Semantic Web and Semantic Audio technologies

Tutorial by

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Queen Mary University of London

School of Electronic Engineering and Computer Science

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Budapest, Hungary

We are on the Web

- Slides, examples and other resources are available at:

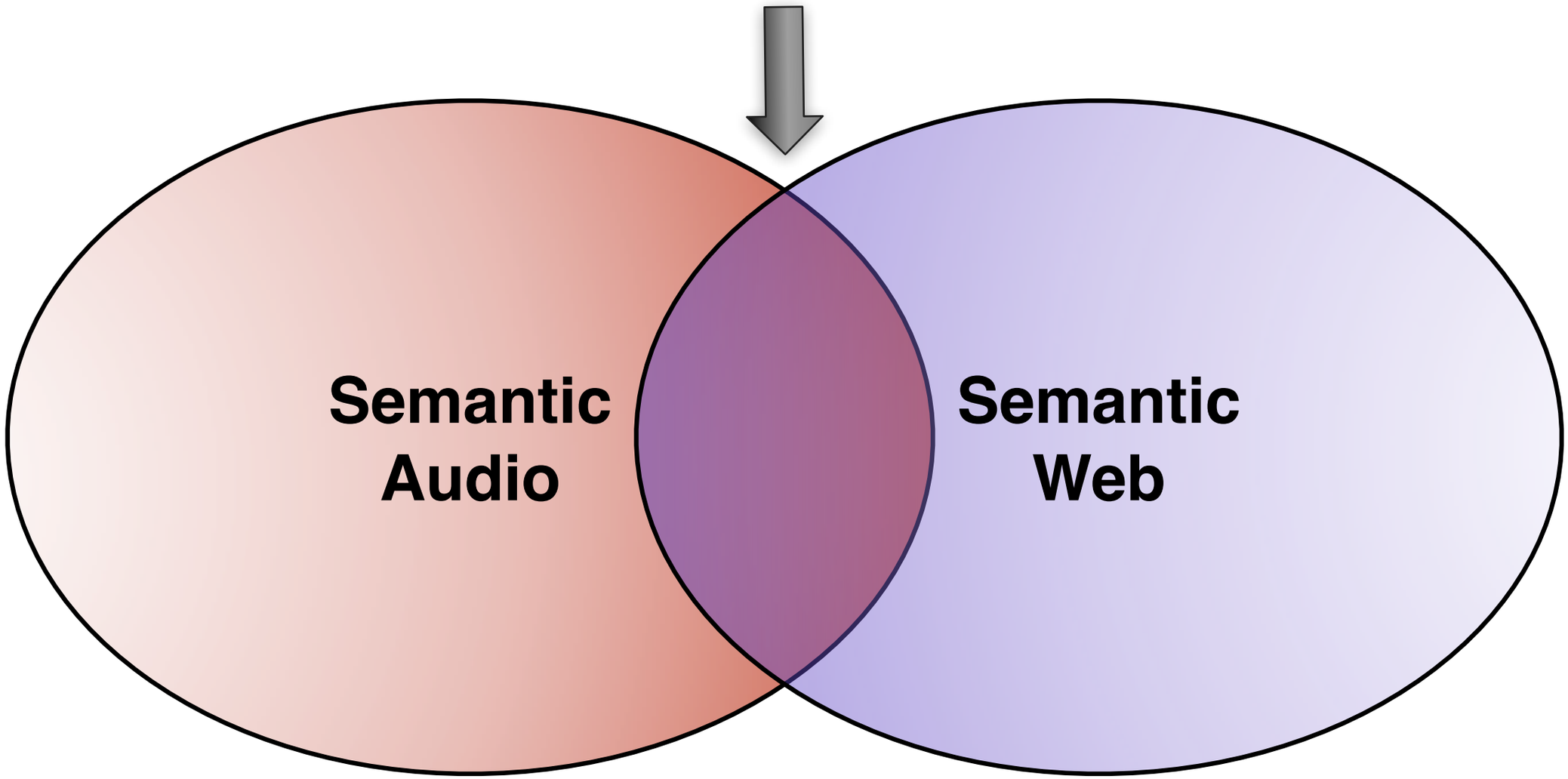
- **www.isophonics.net/content/aes132-tutorial**

Outline

- Introduction and Motivations
- Semantic Web Technologies
- Semantic Web Applications
  - Short Hands on Session (1)
- Music Ontology
- Studio Ontology
- Semantic Audio Tools
  - Short Hands on Session (2)
- Semantic Audio in Music Production

Introduction

- The focus of this tutorial is the intersection of the two fields



Introduction

- What is Semantic Audio ?

- What is the Semantic Web ?

- How are they related,
- and why should we care?

Introduction

- **What is Semantic Audio ?**
  - a confluence of technologies for
  - **interacting with audio** in human terms
- **Semantic Audio technologies include:**
  - Audio content analysis
    - e.g. Digital Signal Processing and Machine Learning
  - Information Management
  - Knowledge Representation
    - e.g. Logic, Ontologies, and database technologies

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- (1) a diverse network of **interconnected data and services**
- in principle, it is similar to how documents are linked using hypertext
- (2) a machine-interpretable representation of the World Wide Web

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Introduction

- **What is the Semantic Web ?**

- **The objective is:**

- Enable machines to complete complex (search) tasks currently requiring human-level intelligence

Motivations

- **How Semantic Audio and the Semantic Web are related?**

- A proliferation of music content on the Web requires Semantic Audio technologies for better access to this content.

Motivations

- **How Semantic Audio and the Semantic Web are related?**

- Semantic Web technologies enable better representation and access to music related information.

Motivations

- **Why should we care?**

- Music Information Retrieval:

  - Find me upbeat and catchy songs between 130-140 bpm, performed by artists collaborating in the London-Shoreditch area, and sort them by musical key.

Motivations

- **Why should we care?**

- Music production:

  - Find me guitar riffs in all my recording projects where an echo and compressor were applied with the given parameters.

Motivations

- **Why should we care?**

- These queries/applications require clever
  - content analysis
  - knowledge representation
  - information management

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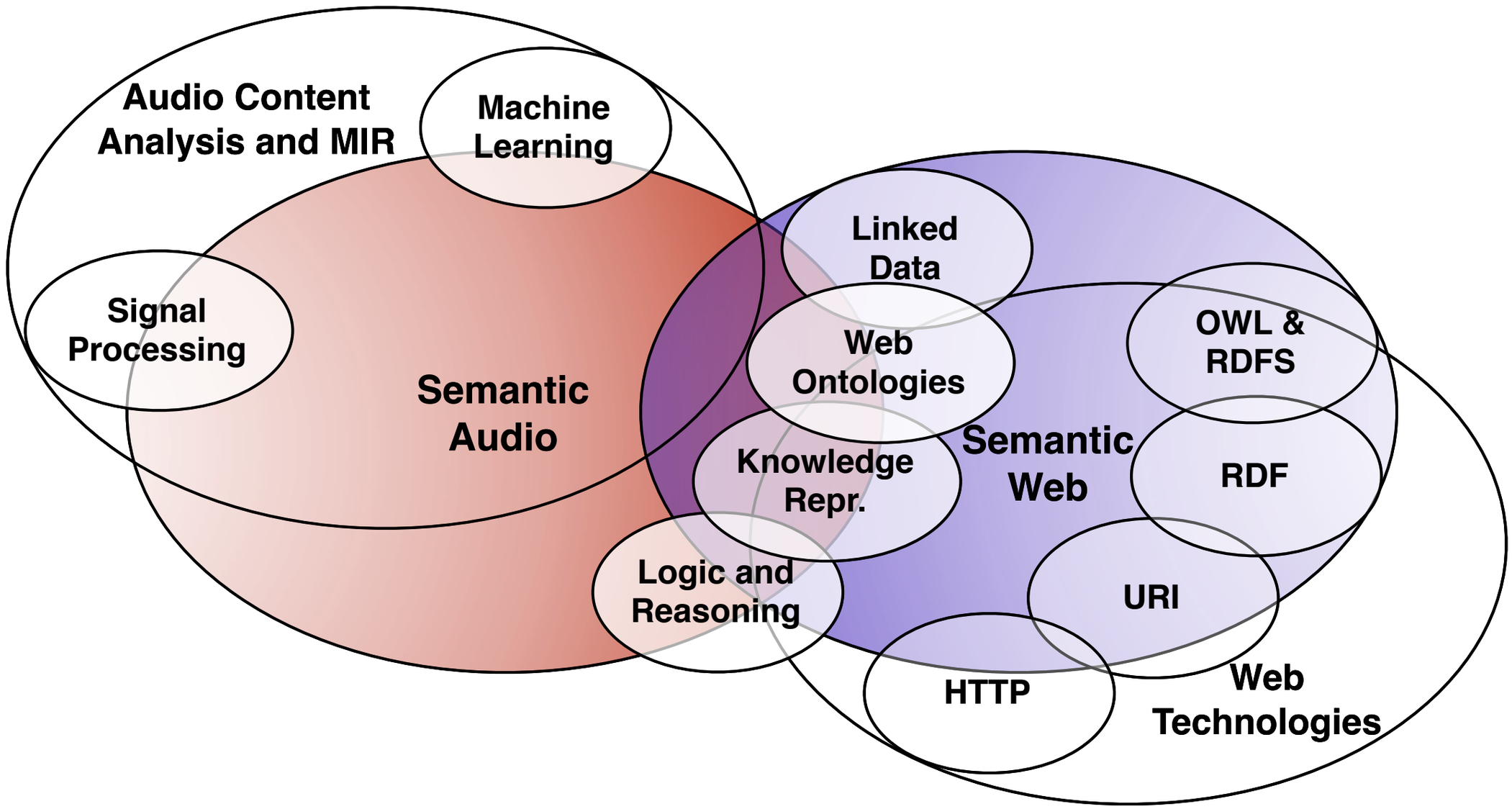
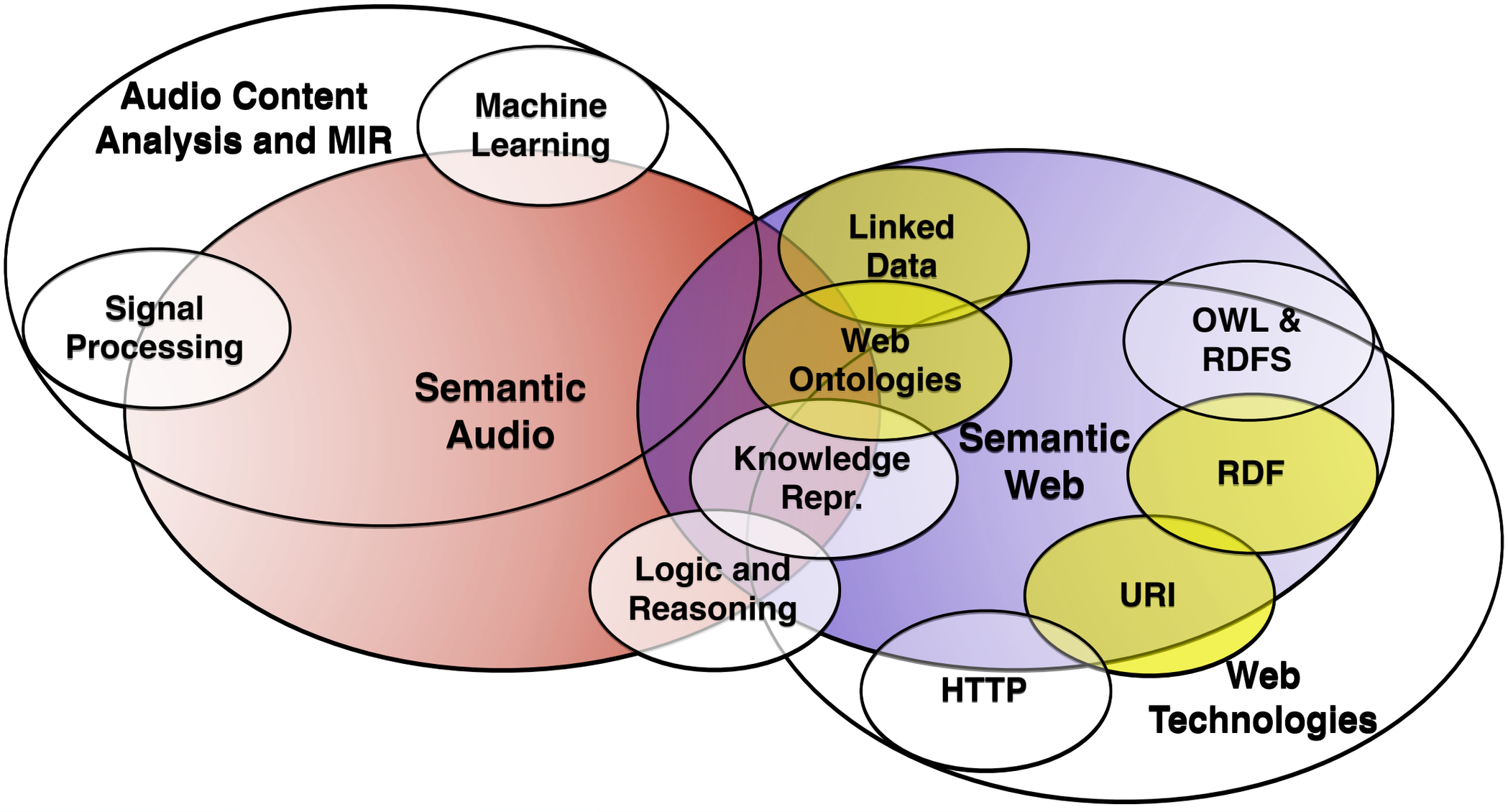


Tutorial Focus

- and the areas marked below



Semantic Web Technologies

Linked Data

Linked Data ? = **Semantic Web** ? = **Web of Data**

- These concepts are often used interchangeably
- Linked Data is a recent movement that focusses on creating a **web of data**
- Just like the Web is a **web of documents**
- Broader premises of the Semantic Web will be realised in the future

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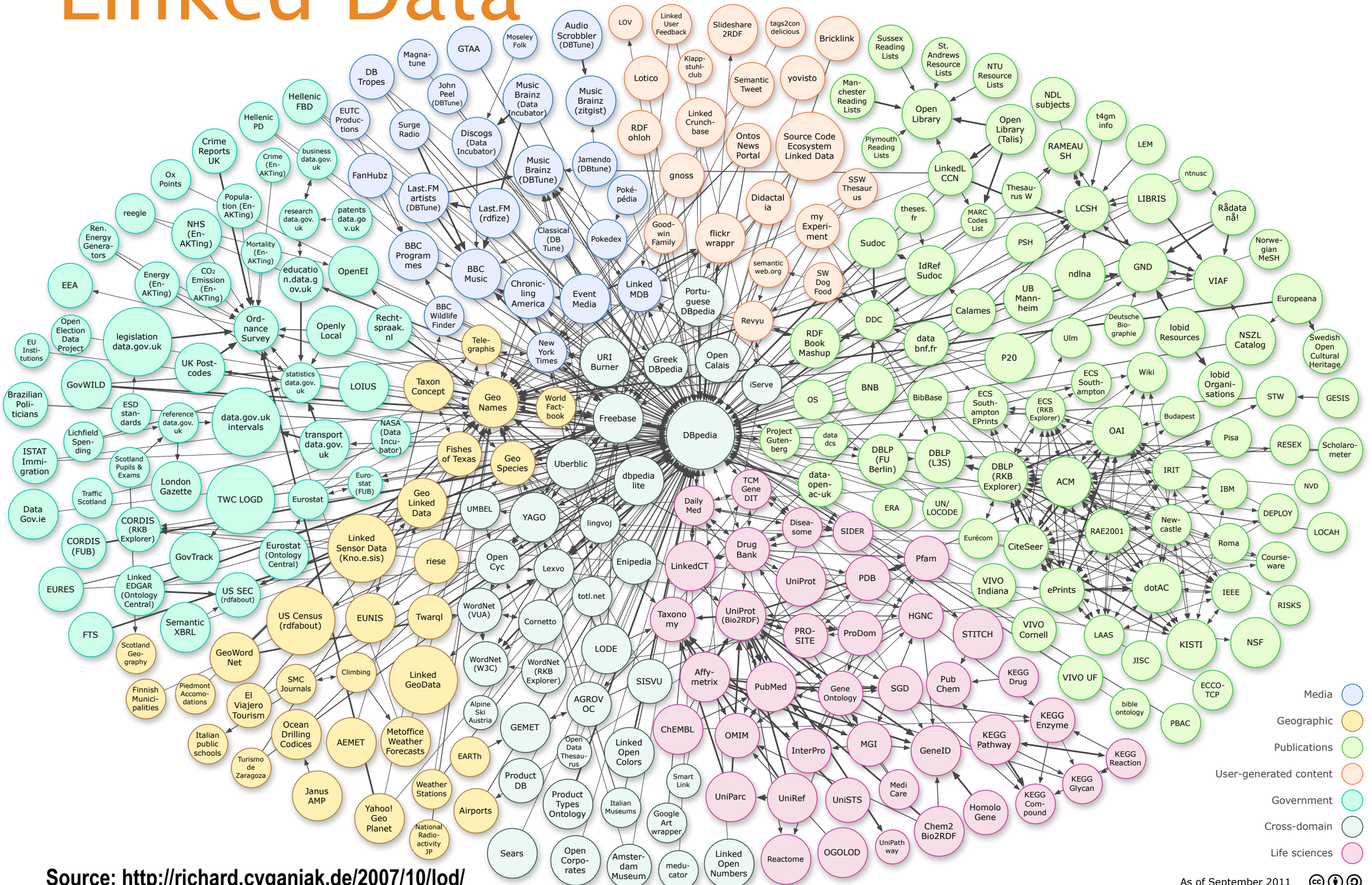

Source: http://richard.cyganiak.de/2007/10/lod/

As of September 2011

Demo Videos

- **What is possible now?**

- The following demos show:

  - (1) audio applications that collect and use data from the Semantic Web

  - (2) audio applications that utilise Semantic Web technologies (but not necessarily linked data)

Demo Video 1

Demo Video 2

Demo Videos

- **How do these applications really work?**
  - They combine information from different sources
- To achieve this we need:
  - interoperability
  - queryability
- **and also:**
  - extensibility
  - modularity

Demo Videos

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Basic Requirements

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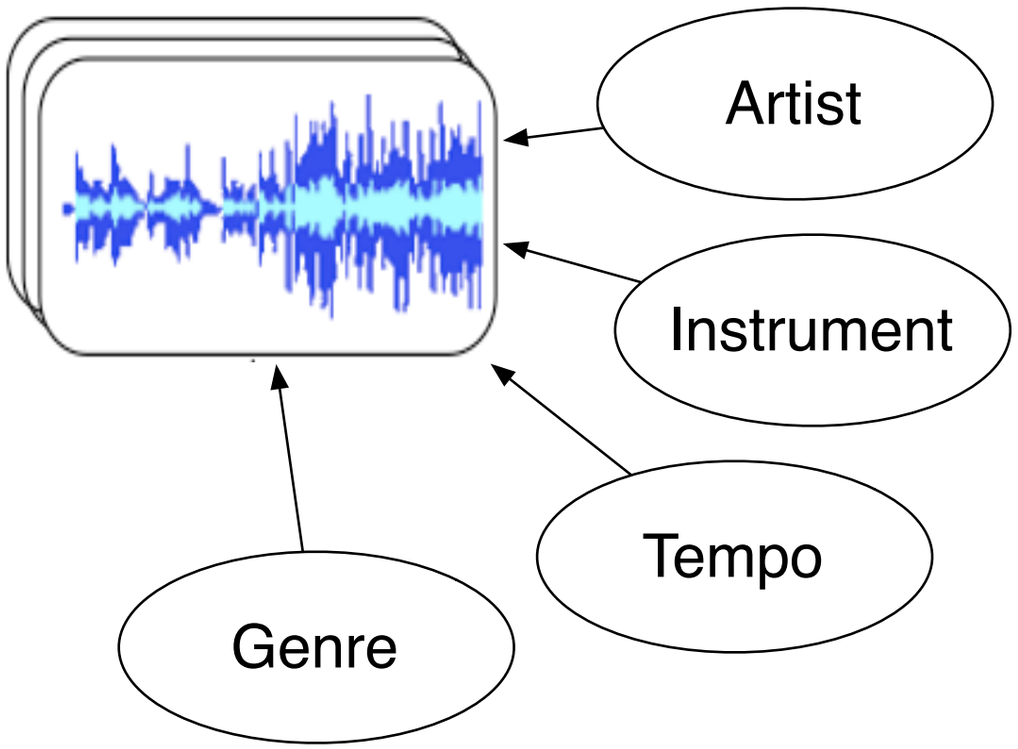
Metadata Structural Diversity

- **But, the heterogeneity of musical metadata presents a problem**



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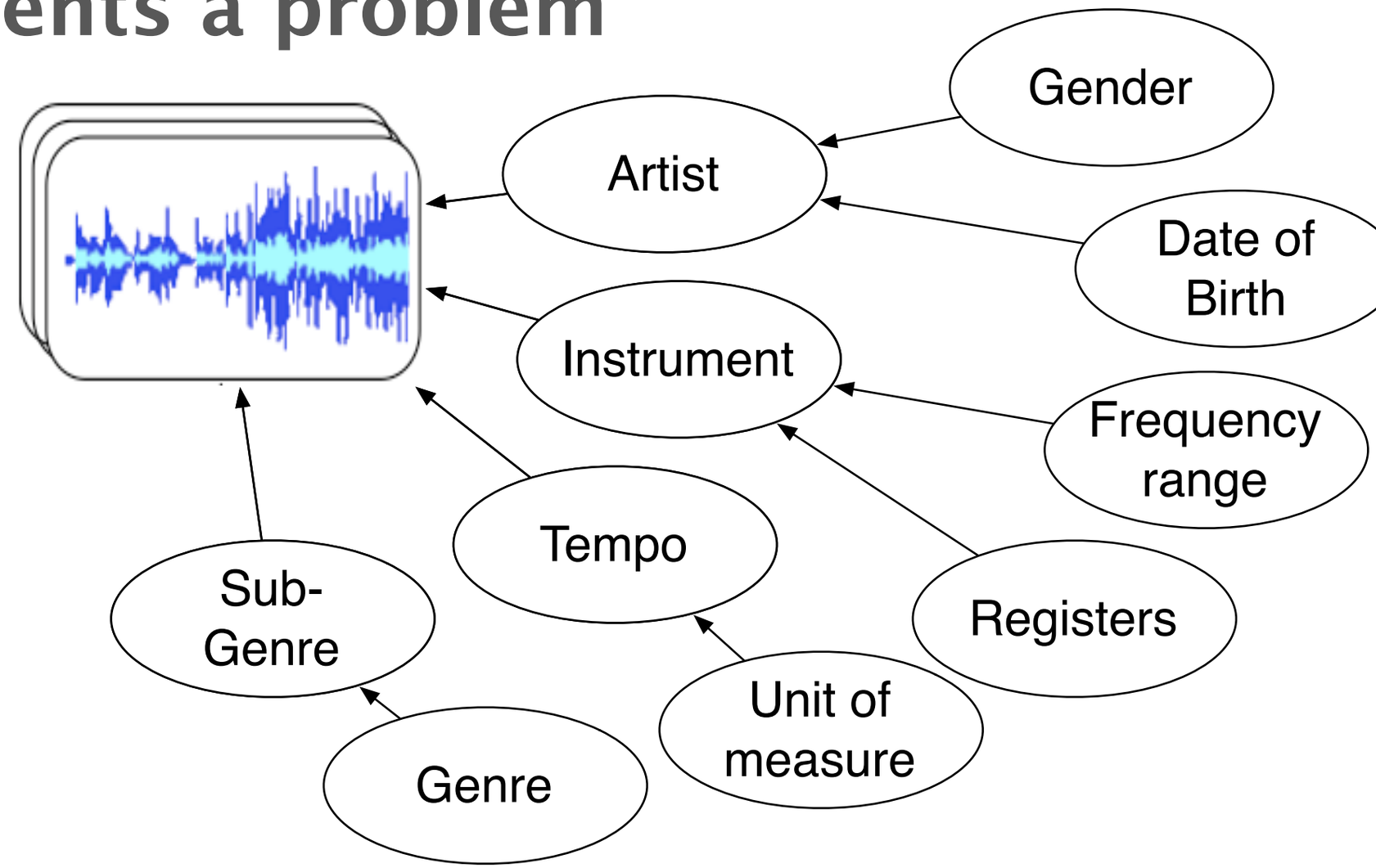

