDT(as.character(bp1df[ind, 3])), nword = nword)
+ }
> cat(getClassComment("chemicalStructure", bp1df))

```

"A utility class that defines a small molecule structure. An instance of this class can also define additional information about a small molecule, such as its chemical formula, names, and synonyms. This information is stored in the slot STRUCTURE-DATA, in one of two formats: the CML format (see URL www.xml-cml.org) or the SMILES format (see URL www.daylight.com/dayhtml/smiles) slot specifies which format used is used. An example is the following SMILES string, which describes the structure of glucose-6-phosphate:

```
'C(OP(=O)(O)O)CH1(CH(O)CH(O)CH(O)CH(O)O1)'.
```

```
> cat(getClassComment("biochemicalReaction", bp1df))
```

"A conversion interaction in which one or more entities (substrates) undergo covalent changes to become one or more other entities (products). The substrates of biochemical reactions are defined in terms of sums of species. This is what is typically done in biochemistry, and, in principle, all of the EC reactions should be biochemical reactions.

Example: ATP + H₂O =
ADP + Pi.

In this reaction, ATP is considered to be an equilibrium mixture of several species, namely ATP⁴⁻, HATP³⁻, H₂ATP²⁻, MgATP²⁻, MgHATP⁻, and Mg₂ATP⁺. Additional species may also need to be considered if other ions (e.g. Ca²⁺) that bind ATP are present. Similar considerations apply to ADP and to inorganic phosphate (Pi). When writing biochemical reactions, it is important not to attach charges to the biochemical reactants and not to include ions such as H⁺ and Mg²⁺ in the equation. The reaction is written in the direction specified by the EC nomenclature system, if applicable, regardless of the physiological direction(s) in which the reaction proceeds. (This definition from EcoCyc)

NOTE: Polymerization reactions involving large polymers whose structure is not explicit should generally be represented as unbalanced reactions in which the monomer is consumed but the polymer remains unchanged, e.g. glycogen + glucose = glycogen."

2.3 BioPAX level 2

Here we check the classes available in BioPAX level 2.

```
> bp2 <- makeRedlURI(paste("file:", system.file("RDF/biopax-level2.owl",
+   package = "Rredland"), sep = ""))
> bp2m <- readRDF(bp2)
> size(bp2m)
```

```
[1] 910
```

```
> bp2df <- as(bp2m, "data.frame")
> isTypeOwlClass <- grep("owl#Class", as.character(bp2df[, 3]))
> strip2pound(bp2df[isTypeOwlClass, 1])
```

```
[1] "dataSource"           "openControlledVocabulary"
[3] "xref"                 "bioSource"
[5] "externalReferenceUtilityClass" "dnaParticipant"
[7] "rnaParticipant"      "dna"
[9] "physicalEntityParticipant" "proteinParticipant"
[11] "complexParticipant"  "smallMoleculeParticipant"
[13] "transportWithBiochemicalReaction" "biochemicalReaction"
[15] "transport"           "complexAssembly"
[17] "conversion"          "physicalEntity"
[19] "interaction"         "entity"
[21] "pathway"             "unificationXref"
[23] "relationshipXref"    "publicationXref"
[25] "physicalInteraction" "smallMolecule"
[27] "protein"             "rna"
[29] "complex"             "sequenceLocation"
[31] "confidence"          "evidence"
[33] "chemicalStructure"   "utilityClass"
[35] "pathwayStep"         "sequenceInterval"
[37] "sequenceSite"        "sequenceFeature"
[39] "modulation"          "catalysis"
[41] "control"             "experimentalForm"
[43] "(r1159910716r141)"   "(r1159910716r156)"
[45] "(r1159910716r159)"   "(r1159910716r166)"
[47] "(r1159910716r170)"   "(r1159910716r173)"
[49] "(r1159910716r176)"   "(r1159910716r182)"
[51] "(r1159910716r186)"   "(r1159910716r189)"
[53] "(r1159910716r201)"   "(r1159910716r204)"
[55] "(r1159910716r207)"   "(r1159910716r211)"
```


2.4 HumanCyc

The BioCyc project (www.biocyc.org) is a collection of pathway/genome databases in a variety of structures. The data resources are available to academic researchers, and a registration/download process must be completed for access. We illustrate use of *Rredland* to work with the BioPAX encoding of HumanCyc. This is 19MB of RDF and an in-core storage model is not likely to be satisfactory. We will use the default BerkeleyDB storage approach.

```
> humu <- makeRedlURI(paste("file:", "humancyc.owl", sep = ""))
> humm <- readRDF(humu, storageType = "bdb", storageName = "hucyc")
```

Note that the vignette cannot assume that you have this OWL file. After the above commands, we have

```
-rw-r--r--  1 stvjc  stvjc  59723776 Jul 28 13:09 test-sp2o.db
-rw-r--r--  1 stvjc  stvjc  39538688 Jul 28 13:07 test-po2s.db
-rw-r--r--  1 stvjc  stvjc  57499648 Jul 28 13:07 test-so2p.db
```

These are the BerkeleyDB hashes representing aspects of the graph.

It is not too difficult to transform into a data frame.