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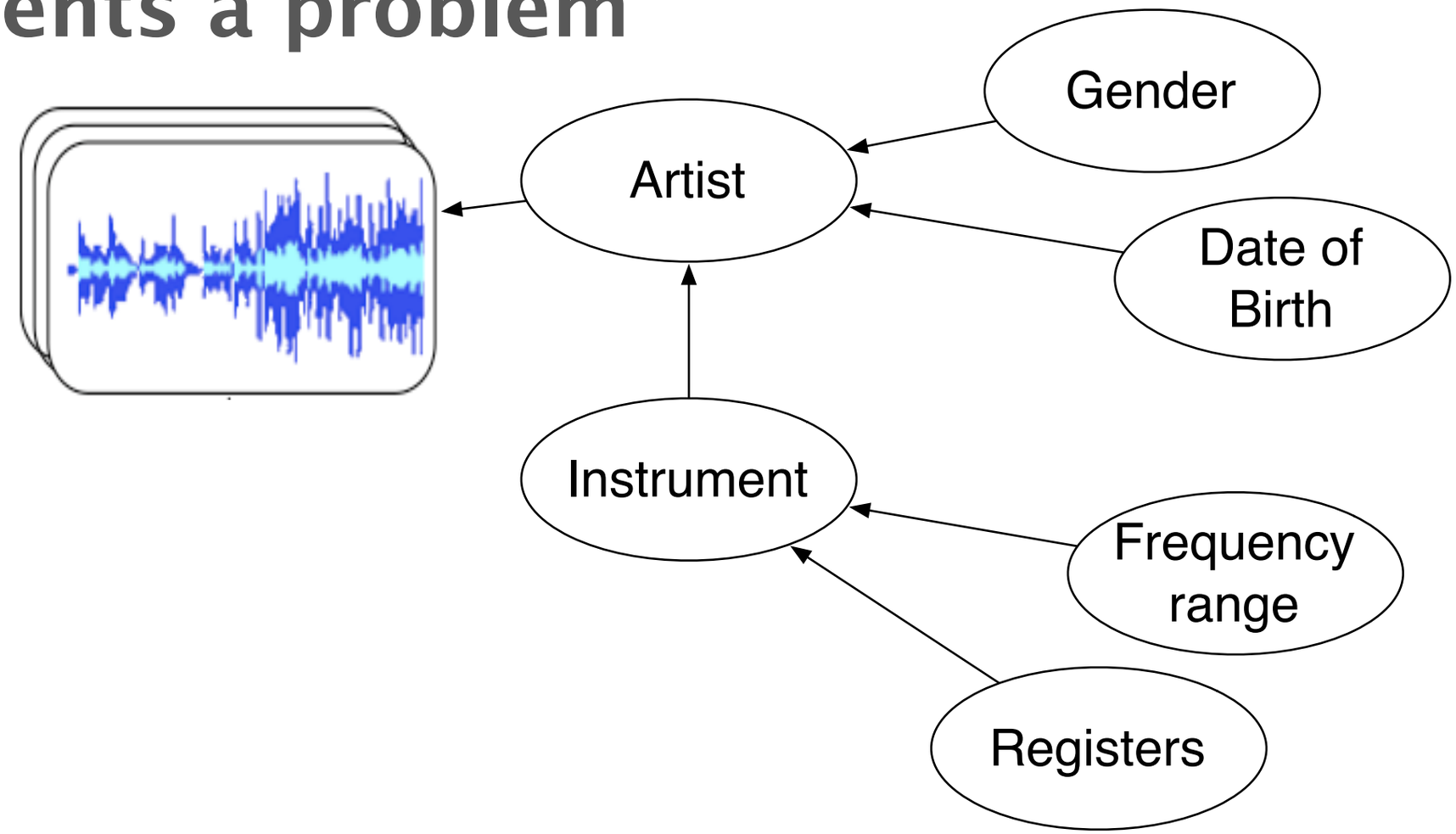

XML and Metadata Standards

- **The XML Factor:**

Image Credit: Dan Zambonini (O'Reilly XML.com blog) http://www.oreillynet.com/xml/blog/

XML and Metadata Standards

- XML and XML-based metadata standards
  - **only specify the syntax** of documents
  - **meaning** (a.k.a. semantics) is **implicit,**
  - and **hard coded** in procedural software

XML and Metadata Standards

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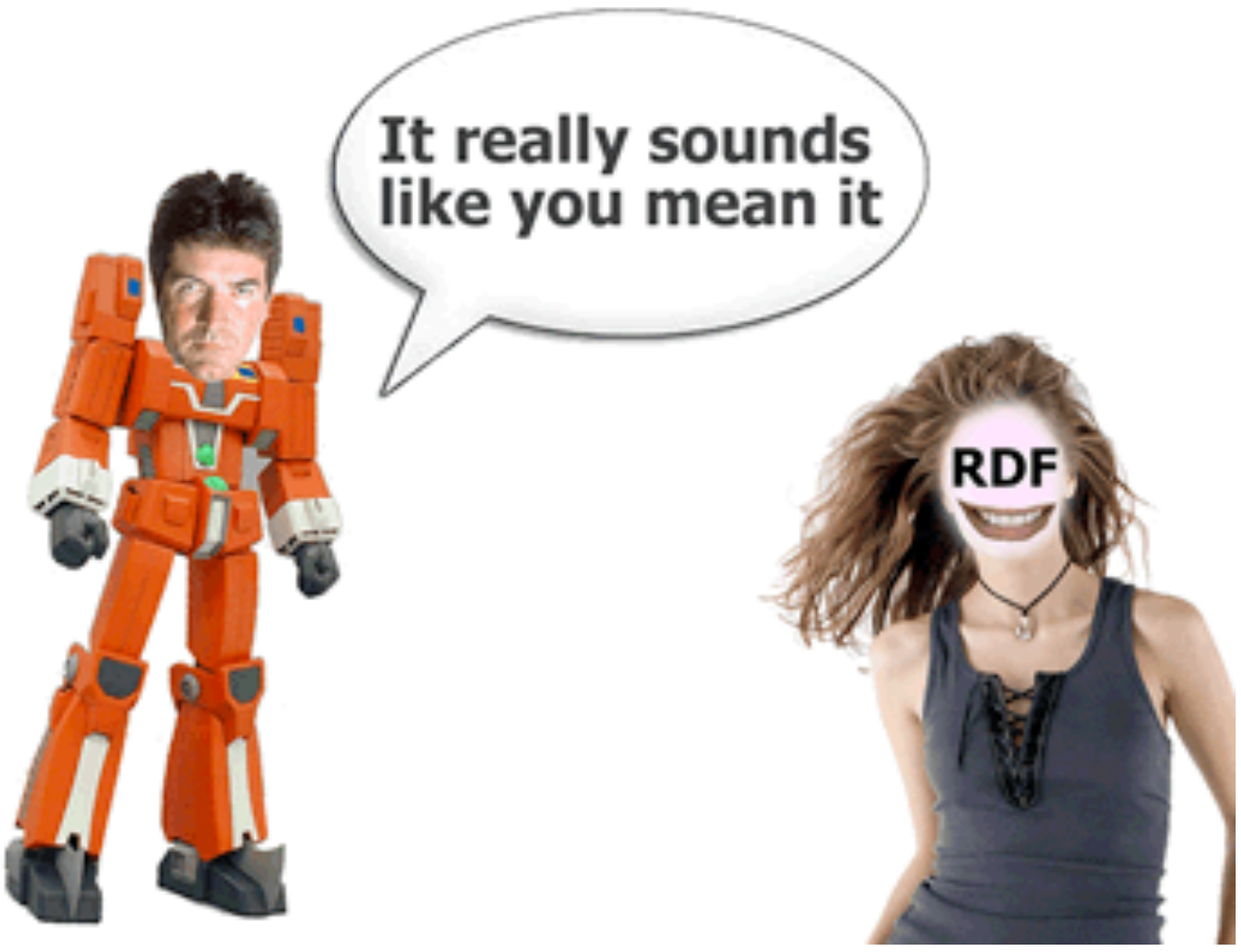

Image Credit: Dan Zambonini (O'Reilly XML.com blog) http://www.oreillynet.com/xml/blog/

XML and Metadata Standards

- **The XML Factor:**

There is no shared model of information and knowledge

Image Credit: Dan Zambonini (O'Reilly XML.com blog) http://www.oreillynet.com/xml/blog/

Resource Description Framework

- **RDF provides a simple model of information**

- **How does it work?**

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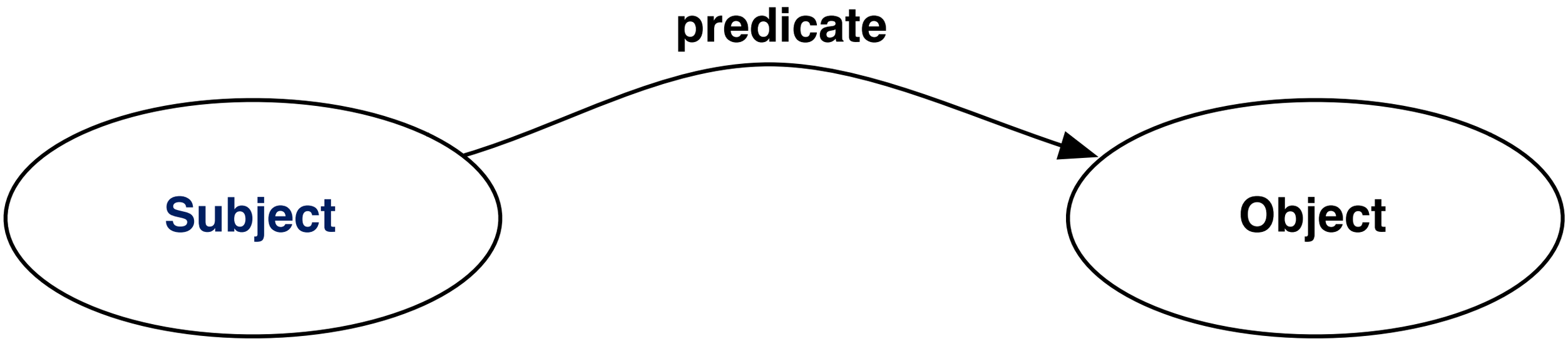
Resource Description Framework



- In RDF information is decomposed into simple **statements.**

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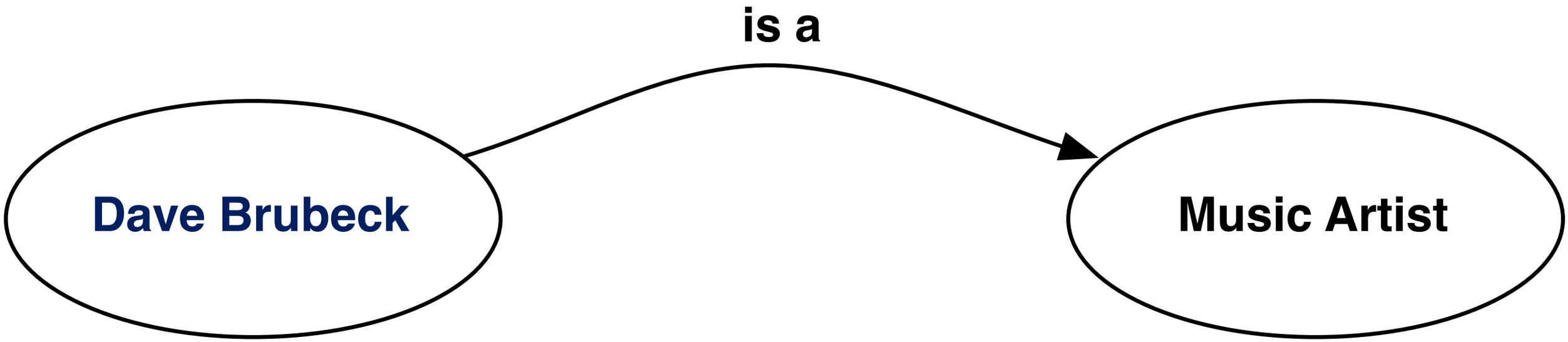

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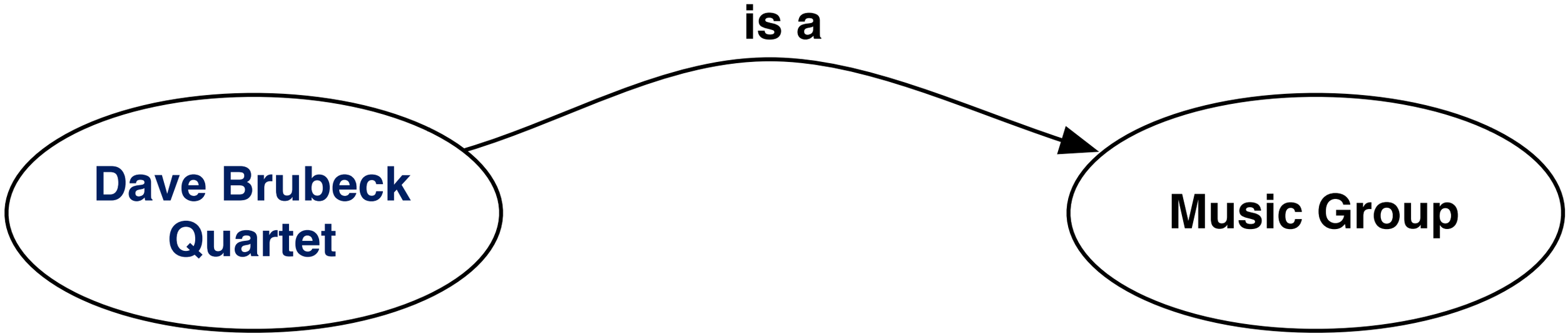

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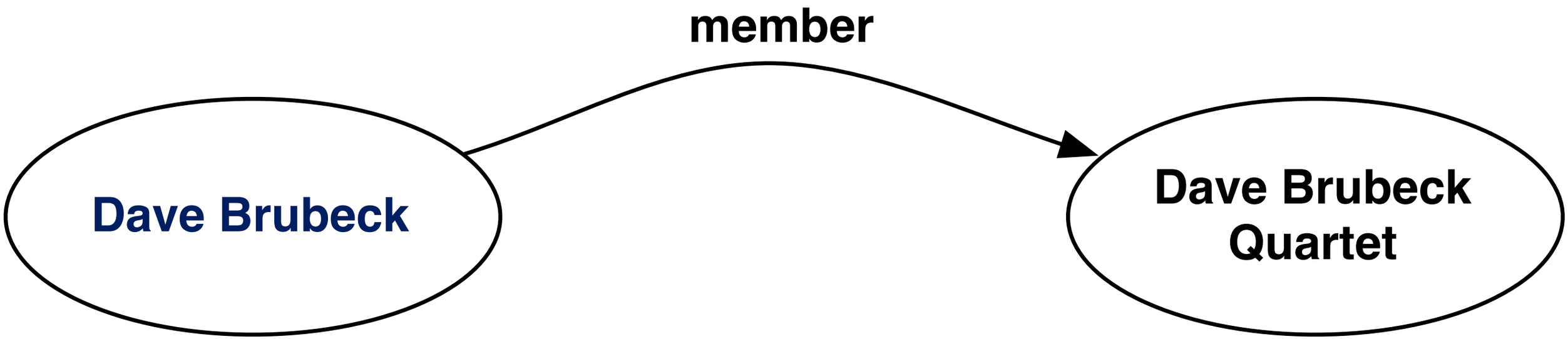

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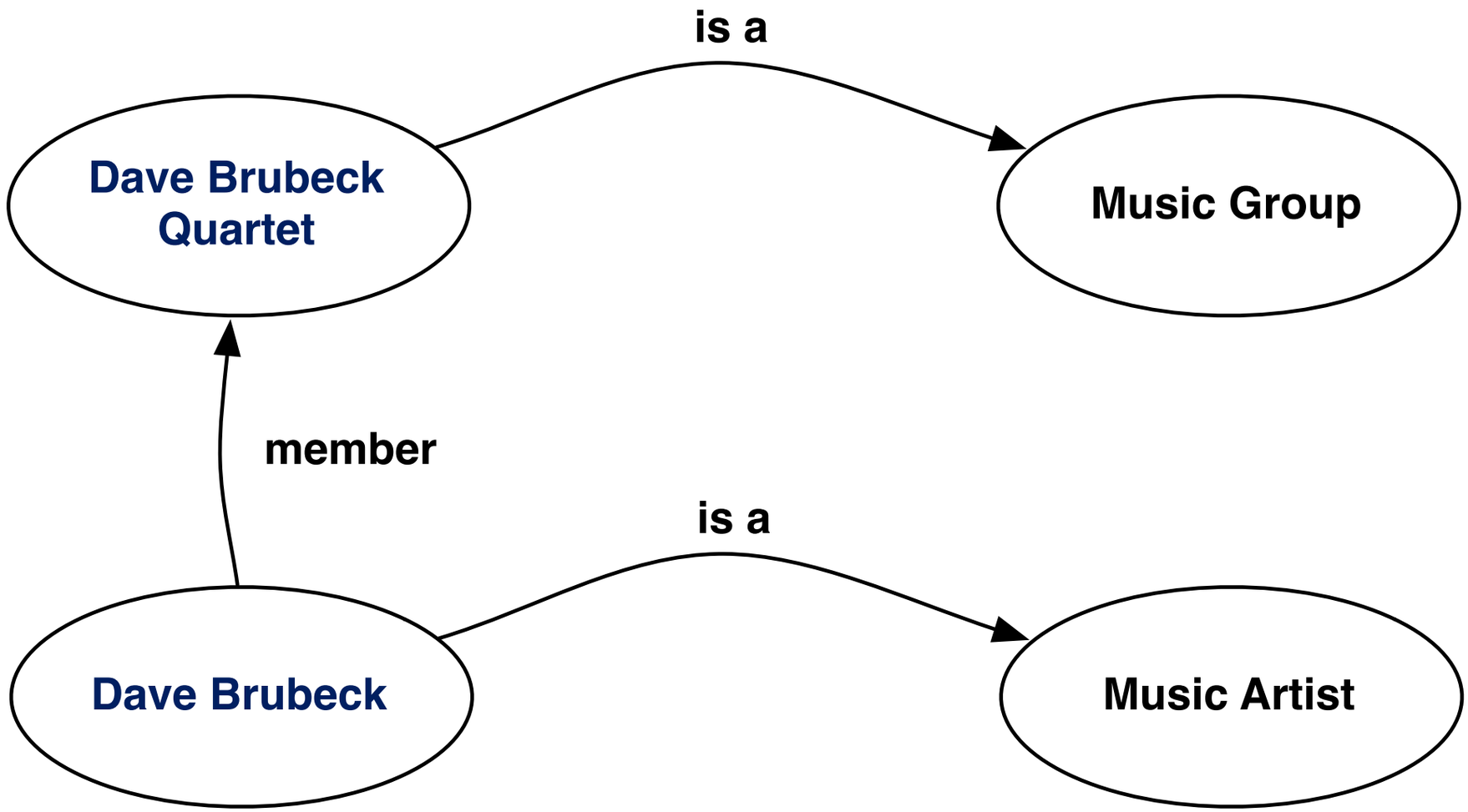
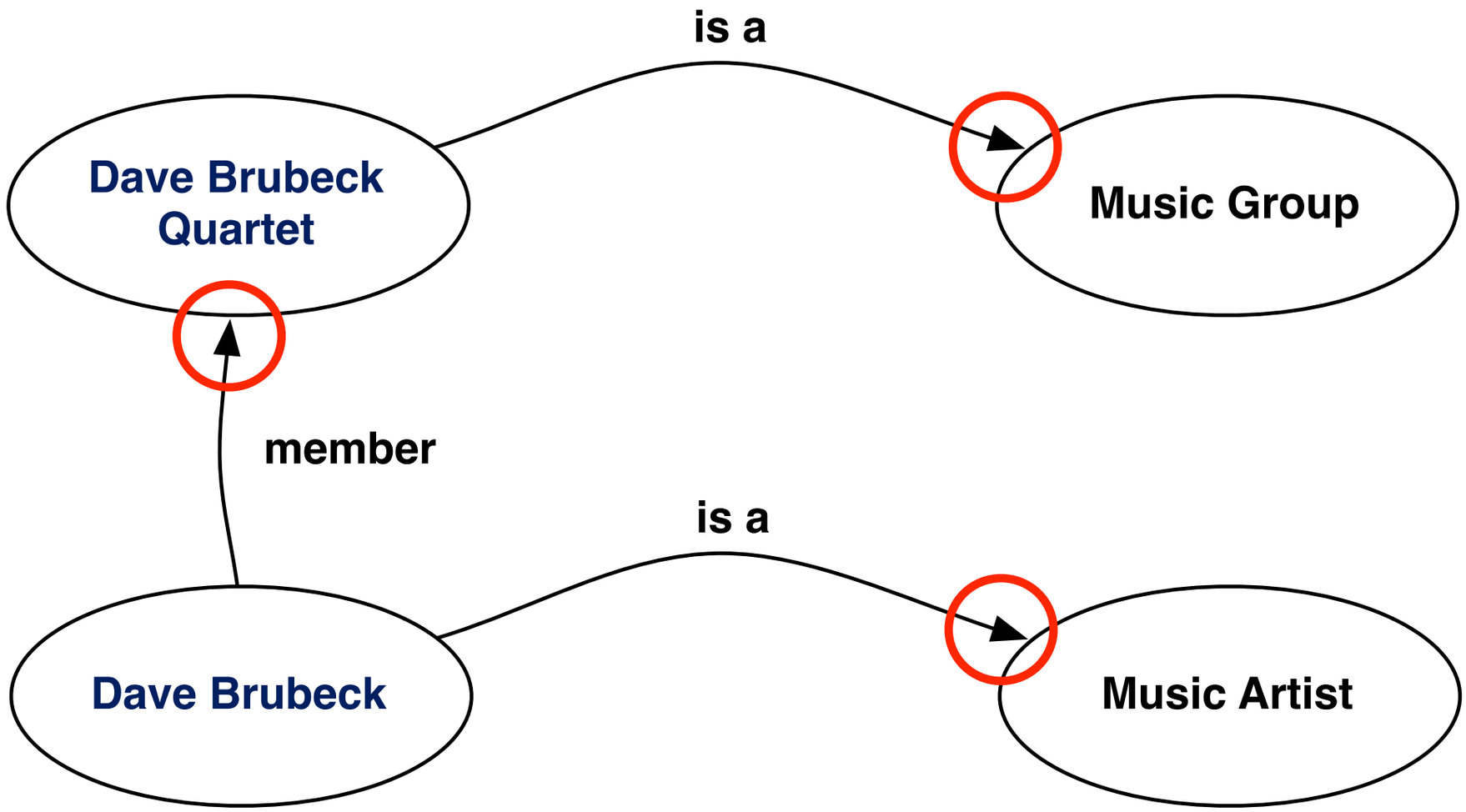


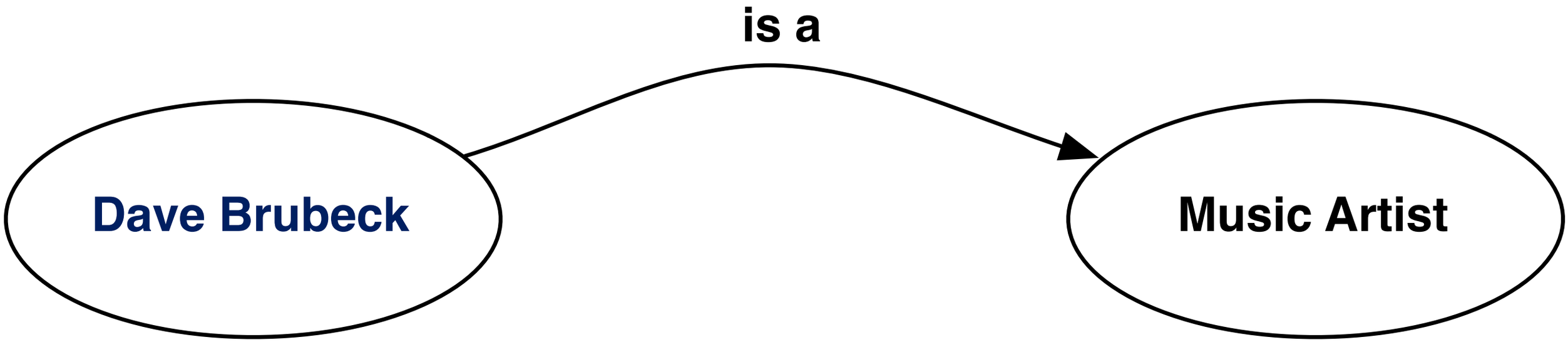
- When combined, statements form a Graph

Resource Description Framework



- When combined, statements form a Graph
- more precisely a **Directed Graph**

Resource Description Framework



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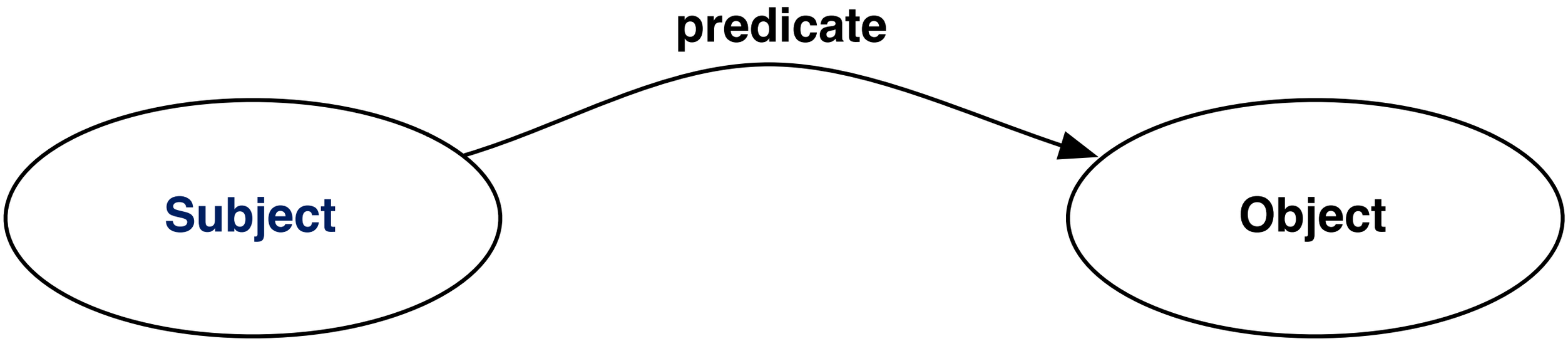
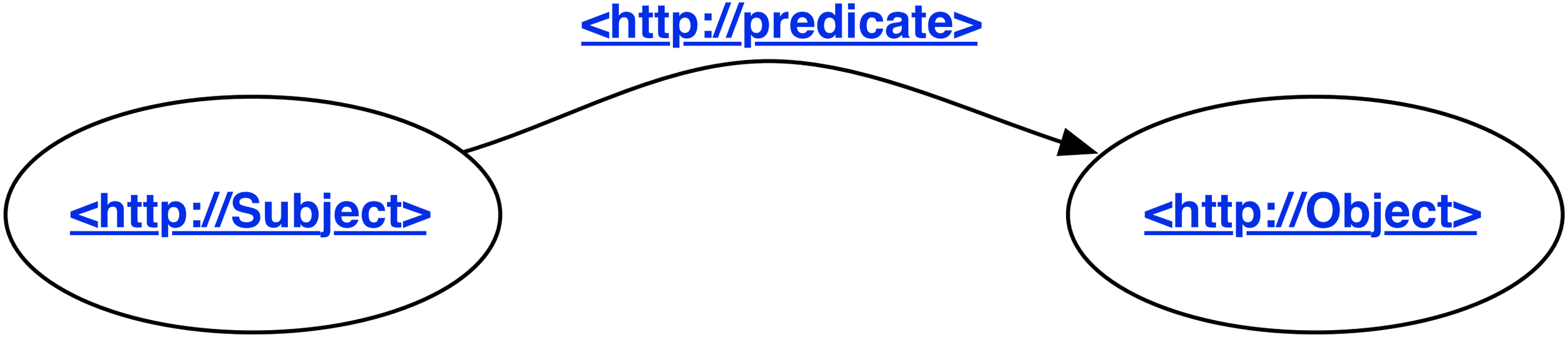


- These statements are also called **triples**
- of terms or **resources**:
- **(subject, predicate, object).**

RDF & Unified Resource Identifiers

- Every term gets a **Unified Resource Identifier** (URI)



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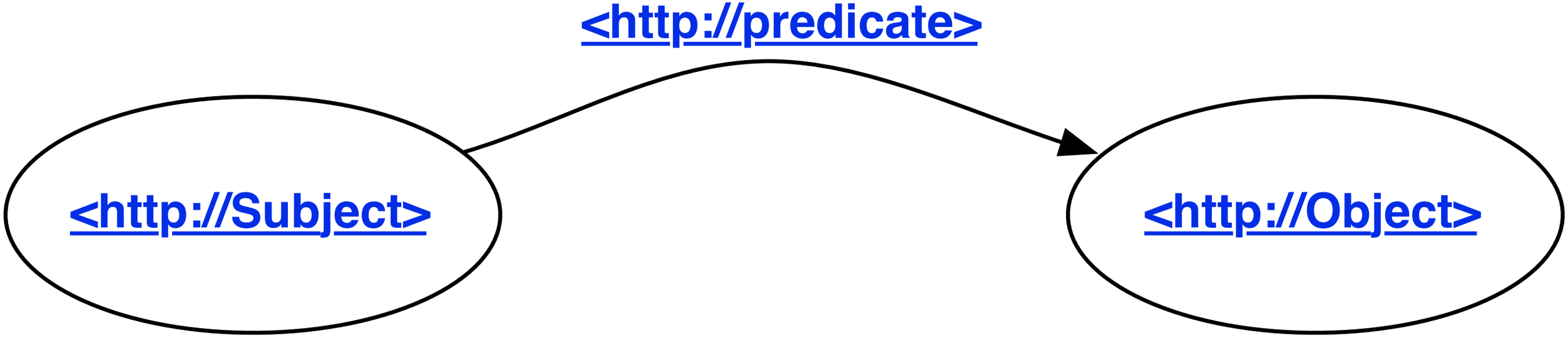

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- We can also:
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RDF Syntax and Serialisation

- **How do we express / store information described by an RDG graph?**

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- **RDF is not RDF/XML !**

- XML was the first standardised syntax for RDF,

but

- **there are many others available that are:**
  - easier to use
  - easier to read (by a human)
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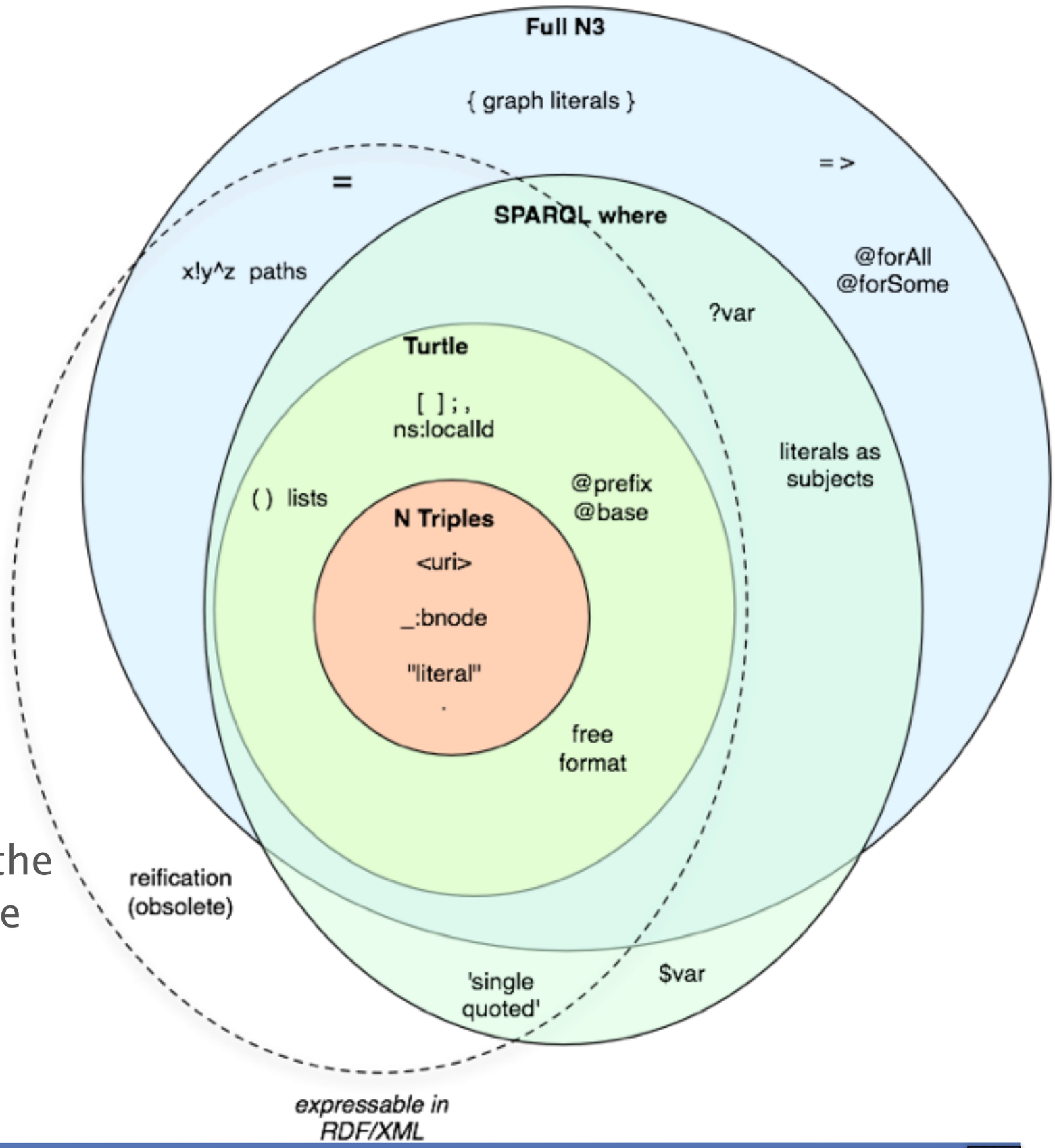
RDF Syntax

- **Some common syntaxes:**
- N Triples
- **Turtle**
- RDF/XML
- RDFa
- JSON-LD
- N3 (this goes beyond the RDF model and the scope of this tutorial)



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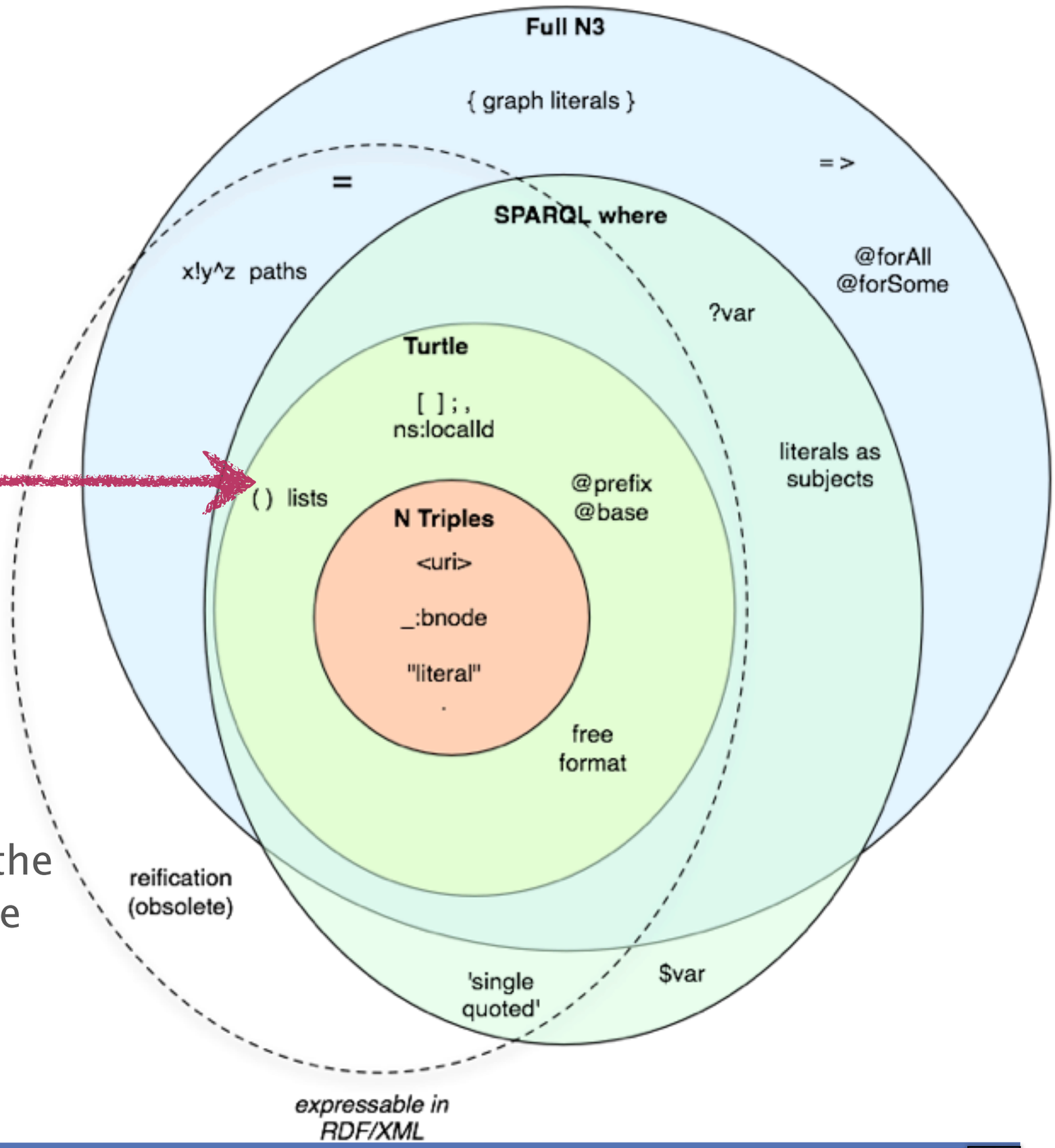

RDF N Triples Syntax

<http://dbpedia.org/resource/Dave_Brubeck>

<http://dbpedia.org/ontology/genre>

<http://dbpedia.org/resource/Cool_Jazz> .

- Here is a statement in **N Triples**.

RDF Turtle Syntax

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@prefix dbpr: <http://dbpedia.org/resource/> .
@prefix dbpo: <http://dbpedia.org/ontology/genre> .

dbpr:Dave_Brubeck dbpo:genre dbpr:Cool_Jazz .
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- Using **CURIEs** and the prefix notation.
- Still 3 lines of RDF but given a large set of statements this is a significant reduction.

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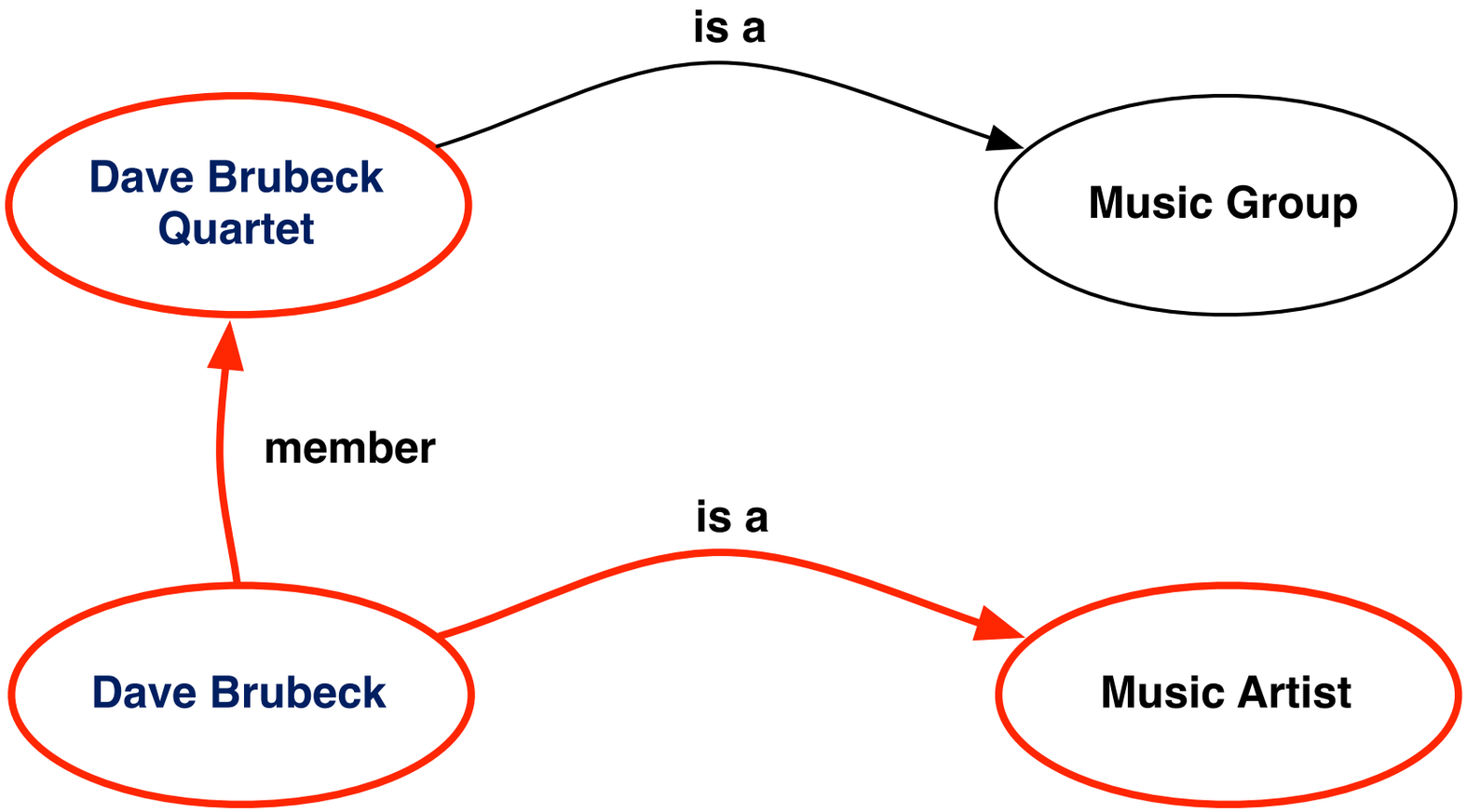
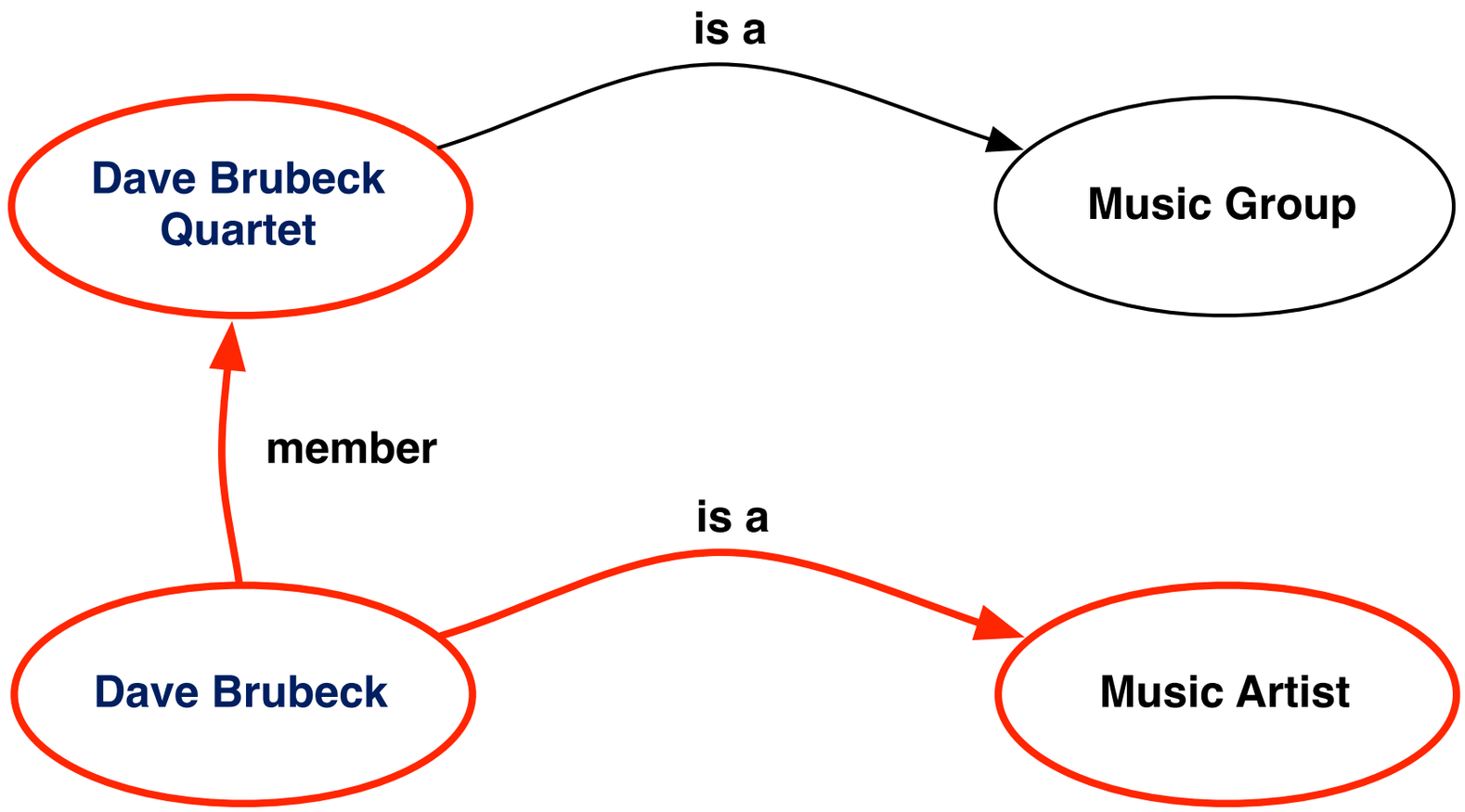



```
:Dave_Brubeck rtf:type mo:MusicArtist ;
    :member :Dave_Brubeck_Quartet.
```

- The prefix can remain empty (:resource) to represent the local scope.