```
> hudf <- as(humm, "data.frame")
> husubs <- as.character(hudf[, 1])
> hupreds <- as.character(hudf[, 2])
> huobs <- as.character(hudf[, 3])
> table(hupreds)
```

hupreds

```
http://www.biopax.org/release/biopax-level1.owl#AUTHORS
31432
http://www.biopax.org/release/biopax-level1.owl#CELLULAR-LOCATION
2800
http://www.biopax.org/release/biopax-level1.owl#COFACTOR
11
http://www.biopax.org/release/biopax-level1.owl#COMMENT
1231
http://www.biopax.org/release/biopax-level1.owl#COMPONENTS
36
http://www.biopax.org/release/biopax-level1.owl#CONTROL-TYPE
36
http://www.biopax.org/release/biopax-level1.owl#CONTROLLED
2216
http://www.biopax.org/release/biopax-level1.owl#CONTROLLER
```

<http://www.biopax.org/release/biopax-level1.owl#DATA-SOURCE> 2216
 167
<http://www.biopax.org/release/biopax-level1.owl#DB> 12251
<http://www.biopax.org/release/biopax-level1.owl#DELTA-G> 23
<http://www.biopax.org/release/biopax-level1.owl#EC-NUMBER> 872
<http://www.biopax.org/release/biopax-level1.owl#ID> 12251
<http://www.biopax.org/release/biopax-level1.owl#LEFT> 1968
<http://www.biopax.org/release/biopax-level1.owl#MOLECULAR-WEIGHT> 666
<http://www.biopax.org/release/biopax-level1.owl#NAME> 6046
<http://www.biopax.org/release/biopax-level1.owl#NEXT-STEP> 895
<http://www.biopax.org/release/biopax-level1.owl#ORGANISM> 1730
<http://www.biopax.org/release/biopax-level1.owl#PATHWAY-COMPONENTS> 1049
<http://www.biopax.org/release/biopax-level1.owl#PHYSICAL-ENTITY> 2800
<http://www.biopax.org/release/biopax-level1.owl#RIGHT> 2020
<http://www.biopax.org/release/biopax-level1.owl#SEQUENCE> 12
<http://www.biopax.org/release/biopax-level1.owl#SOURCE> 5534
<http://www.biopax.org/release/biopax-level1.owl#SPONTANEOUS> 3
<http://www.biopax.org/release/biopax-level1.owl#STEP-INTERACTIONS> 2869
<http://www.biopax.org/release/biopax-level1.owl#STOICHIOMETRIC-COEFFICIENT> 2783
<http://www.biopax.org/release/biopax-level1.owl#STRUCTURE> 776
<http://www.biopax.org/release/biopax-level1.owl#STRUCTURE-DATA> 776
<http://www.biopax.org/release/biopax-level1.owl#STRUCTURE-FORMAT>

```

776
http://www.biopax.org/release/biopax-level1.owl#SYNONYMS
10032
http://www.biopax.org/release/biopax-level1.owl#TAXON-XREF
1
http://www.biopax.org/release/biopax-level1.owl#TERM
10
http://www.biopax.org/release/biopax-level1.owl#TITLE
5534
http://www.biopax.org/release/biopax-level1.owl#XREF
13605
http://www.biopax.org/release/biopax-level1.owl#YEAR
5460
http://www.w3.org/1999/02/22-rdf-syntax-ns#type
22984
http://www.w3.org/2000/01/rdf-schema#comment
1

```

To find the named pathways,

```

> isPw <- grep("pathway", husubs)
> isNa <- grep("NAME", hupreds)
> isnp <- intersect(isPw, isNa)
> cleanXSDT(huobs[isnp][1:10])

```

```

[1] "\"biosynthesis of aspartate and asparagine; interconversion of aspartate and aspa
[2] "\"serine and glycine biosynthesis\""
[3] "\"alanine biosynthesis II\""
[4] "\"alanine biosynthesis I\""
[5] "\"alanine biosynthesis III\""
[6] "\"superpathway of alanine biosynthesis\""
[7] "\"arginine biosynthesis III\""
[8] "\"citrulline biosynthesis\""
[9] "\"asparagine biosynthesis I\""
[10] "\"aspartate biosynthesis and degradation\""

```

So we see in the predicate set what kinds of relationships are described, and we get a glimpse of the pathway names addressed in this resource.

Note that there is no need to parse the data once the Berkeley DB hashes are made available. The `BDBSexists` option on `readRedlModel` can be used to revive a model-hash association.

3 Future work

We will need to take unions of RDF models and C code will be required for that. We need R interfaces to Redland approaches to model filtering. Some graph/set-theoretic activities can be introduced to bring some RDF/RDFS inferencing in.