RDF Turtle Syntax

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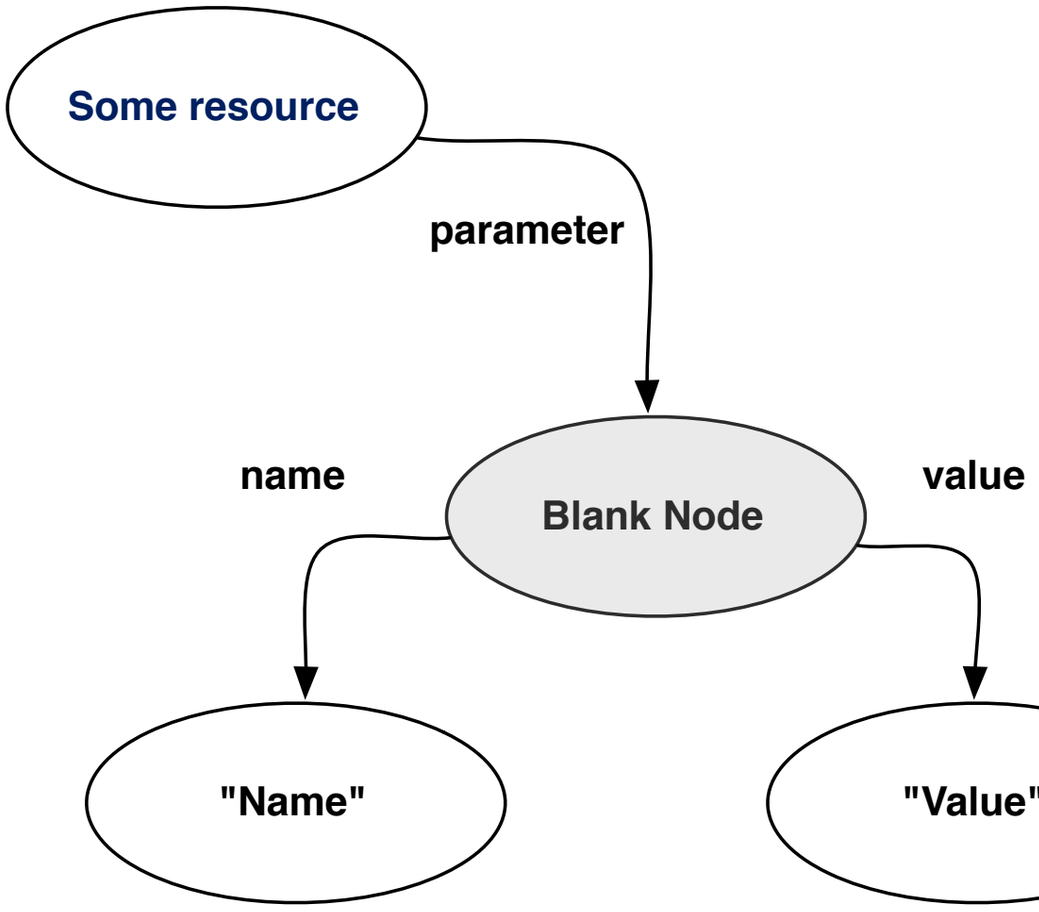
- The **semicolon** can be used to group statements about the same resource.

RDF Turtle Syntax: Blank nodes




```
:resource [
    :name “parameter name” ;
    :value “20”
    ] .
```

- **Blank nodes represent unnamed resources**
- They are very useful when representing complex data

Linking different datasets

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix mo: <http://purl.org/ontology/mo/> .

<http://www.bbc.co.uk/music/artists/1545000730-525f-4ed5-
aaa8-92888-f060f5f#artist>
    rdf:type mo:MusicArtist ;
    owl:sameAs <http://dbpedia.org/resource/Dave_Brubeck> .
```

- **owl:sameAs** predicate can be used to link resources in different datasets that hold information about the same resource.

RDF Turtle Syntax: Summary

- URIs : <**http://some_resource.org**>
- CURIEs: **mo:MusicArtist**
- @prefix: declare namespaces
- Blank nodes: [...] **or _:bnode**
- Literal values: **“some string”**
- Typed literals: **“20”^^xsd:int**
- Group statements: semicolon (**;**)
- Group objects: colon (**,**)
- Close statements: dot (**.**)
- Shorthand for rdf:type: **a**

RDF Storage and Databases

- **Linked data repositories**
  - **use eg. HTTP GET**
  - this is usually done through content negotiation
- **Triple Stores**
  - Garlic's 4Store
  - Openlink Virtuoso
- Lots of programming libraries
  - redland (C), rdflib (Python), Jena (Java)

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Querying RDF with SPARQL

- **SPARQL** protocol and RDF Query Language
- Similar to Turtle
- It has several query types, e.g.
  - SELECT
  - CONSTRUCT
- variables: **?x**
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PREFIX dbpr: <http://dbpedia.org/resource/>
PREFIX dbpo: <http://dbpedia.org/ontology/>

SELECT ?genre
WHERE {
dbpr:Dave_Brubeck dbpo:genre ?genre .
}
```

- Find a genre classification according to DBPedia

Querying RDF with SPARQL

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- Find other artists (?x) having the same genre

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```

- Let's try this in practice

Linked Data Services

- There are many music related linked data services and applications available
- **DBTube.org**
  - http://dbtune.org/
- **Linked Brainz** (MusicBrainz database)
  - http://linkedbrainz.c4dmpresents.org/
- **Musicnet**
  - http://musicnet.mspace.fm/
- **BBC Music website**
  - http://www.bbc.co.uk/music

Ontologies

RDF and Ontologies

- Elements of RDF statements can be selected in an ad-hoc manner.

- We need a way to **give "meaning"** to each subject, predicate and object.

- **Represent knowledge in a formal way.**

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- **Represent knowledge in a formal way.**

Knowledge Representation

- This can be done using **First Order Logic**

$$\forall x(\mathsf{AudioClip}(x) \leftrightarrow \exists y(\mathsf{hasSignal}(x, y) \wedge \mathsf{Signal}(y)))$$

$$\exists x, y(\mathsf{AudioClip}(x) \wedge \mathsf{tempo}(x, 120)$$
$$\wedge \mathsf{name}(x, myrecording)$$
$$\wedge \mathsf{hasSignal}(x, y) \wedge \mathsf{Signal}(y))$$

- But this is too hard for practical reasoning

- **Description Logics** are subsets of this logic that provide the logical foundations for **Web Ontologies and Ontology languages**

Knowledge Representation

- This can be done using **First Order Logic**

$$\forall x(\mathsf{AudioClip}(x) \leftrightarrow \exists y(\mathsf{hasSignal}(x, y) \wedge \mathsf{Signal}(y)))$$

$$\exists x, y(\mathsf{AudioClip}(x) \wedge \mathsf{tempo}(x, 120)$$
$$\wedge \mathsf{name}(x, myrecording)$$
$$\wedge \mathsf{hasSignal}(x, y) \wedge \mathsf{Signal}(y))$$

- But this is too hard for practical reasoning

- **Description Logics** are subsets of this logic that provide the logical foundations for **Web Ontologies and Ontology languages**

Ontologies

- An Ontology is:

- **a shared conceptualisation of a world or domain**

- it includes:
  - 1) individuals,
  - 2) classes, groups of individuals that have something in common,
  - 3) possible relationships between them

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Ontologies

- There might be many ontologies for the same domain
- They all may be valid (and useful),
- but it is unlikely they cover everything,
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Ontology Languages

- There is a stack of languages (W3C recommendations)

- **OWL2**: extended data model
- **OWL**: allows for equivalence, cardinality constraints, etc...
  - OWL-Full
  - OWL-DL
  - OWL-Lite
- **RDFS**: allows for describing class and property hierarchies

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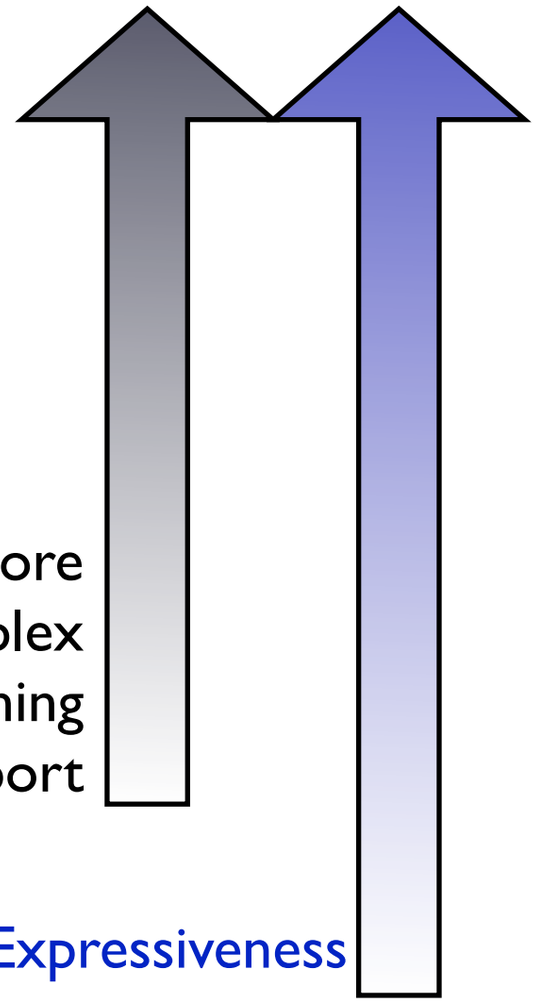

The Music Domain

- To describe music we need to communicate:

- **editorial (bibliographic) information**
- **information about intellectual works and workflows**
  - people and their works
- **cultural and social information**
- **content-based information**
- **provenance and trust**
  - who says what and can we trust it?

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Some useful ontologies

- **Dublin Core**
- **Friend of a Friend** (FOAF) vocabulary
  - to talk about people, groups, and
- **OWL-Time**:
  - basic temporal concepts
- **Timeline Ontology**:
  - relate temporal concepts with regards to different timelines
- **Event Ontology**:
  - describe time based events

The Music Ontology

The Music Ontology

- **Combines several ontologies to describe music related information**

```
mo:MusicArtist
        rdf:type owl:Class ;
        rdfs:comment """A person or a group of people (or
        a computer, whose musical creative work shows
        sensitivity and imagination """ ;
        rdfs:isDefinedBy <http://purl.org/ontology/mo/>;
        rdfs:label "music artist" ;
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Credit: Yves Raimond et al, http://musicontology.com/

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Timeline and Event Ontologies

- **The Timeline Ontology extends OWL-Time and defines the TimeLine concept.**
- Temporal objects (signal, video, performance, work, etc.) can be associated with a timeline.

- **The Event ontology relates arbitrary events to:**
  - temporal entities
  - geographical coordinates
  - participating agents
  - passive factors (such as tools)
  - and products (results of an event)
  - allows to decompose complex events into sub-events

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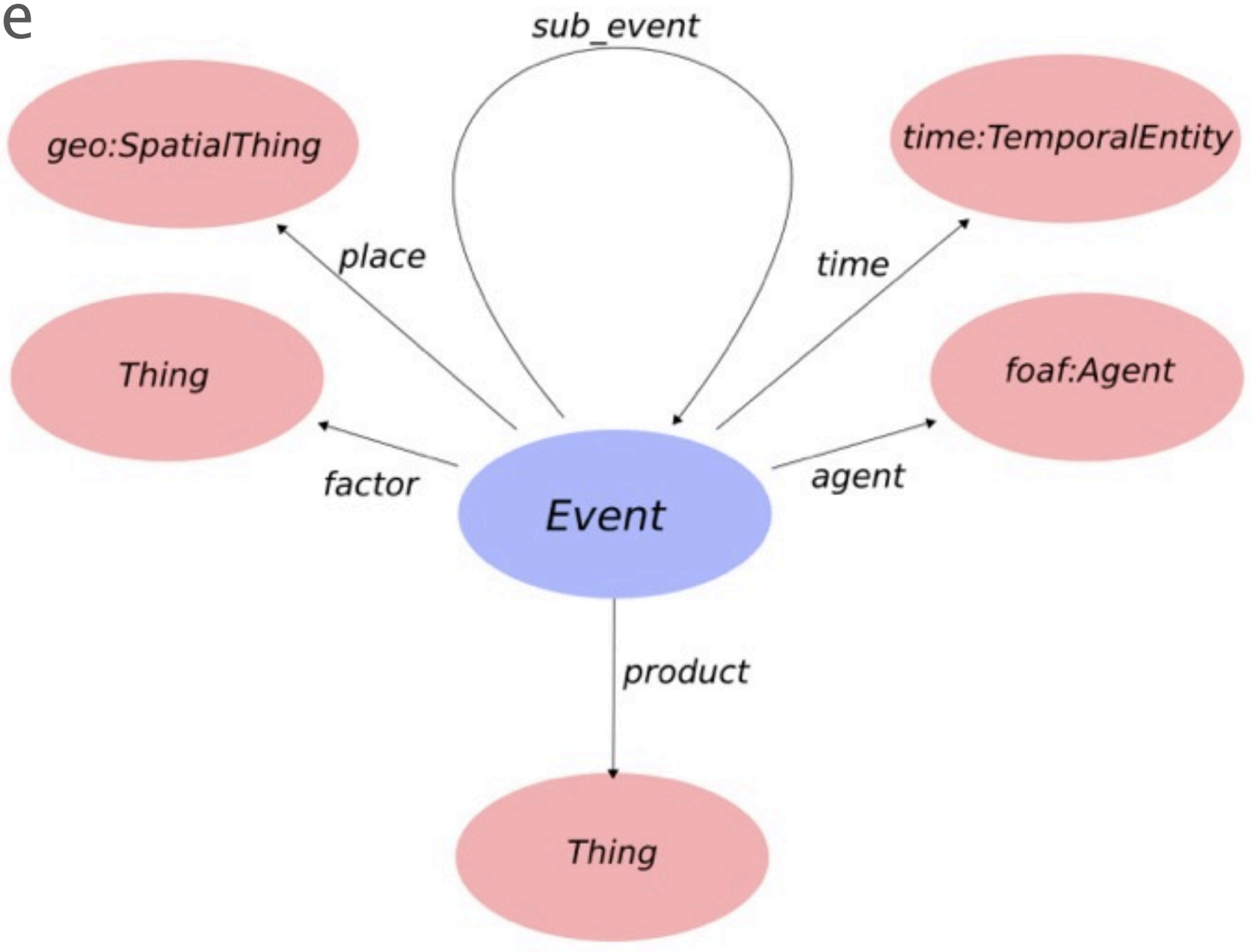
Timeline and Event Ontologies

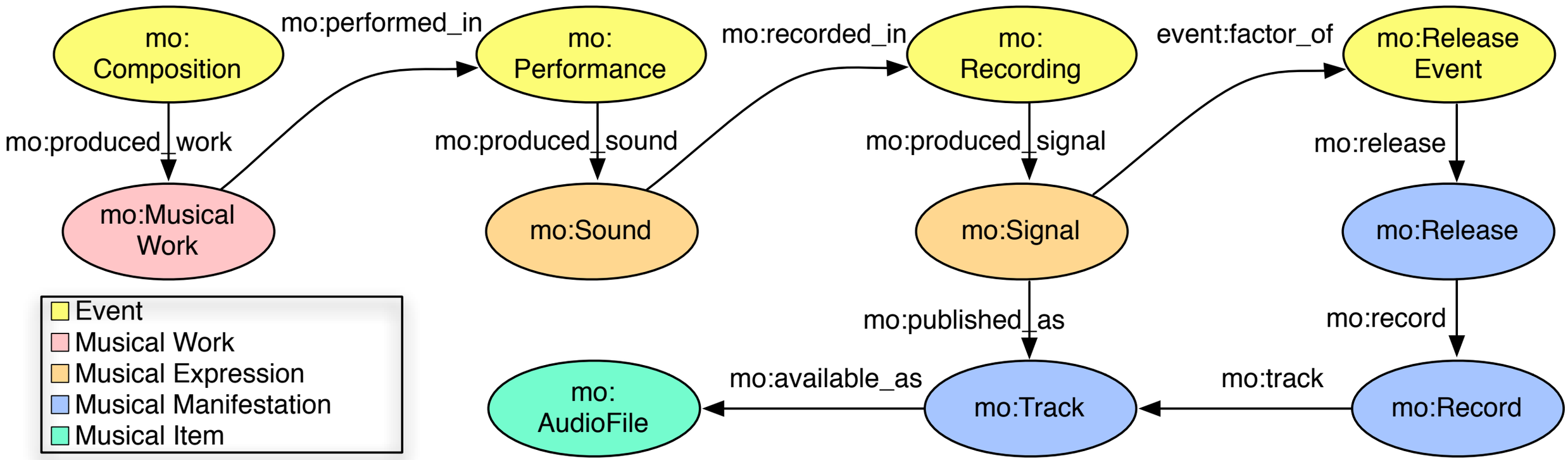
- An event may be (for instance):
- a concert,
- a performance or
- a note onset



http://purl.org/NET/c4dm/event.owl#

The Music Ontology

- Defines a Music Production Workflow Model



The Music Ontology

- A large set of extensions are available, including:

- **The Audio Features Ontology**

- **The Chord ontology**

- **The Studio Ontology**

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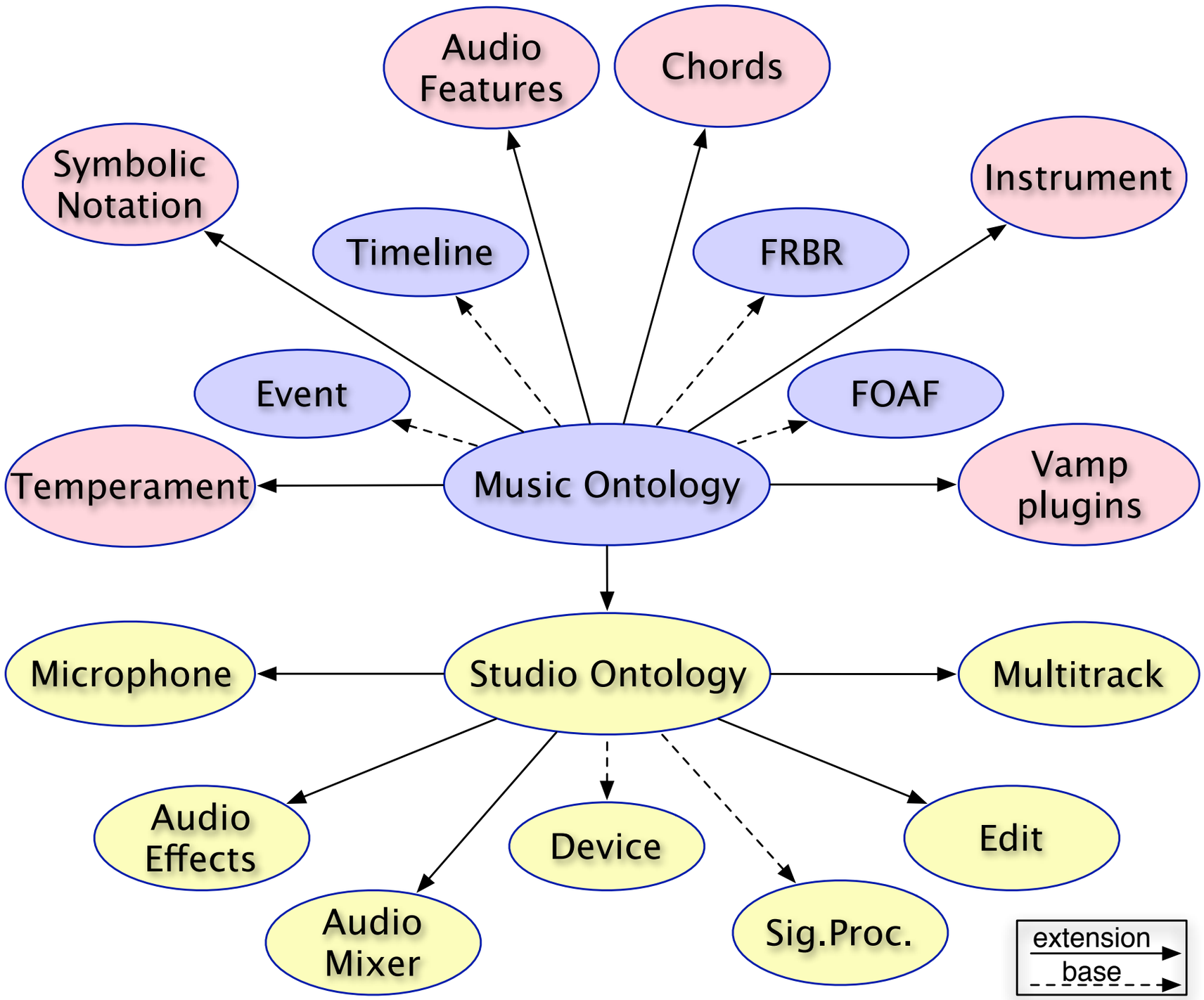
Ontology Frameworks



The Studio Ontology

The Studio Ontology

- Enables collecting information about audio production.

- Motivations
- Notation for capturing the contribution of the engineer to creative work
- Improved Information and workflow management in the studio
- Exploit music production data in MIR systems
- Enable building intelligent music production systems

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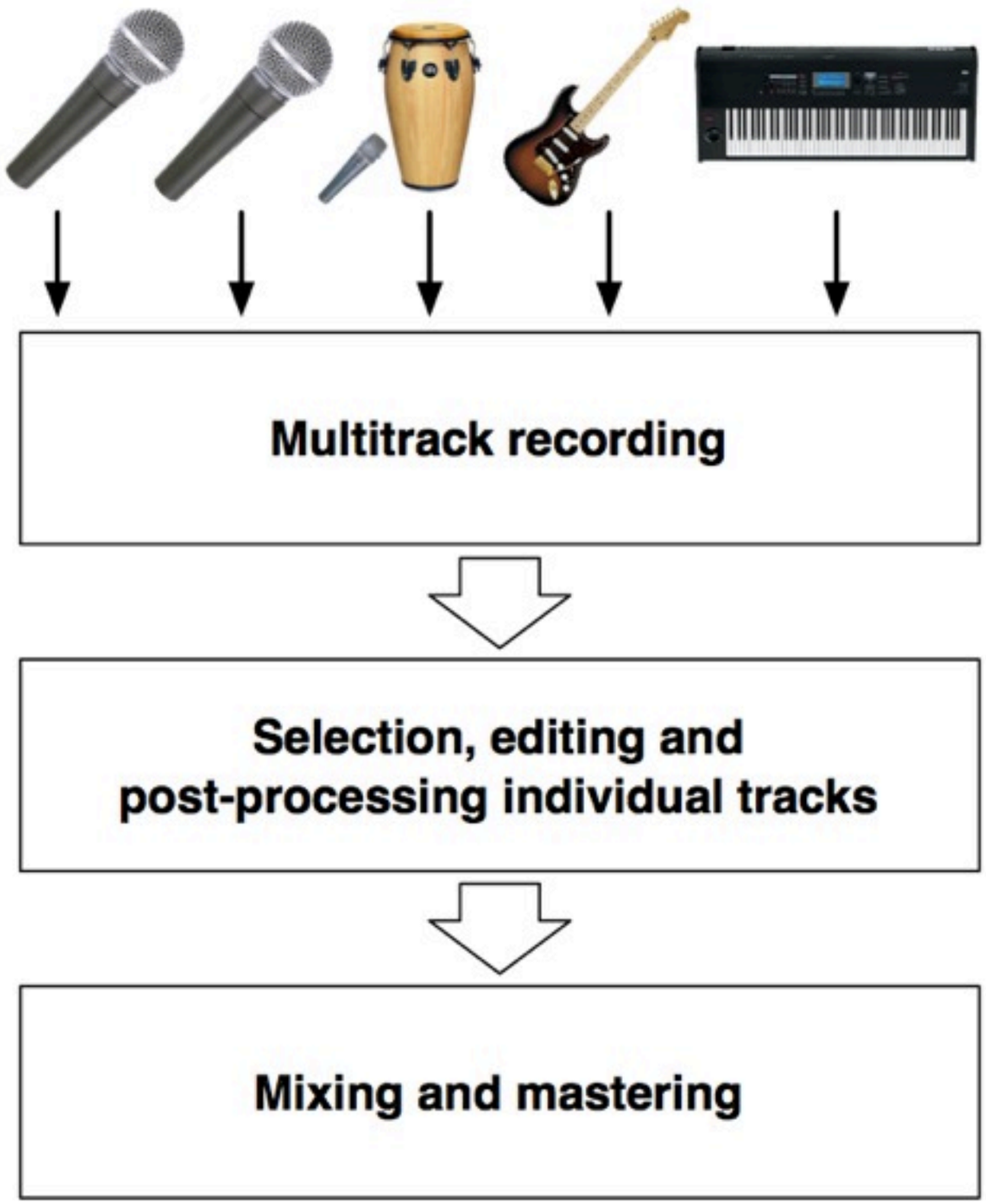

- Two parts:
  - **Technical** (domain independent)
  - **Musical** (domain specific)

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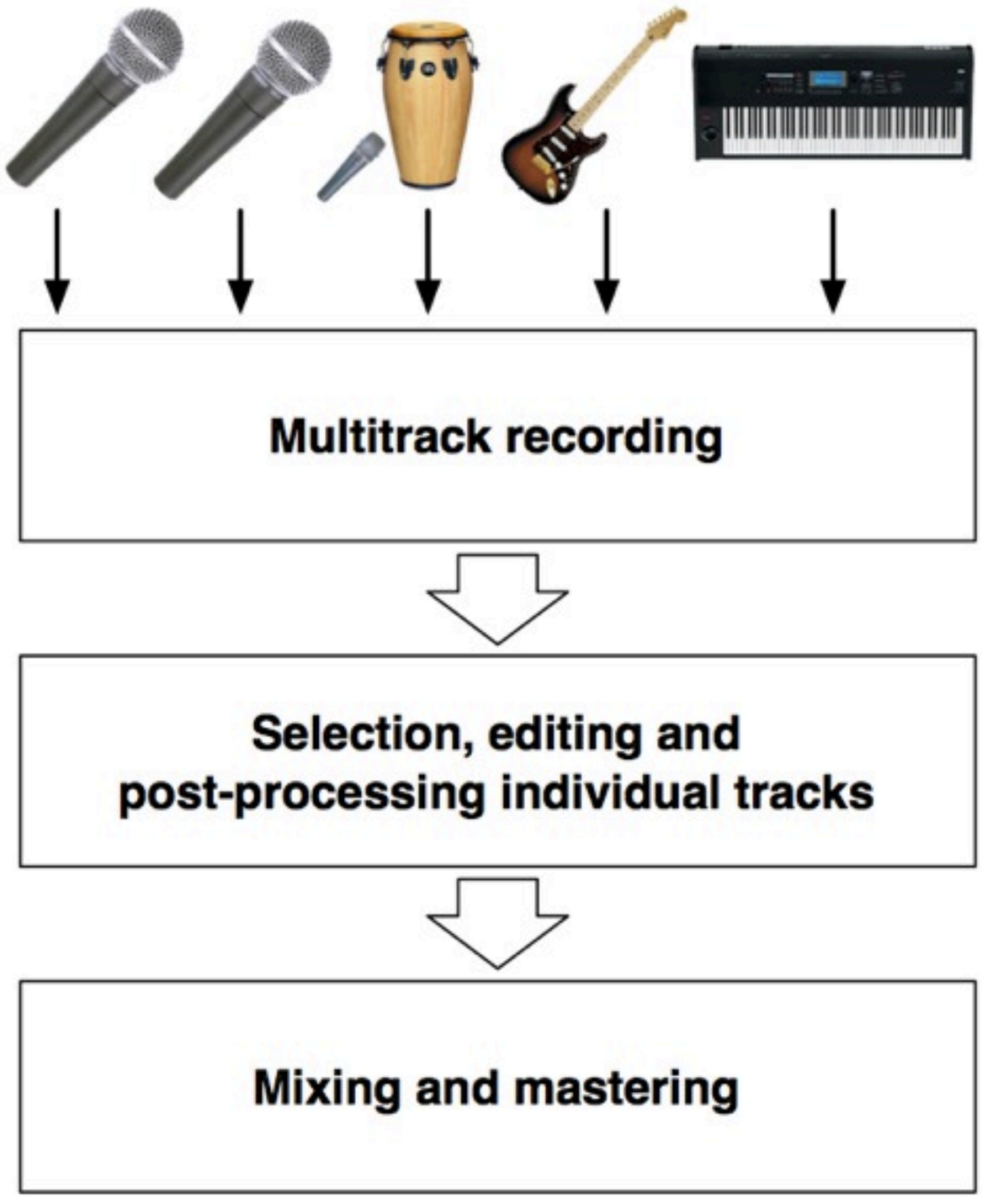
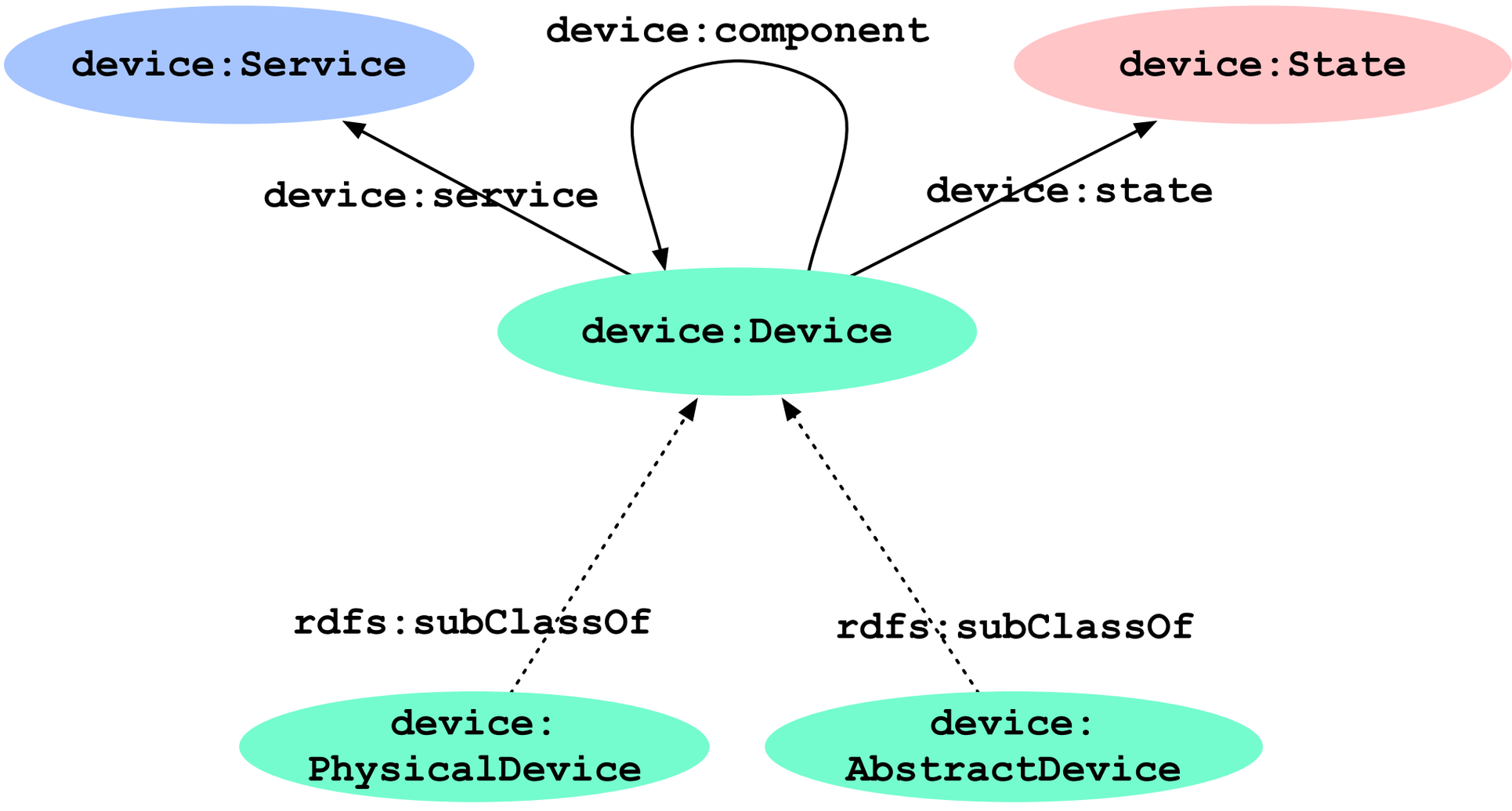


The Studio Ontology

- **Domain independent components:**
  - Technological artefacts (devices) and their connections



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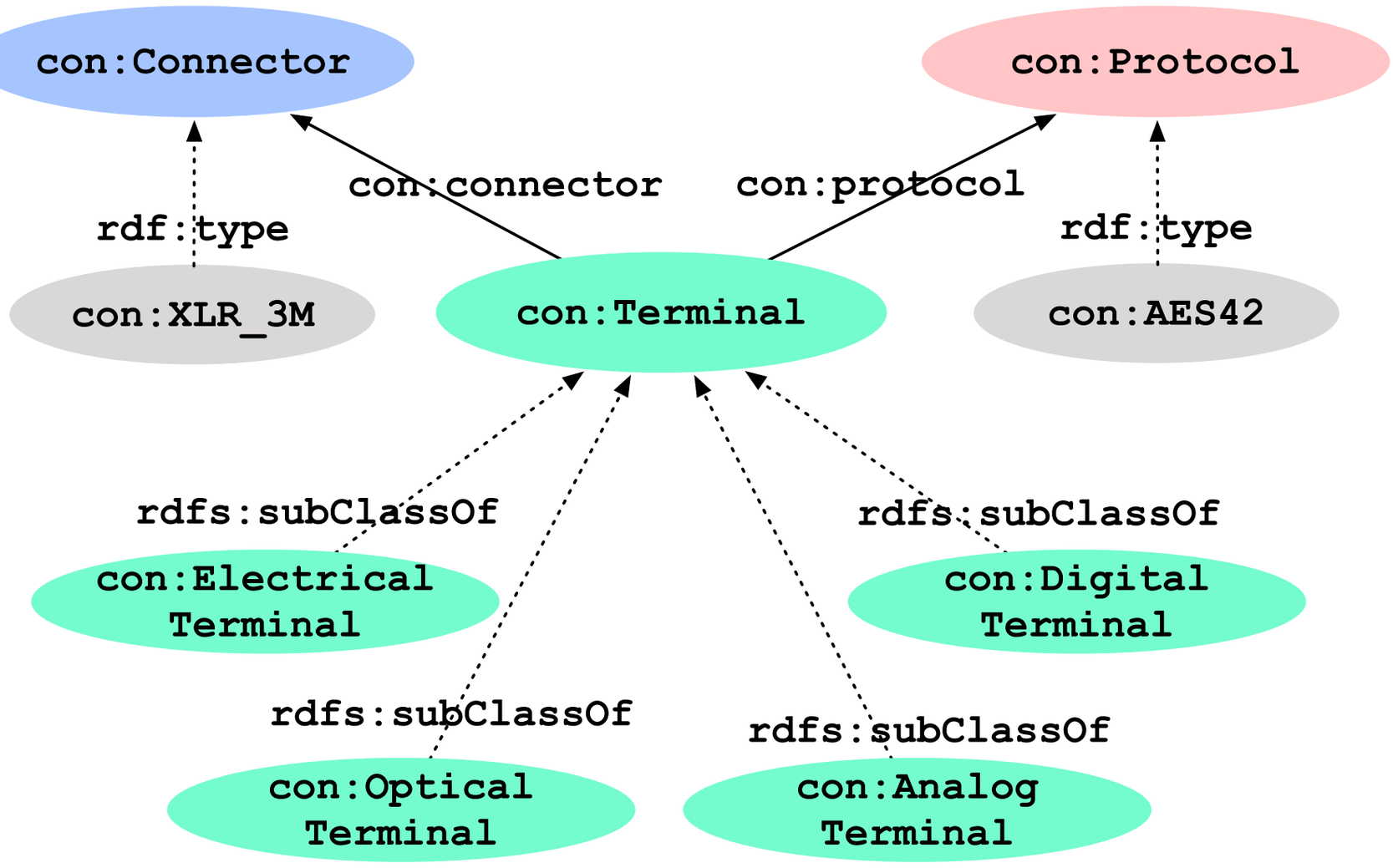

The Studio Ontology

- **A model of audio processing devices**

- **Phenomenon:** a physical process that produces for instance an audio effect
- **Model:** a computational model of the process
- **Implementation:** a particular implementation of the model, e.g. in C++
- **Device:** a concrete device that someone can own

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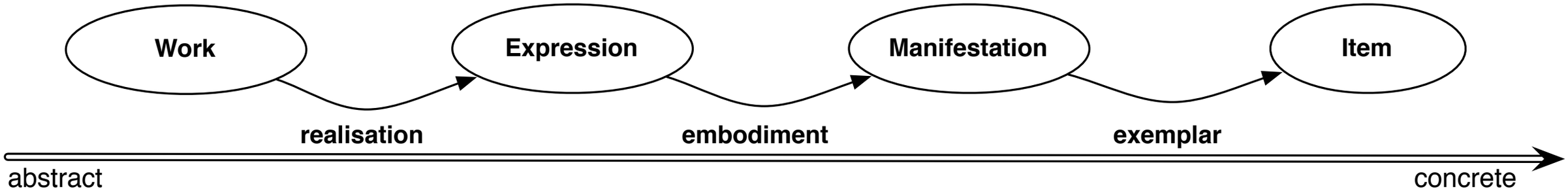
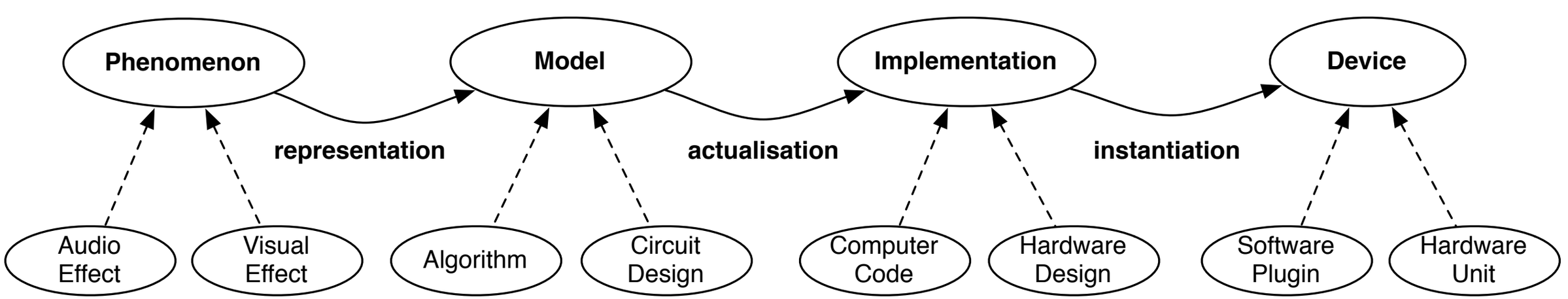
FRBR model





Signal Processing Device model

The Studio Ontology

- **Signal processing workflow model**
- with separate
  - **Event flow**
  - **Signal flow**

- This supports the requirements of real-time recording and audio processing scenarios
- as well as post-production.

The Studio Ontology

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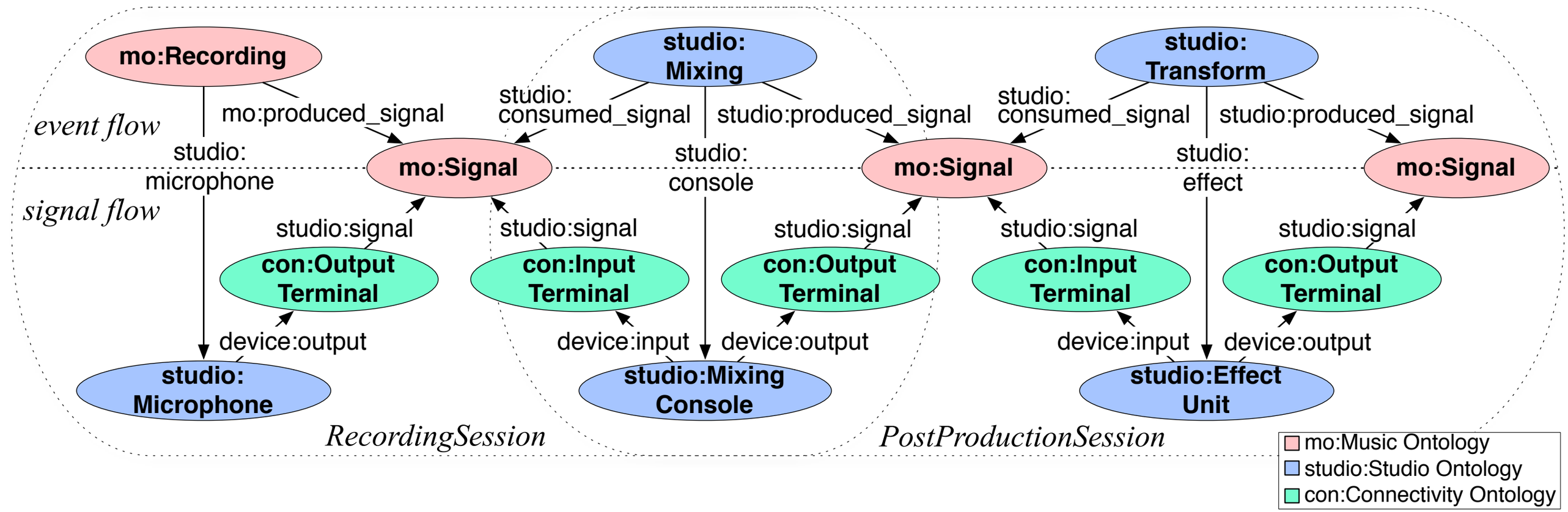
  - **Signal flow**

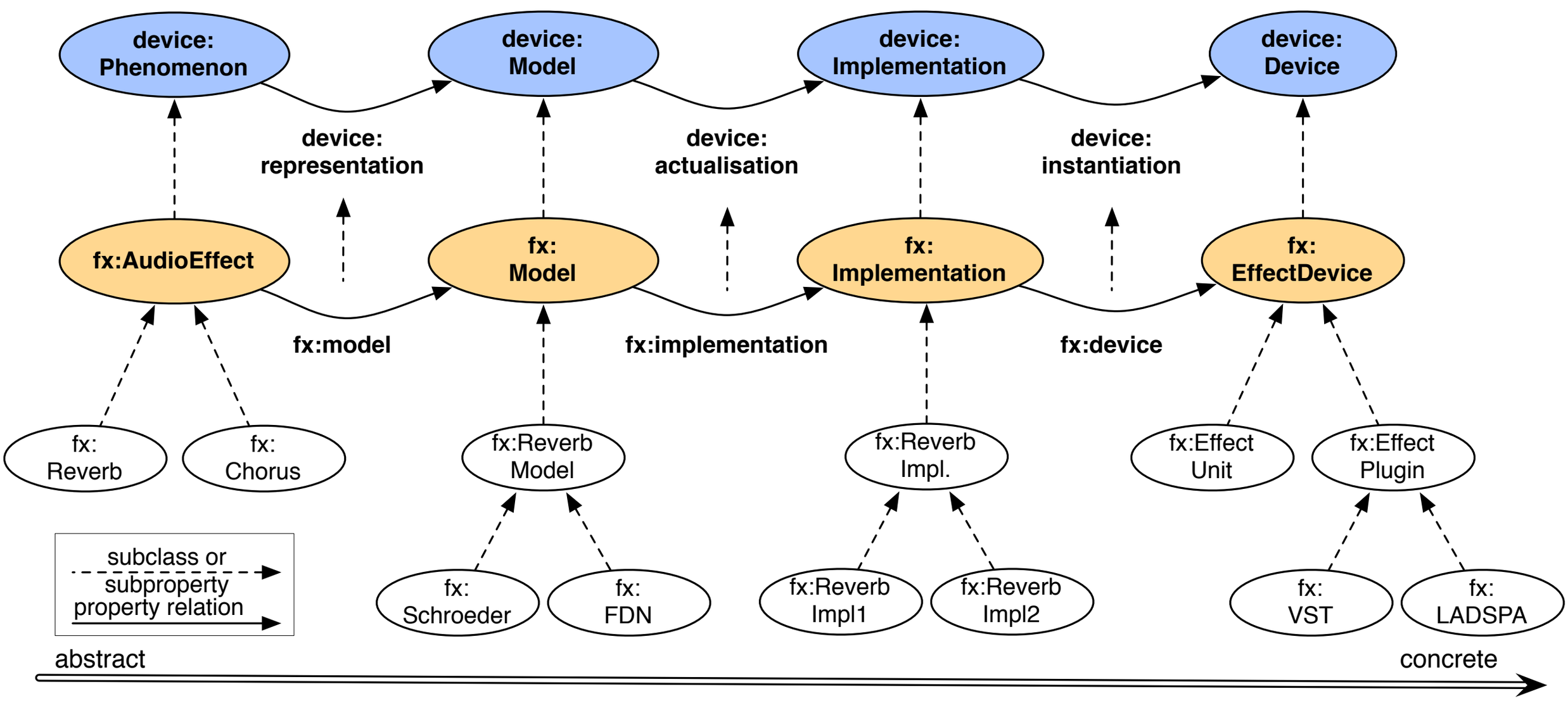


The Studio Ontology

- Extensions in 4 areas (more modules are in preparation)
  - **Audio Recording**
  - **Audio Mixing**
  - **Audio Effects**
  - **Audio Editing**

Audio Effects Ontology

- **A model of audio effects from physical phenomena to concrete devices**



Ontologies and tools for Semantic Audio

The Audio Features Ontology

- **Key points:**
  - Features represented by Events or Signals
  - Timelines link things together
- **Basic feature types:**
  - **Instants:** Time point like features,
    - e.g. a note onset
  - **Intervals:** Temporal segments,
    - e.g. the duration of the intro of a song
  - **Dense features:** signal like features,
    - e.g. a spectrogram

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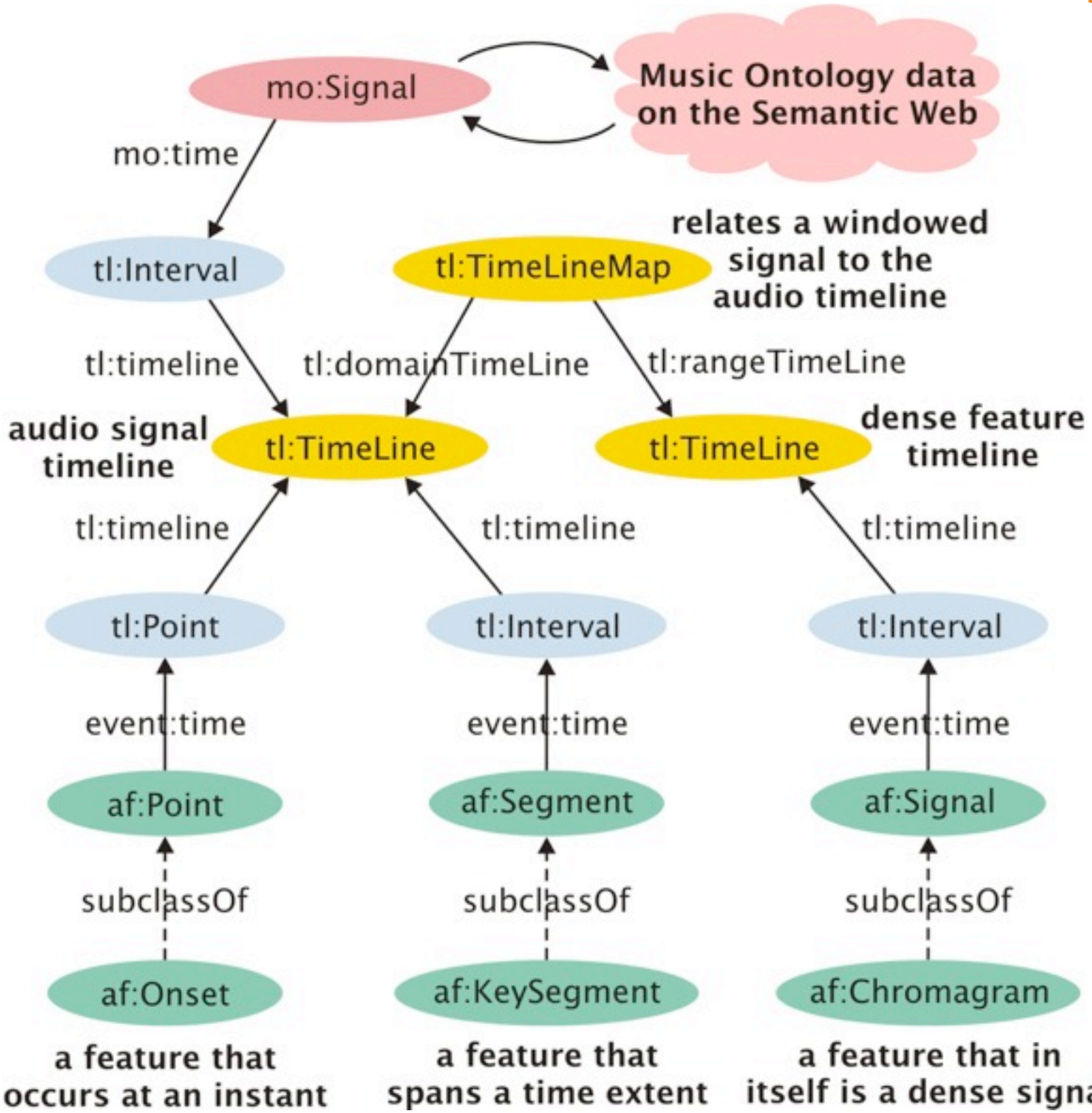


The Audio Features Ontology

- (1) A note onset on the signal timeline:

```
@prefix tl: <http://purl.org/NET/c4dm/timeline.owl#>.
@prefix af: <http://purl.org/ontology/af/>.

:signal_timeline a tl:Timeline .
:onset_23 a af:Onset;
        event:time [
            a tl:Instant ;
            tl:timeline :signal_timeline ;
            tl:at "PT1.710S"^^xsd:duration ;
        ] .
```

- An instant on a timeline

The Audio Features Ontology

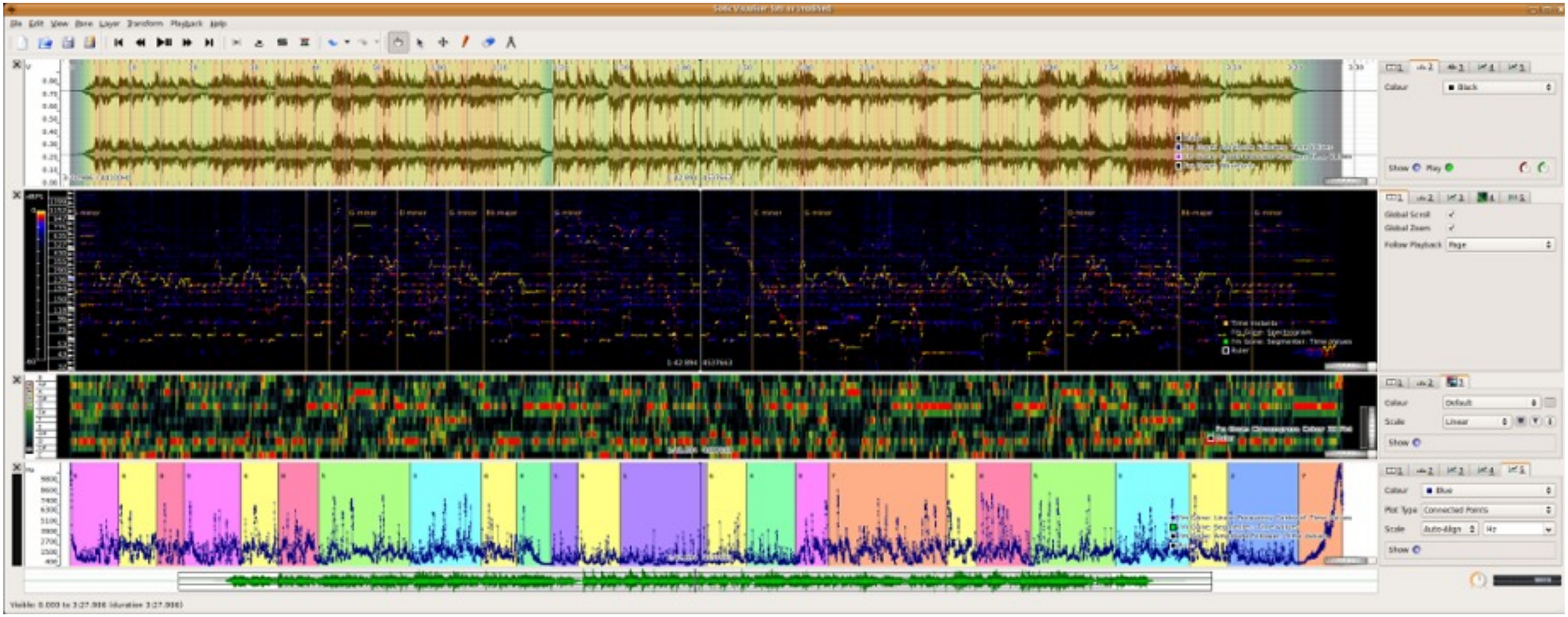
- (2) A key segment:

```
:signal_timeline a tl:Timeline .
:key_segment_1 a af:Segment;
     rdfs:label """Bb major""" ;
     af:feature "11" ;
     event:time [
       a tl:Interval ;
       tl:timeline :signal_timeline ;
       tl:start "PT30.1S";
       tl:duration "PT200S";
     ] .
```

- An interval on a timeline

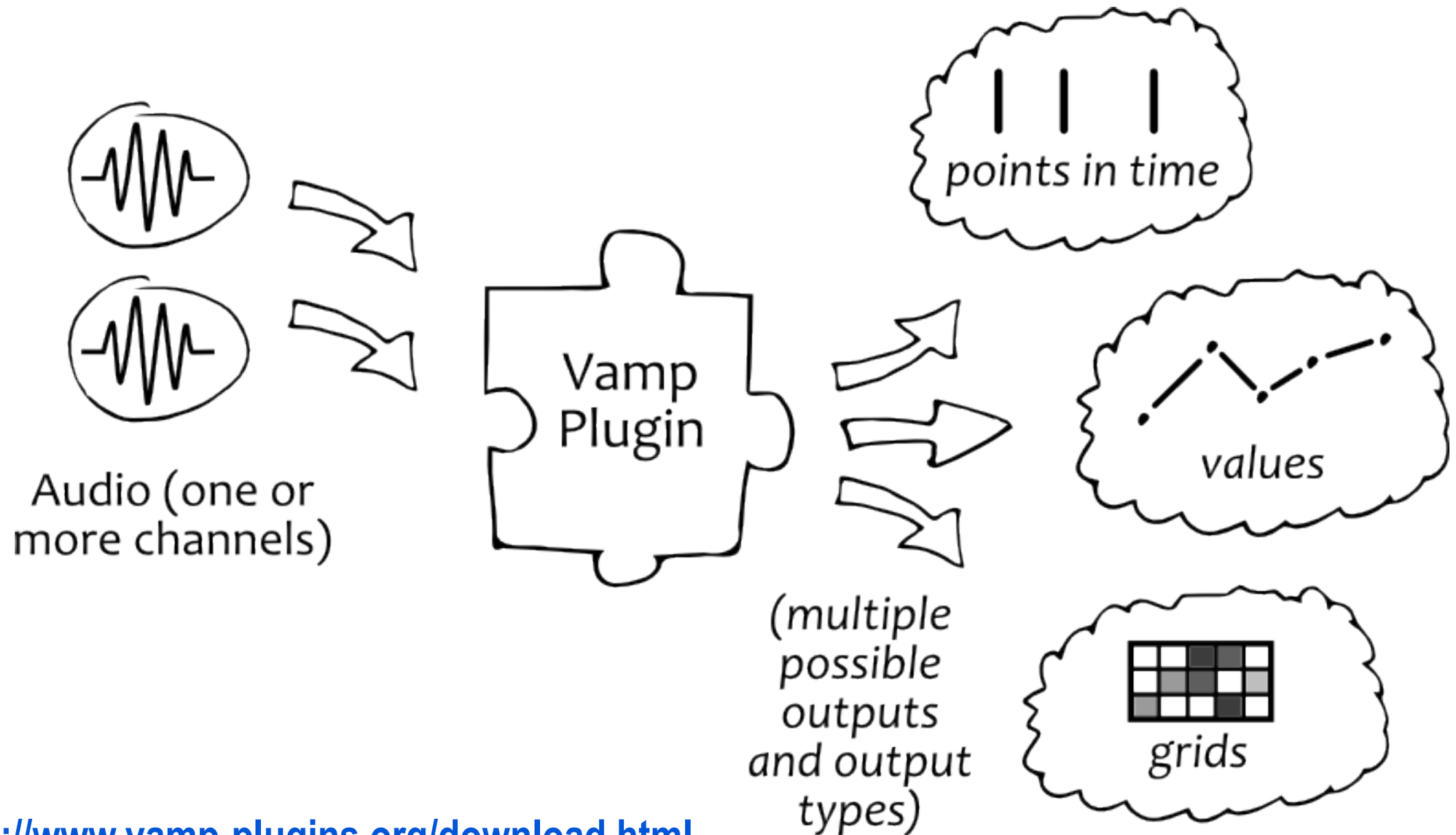
Semantic Audio Tools

- Tools that produce and read RDF according to these ontologies include:
  - **Sonic Annotator**
  - **Sonic Visualiser**



Vamp Plugins

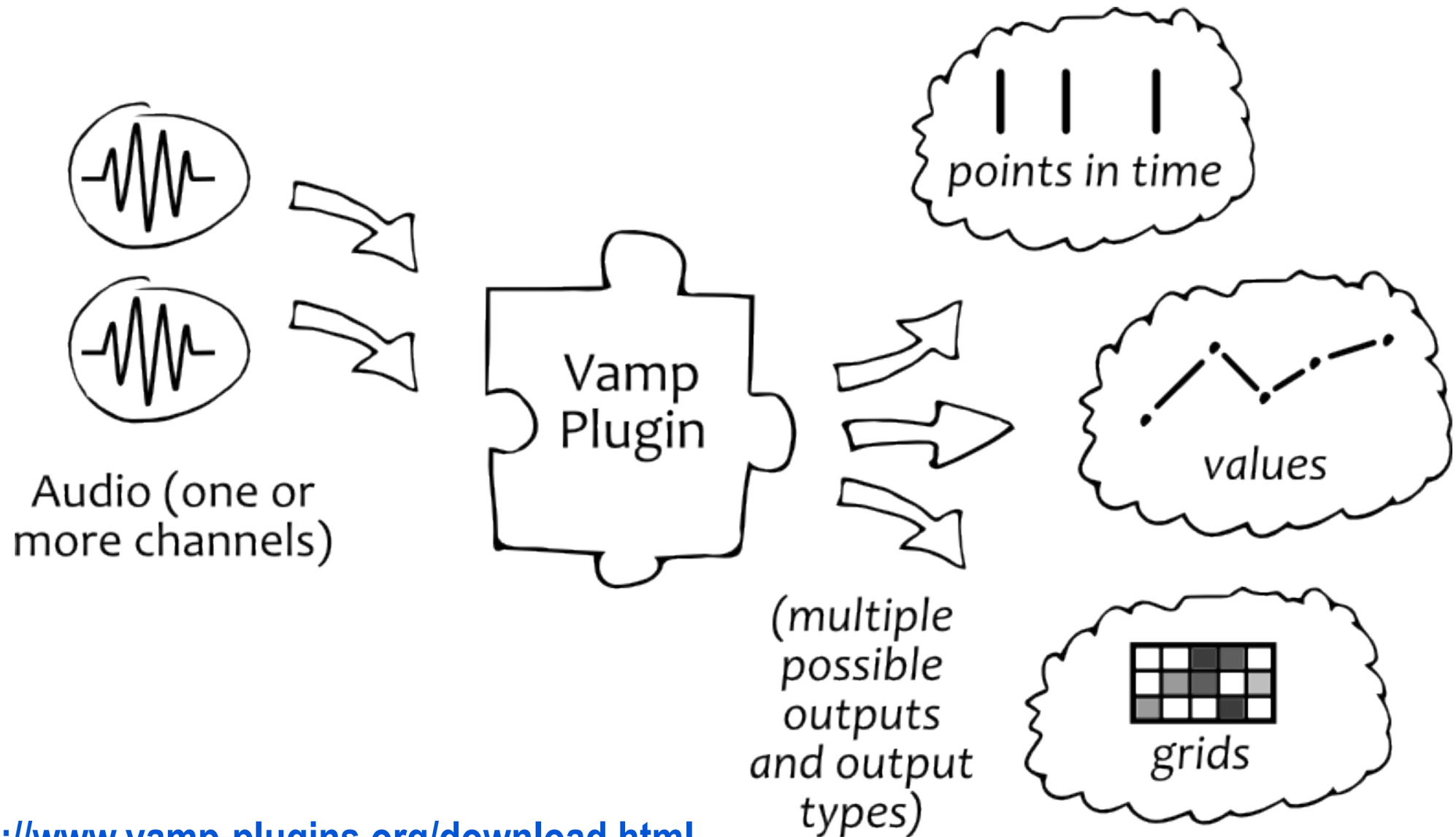
- An Application Programming Interface for feature extraction



http://www.vamp-plugins.org/download.html

Vamp Plugins

- Vamp plugins take audio input and return structured data (but not RDF!)



http://www.vamp-plugins.org/download.html

Vamp Plugins

- **Vamp Plugin Ontology:**
  Links the results with a plugin and the enclosed algorithm that computed them.

- **Vamp Transform Ontology:**
  Allows to express the parameters (e.g. window size) that were used to obtain a particular set of results.

- **Plugins, parameters and results are linked, and described using the same format!**

Sonic Annotator

- A command line Vamp plugin host that outputs RDF
- **Key features:**
- A program for analysing large collections available locally, or on the Web.
- It can read a very wide range of audio file formats.
- Reads Vamp plugin configuration in RDF
- Returns the features in RDF linked with the configuration and editorial data (if available)

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Sonic Annotator

- (1) Create an RDF transform skeleton:

```
$ sonic-annotator -s \
vamp:vamp-example-plugins:fixedtempo:tempo > transform.n3
```

- (2) Edit the file if necessary and run the feature extractor:

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$ sonic-annotator -t transform.n3 \
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- This will dump the results on the standard output.
  - A detailed tutorial is available at
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SAWA

- Sonic Annotator Web Application

- **A tool for Web-based audio analysis**

- Runs Vamp feature extractor plugins on a small uploaded audio collection

- Configured using RDF and return RDF data according to the Audio Features Ontology.

SAWA

Configure Transform: Note Onset Detector, Onset Detection Function output

Parameter	Value	Limits	Unit
Block Size	1024	-	Samples
Step Size	512	-	Samples
Onset Detection Function Type	Complex Domain	(0 - 4)	-
Adaptive Whitening	☑	on/off	-
Onset Detector Sensitivity	50	(0 - 100)	%

Options

Transform name: **User001**
Transform identifier: fff1a579-3858-5eb5-bca8-c311bc33464a
Transform enabled: ☑
Treat transform as non-deterministic (do not use cache): ☐

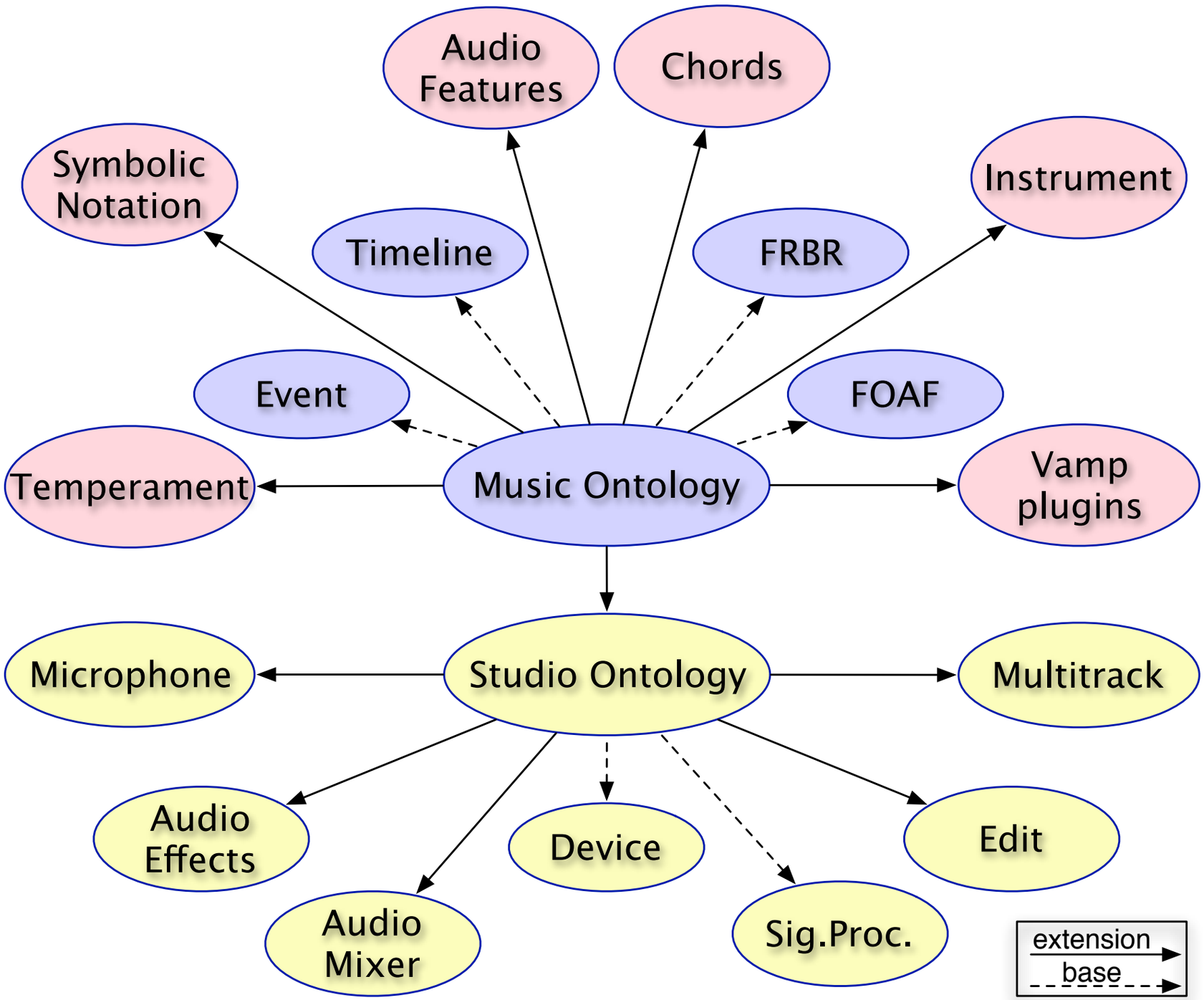
Update | Save | Save As | Delete | Cancel

```
@prefix xsd:      <http://www.w3.org/2001/XMLSchema#> .
@prefix vamp:     <http://purl.org/ontology/vamp/> .
@prefix :         <#> .

:transform a vamp:Transform ;
    vamp:plugin <http://vamp-plugins.org/rdf/plugins/qm-vamp-plugins#qm-onsetdetector> ;
    vamp:step_size "512"^^xsd:int ;
    vamp:block_size "1024"^^xsd:int ;
```

Ontologies and Tools for Music Production

Audio FX Ontology



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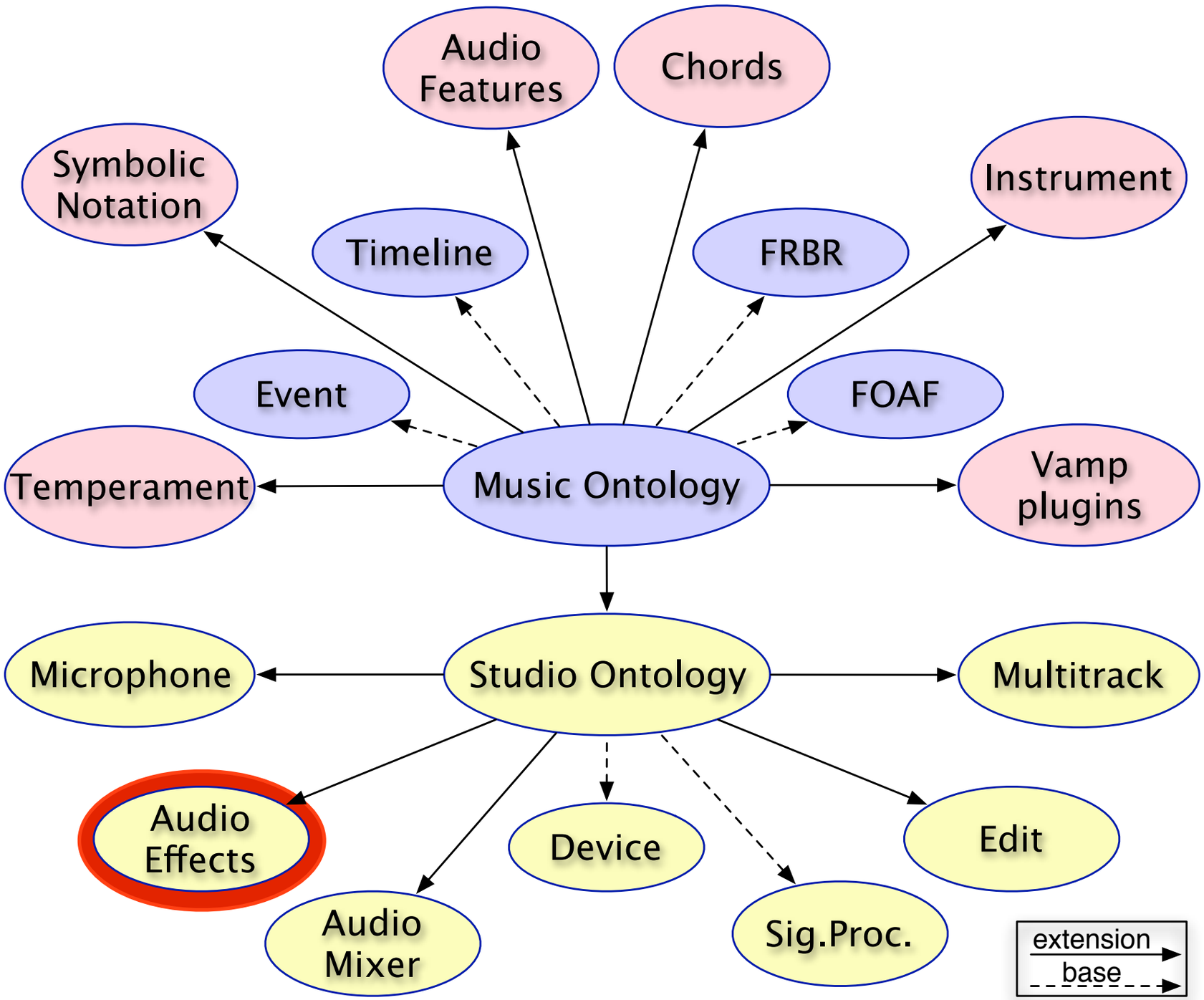

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- enable communication between musicians, developers and engineers

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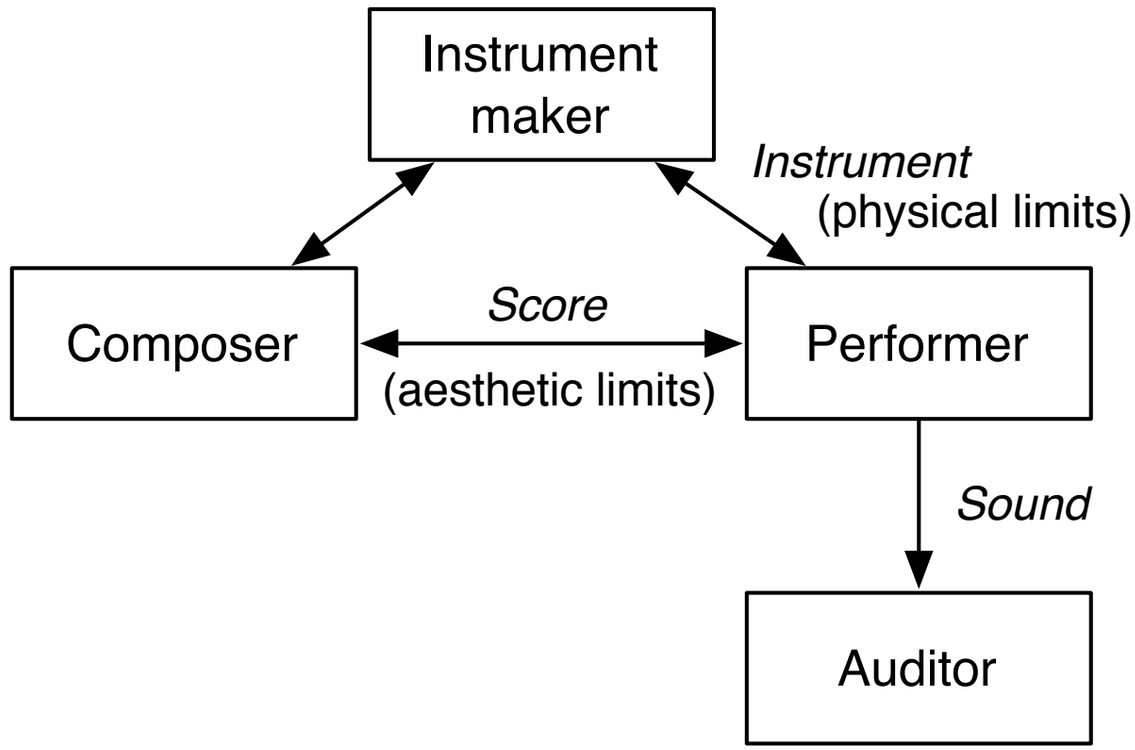

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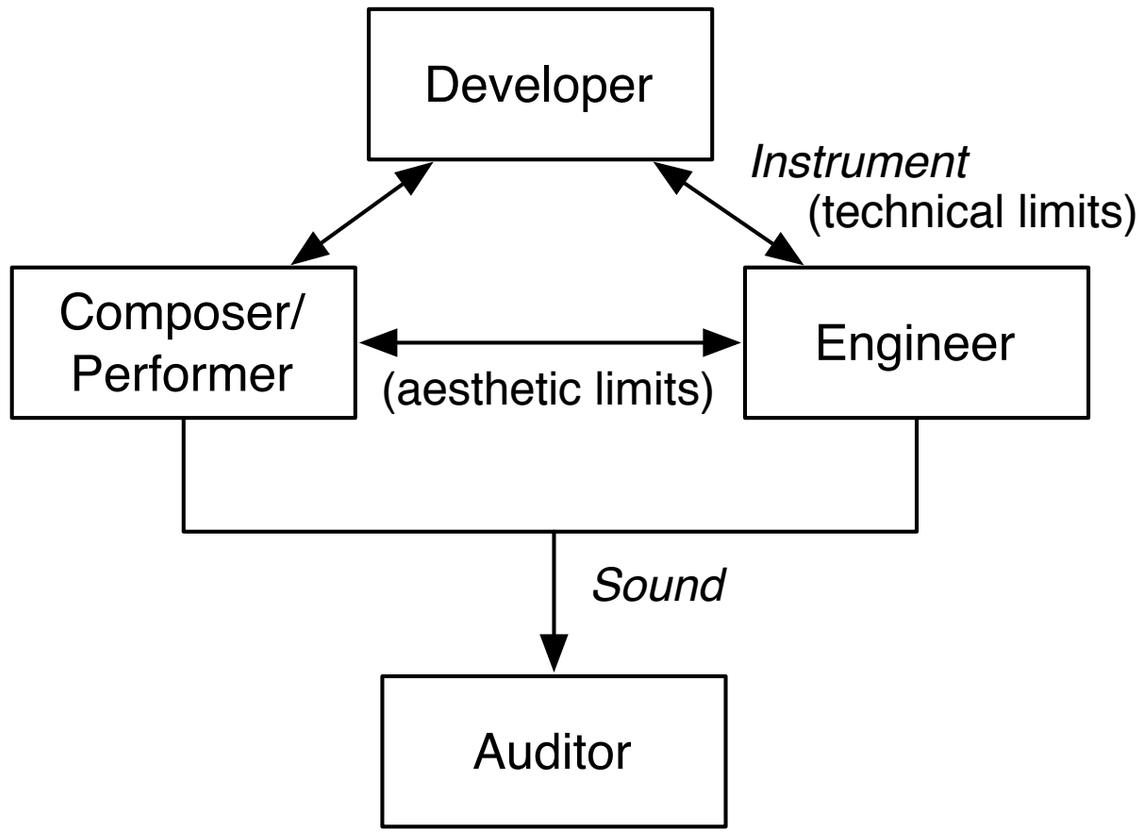

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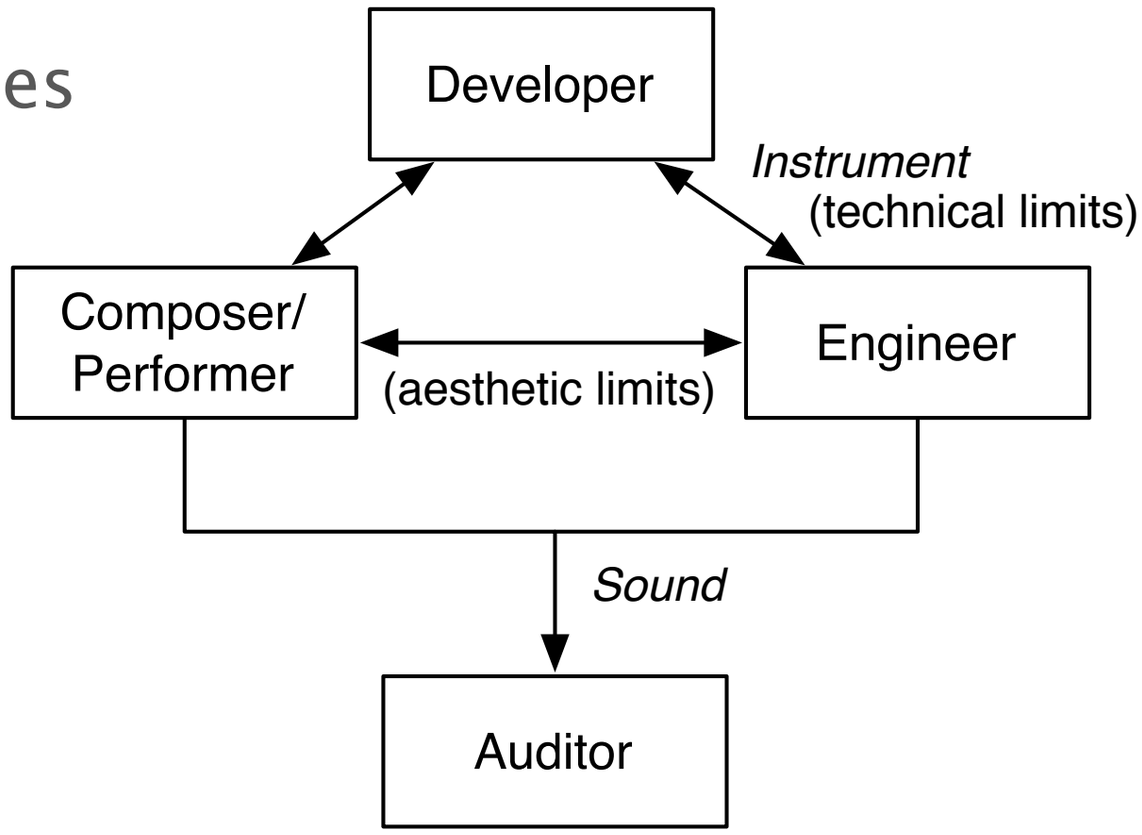
- interdisciplinary classification of audio effects:
  - perceptual attributes
  - implementation techniques
  - application



Audio FX Ontology

- enable communication between musicians, developers and engineers
- interdisciplinary classification of audio effects:
  - perceptual attributes
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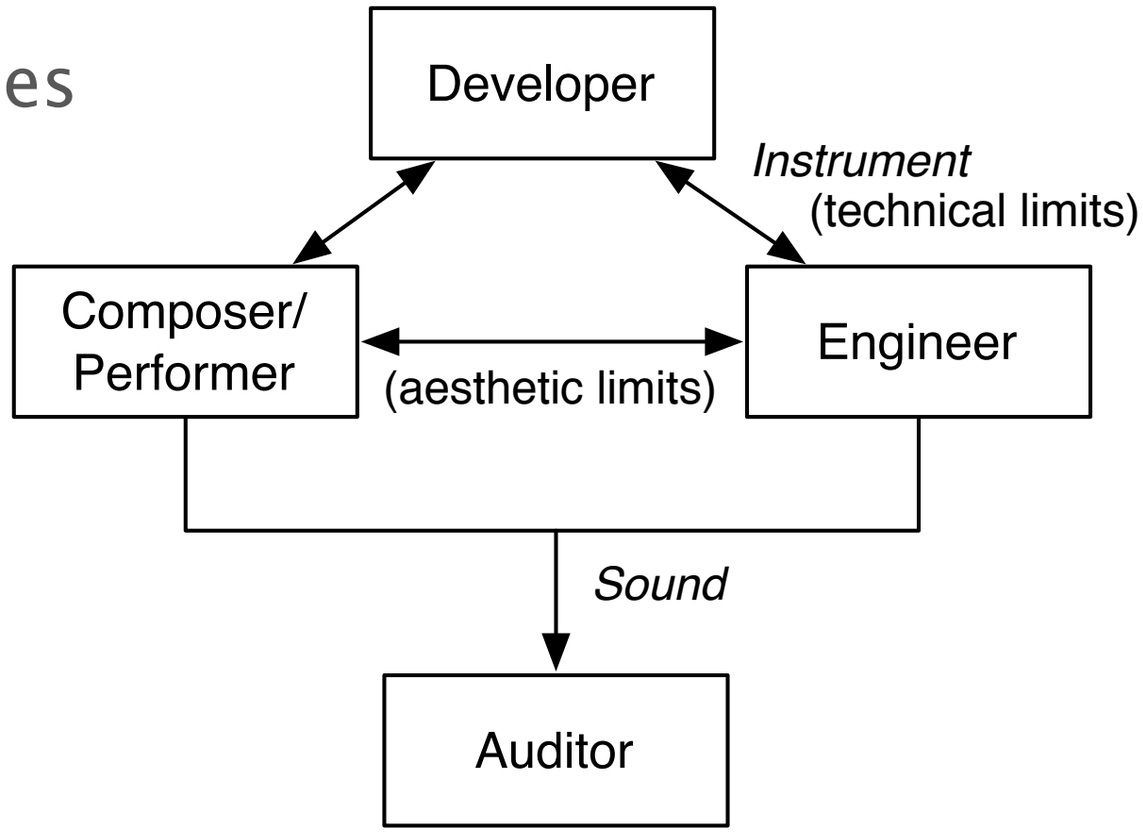
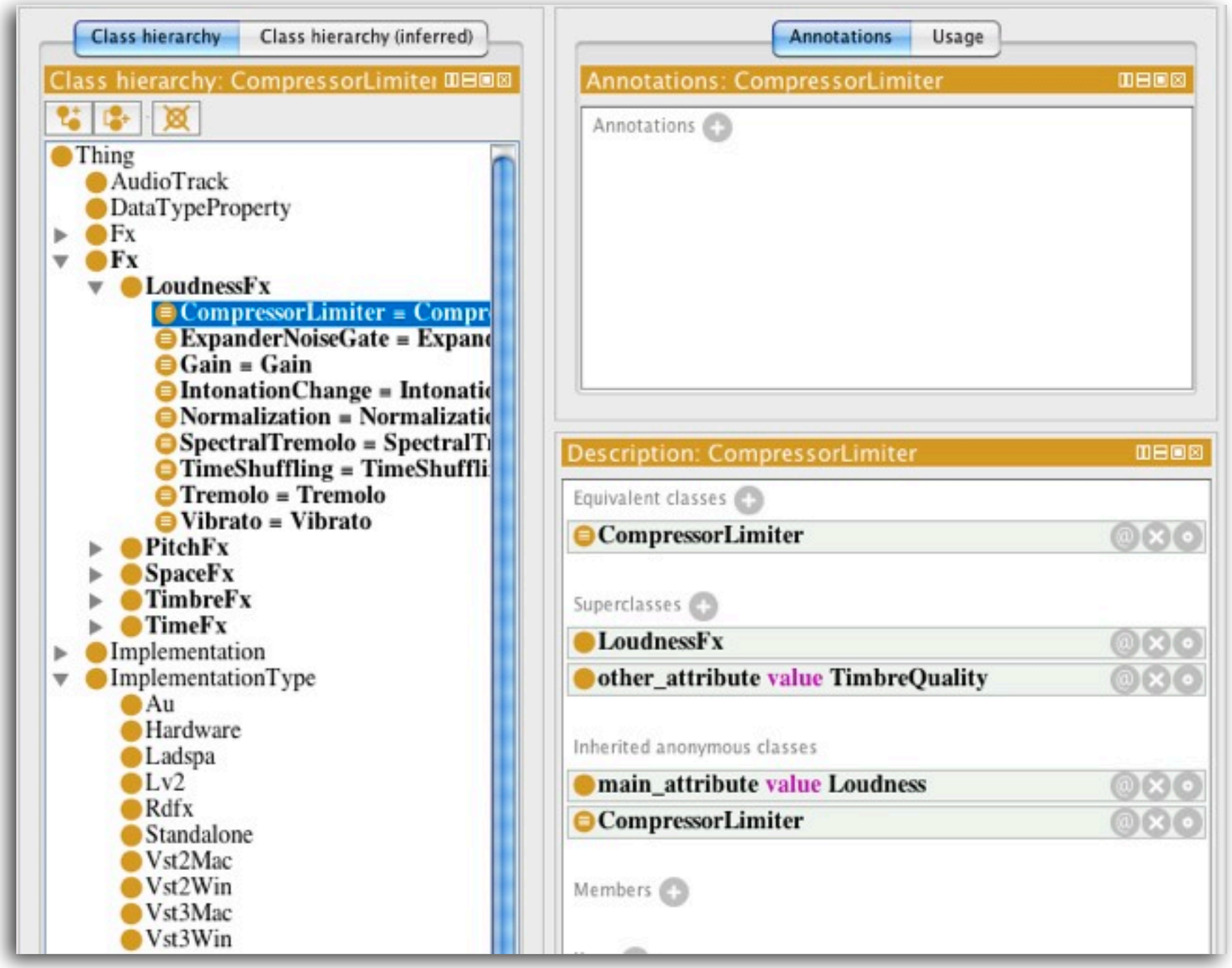
  - application
- Modularised
  - Vocabulary
    - List of FX
    - Descriptors
    - Application of FX
  - Classifications



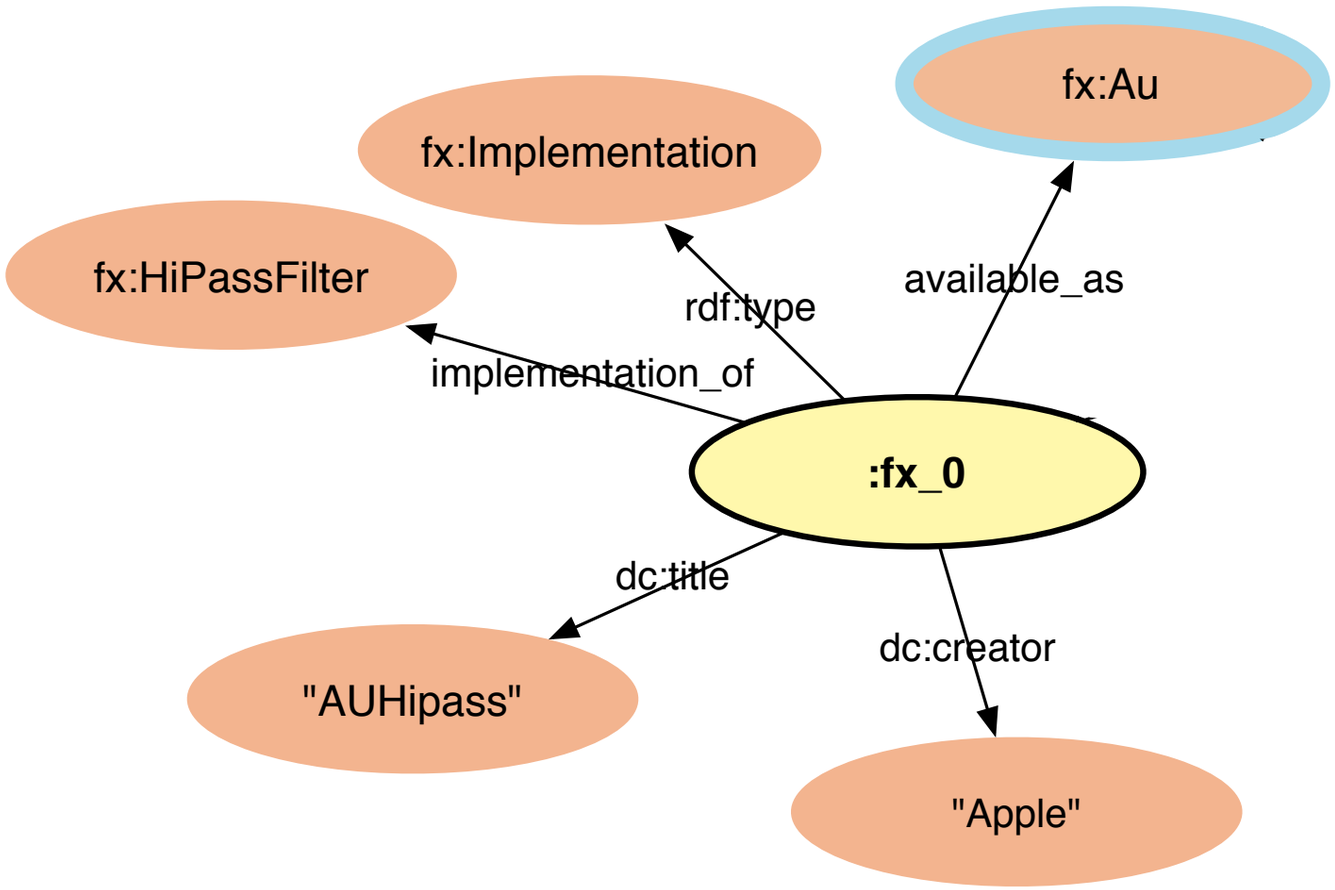
Perceptual Classification

- Loudness
- Pitch/Harmony
- Space
- Timbre
- Time/Duration



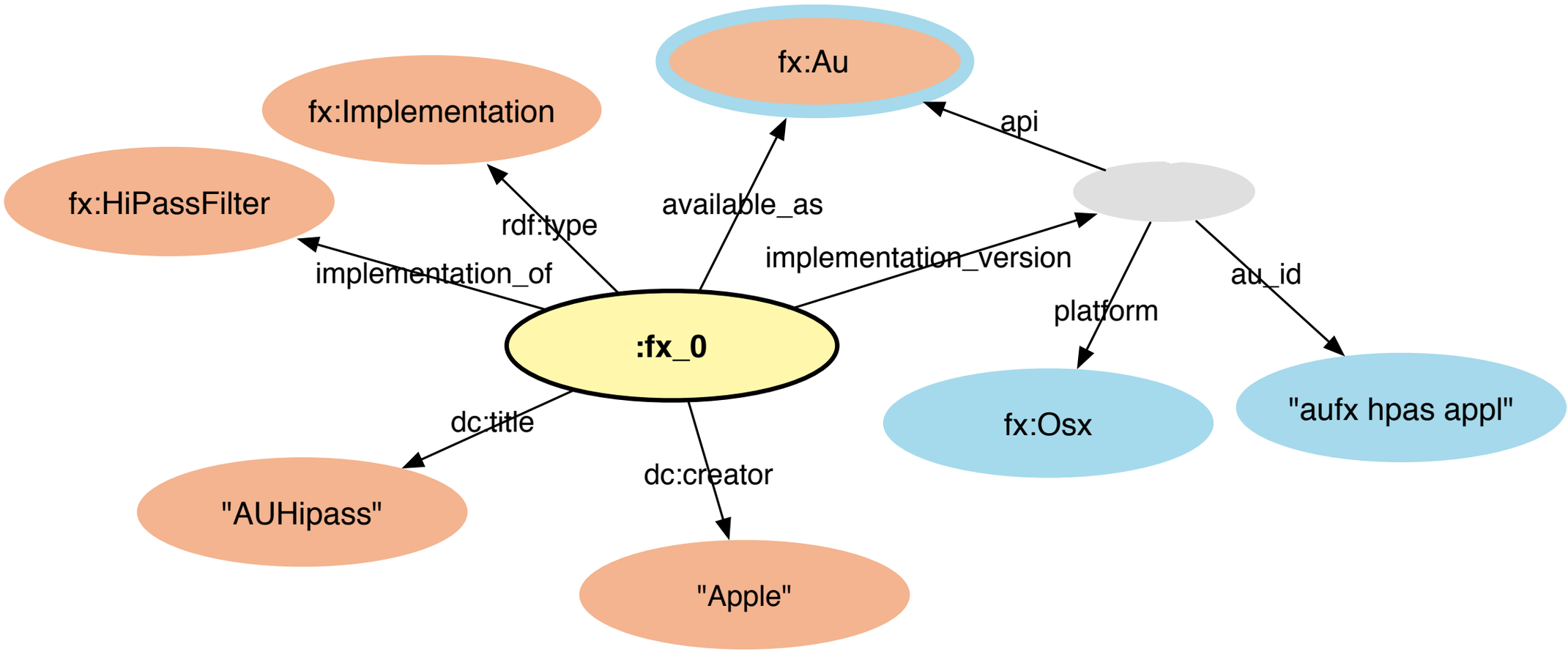
Audio FX Description

- general descriptors



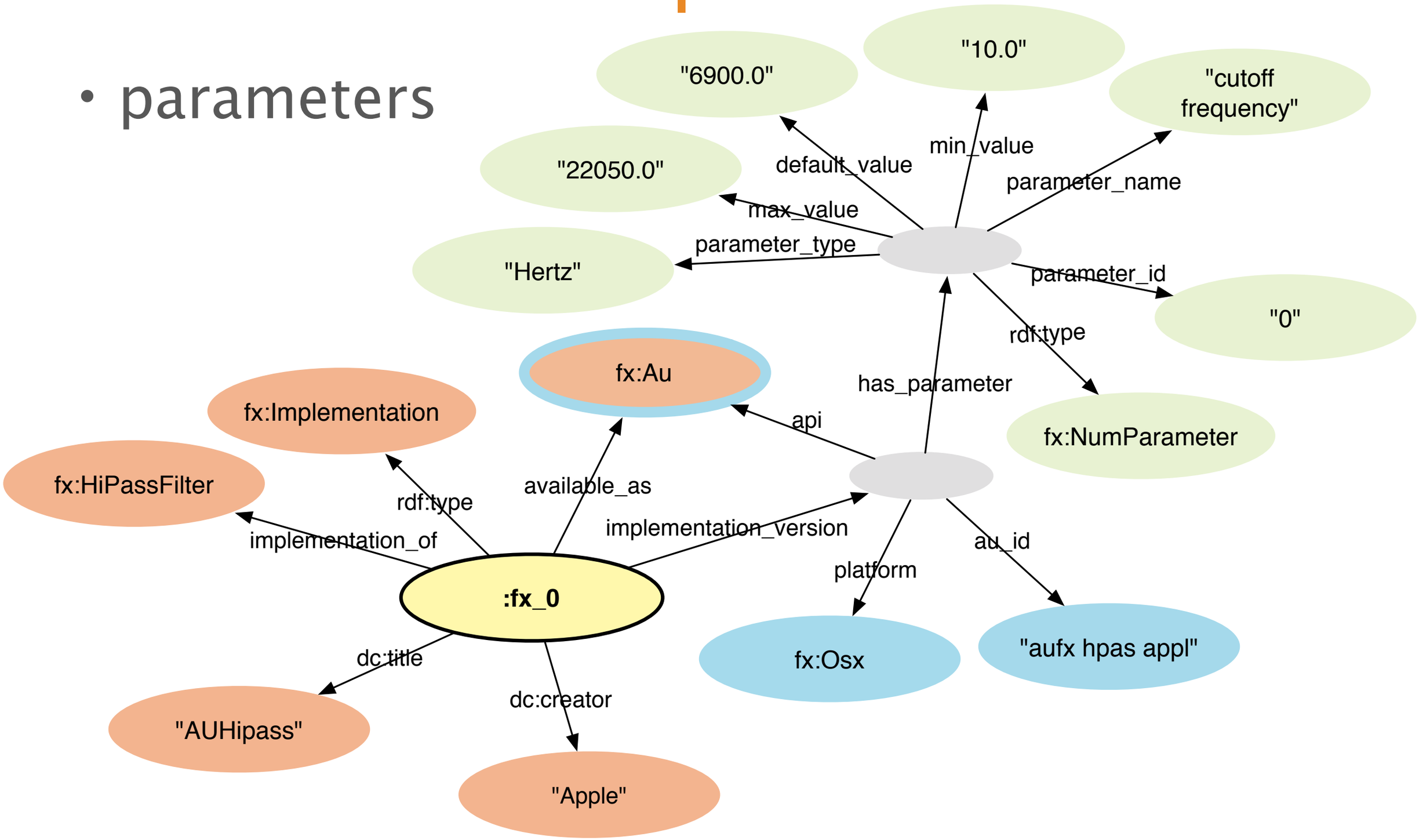
Audio FX Description

- specific version



Audio FX Description

- parameters



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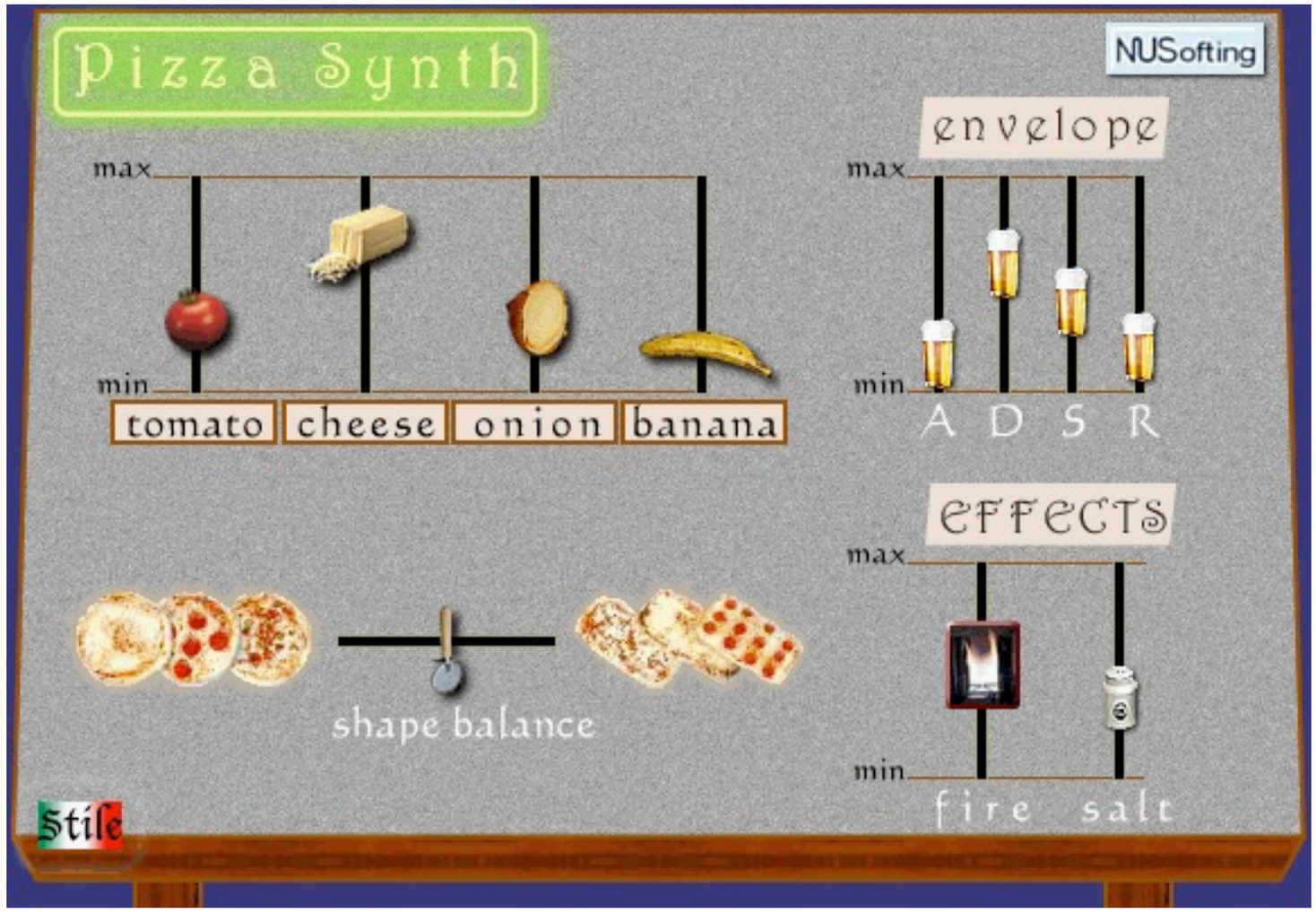

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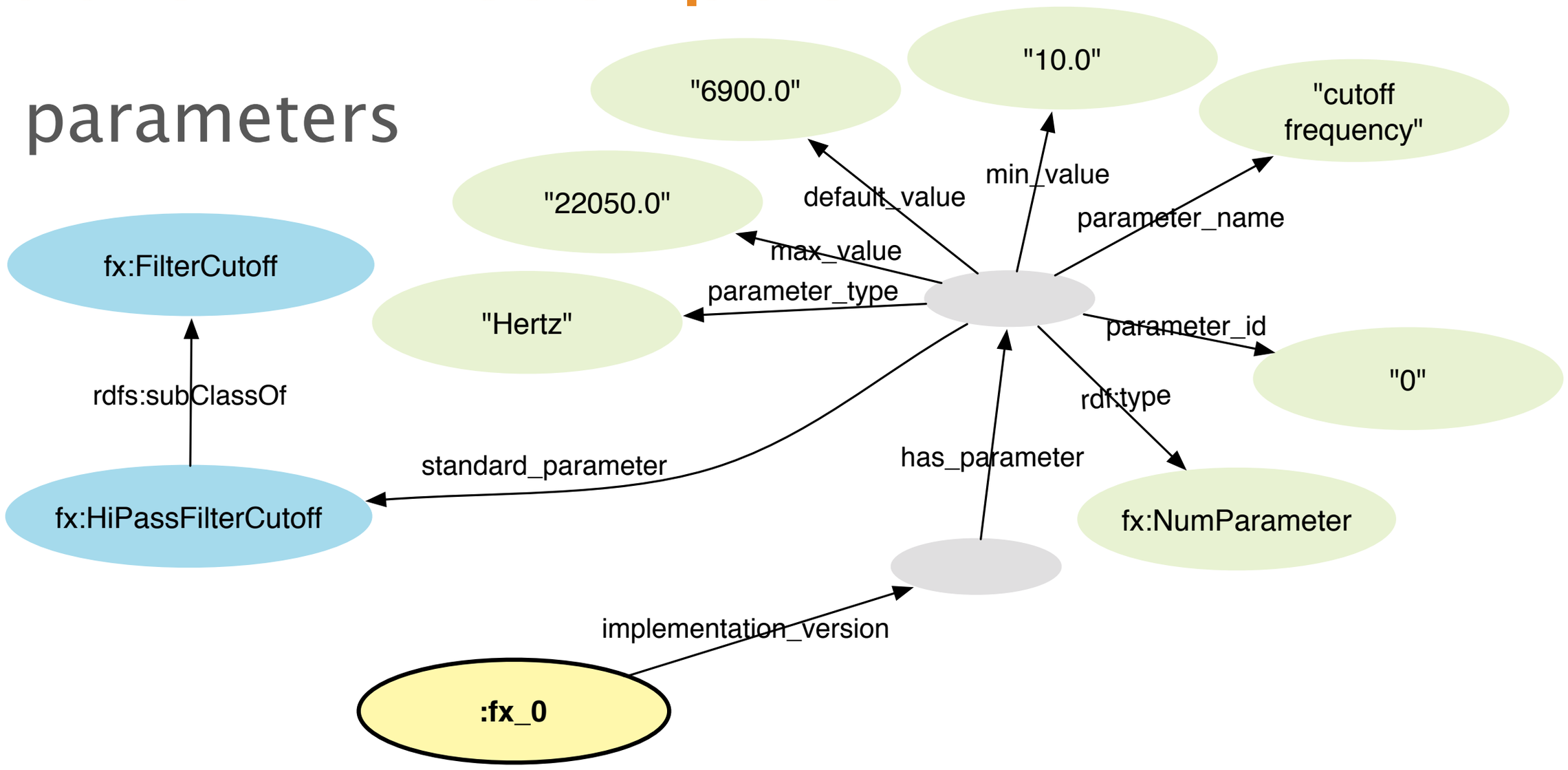

- definition of standard parameter classes

Audio FX Description

- link to classification system
- e.g. perceptual (fxp)

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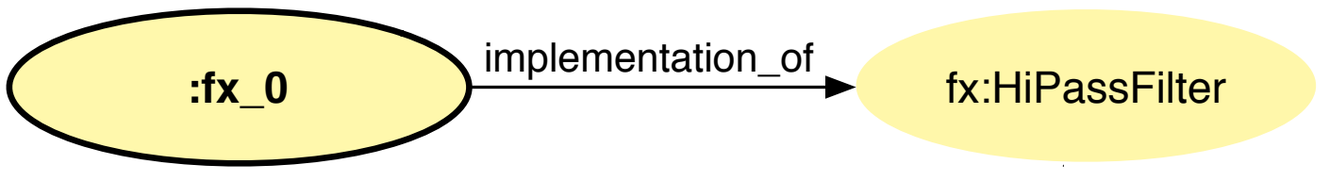

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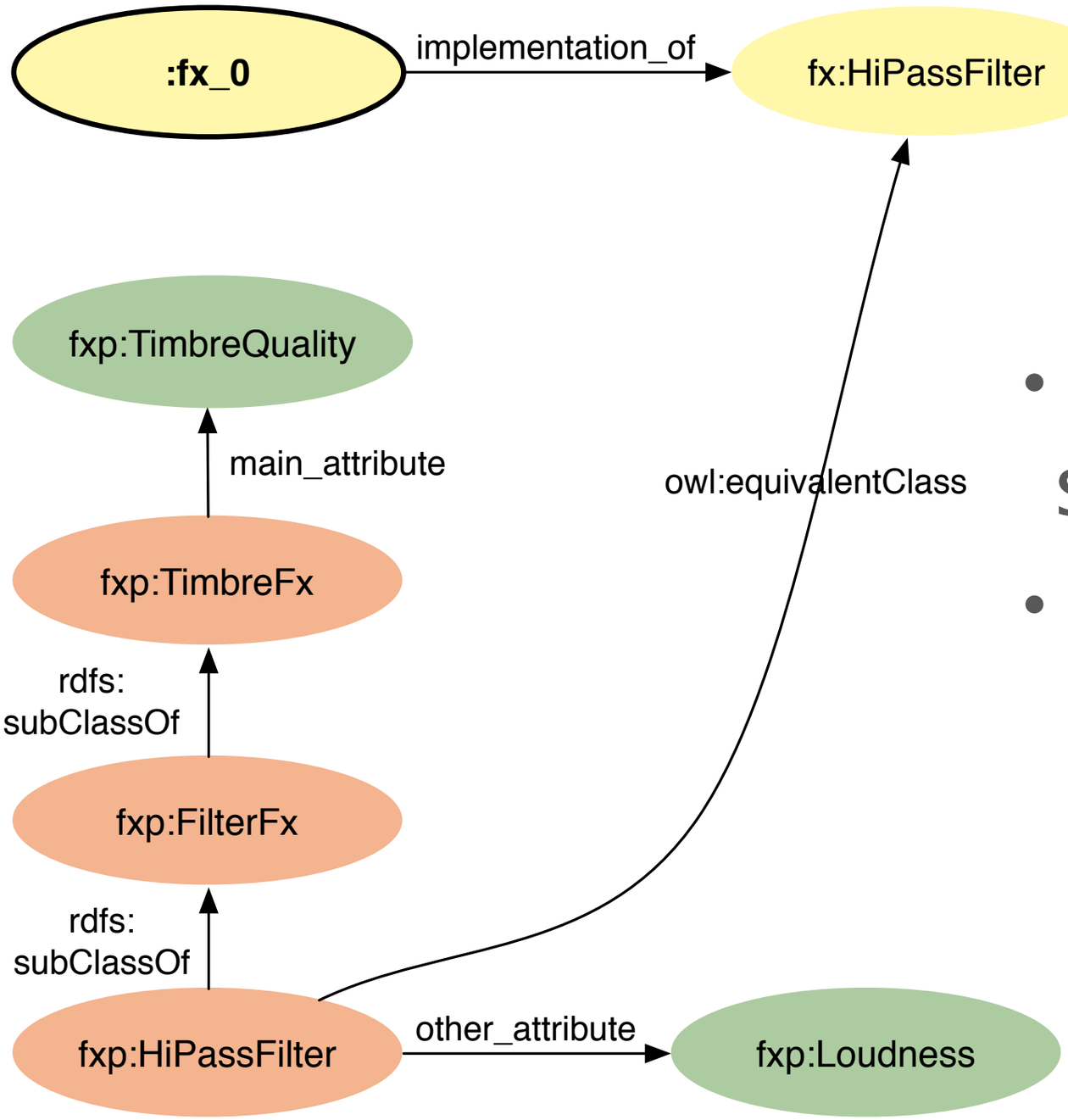
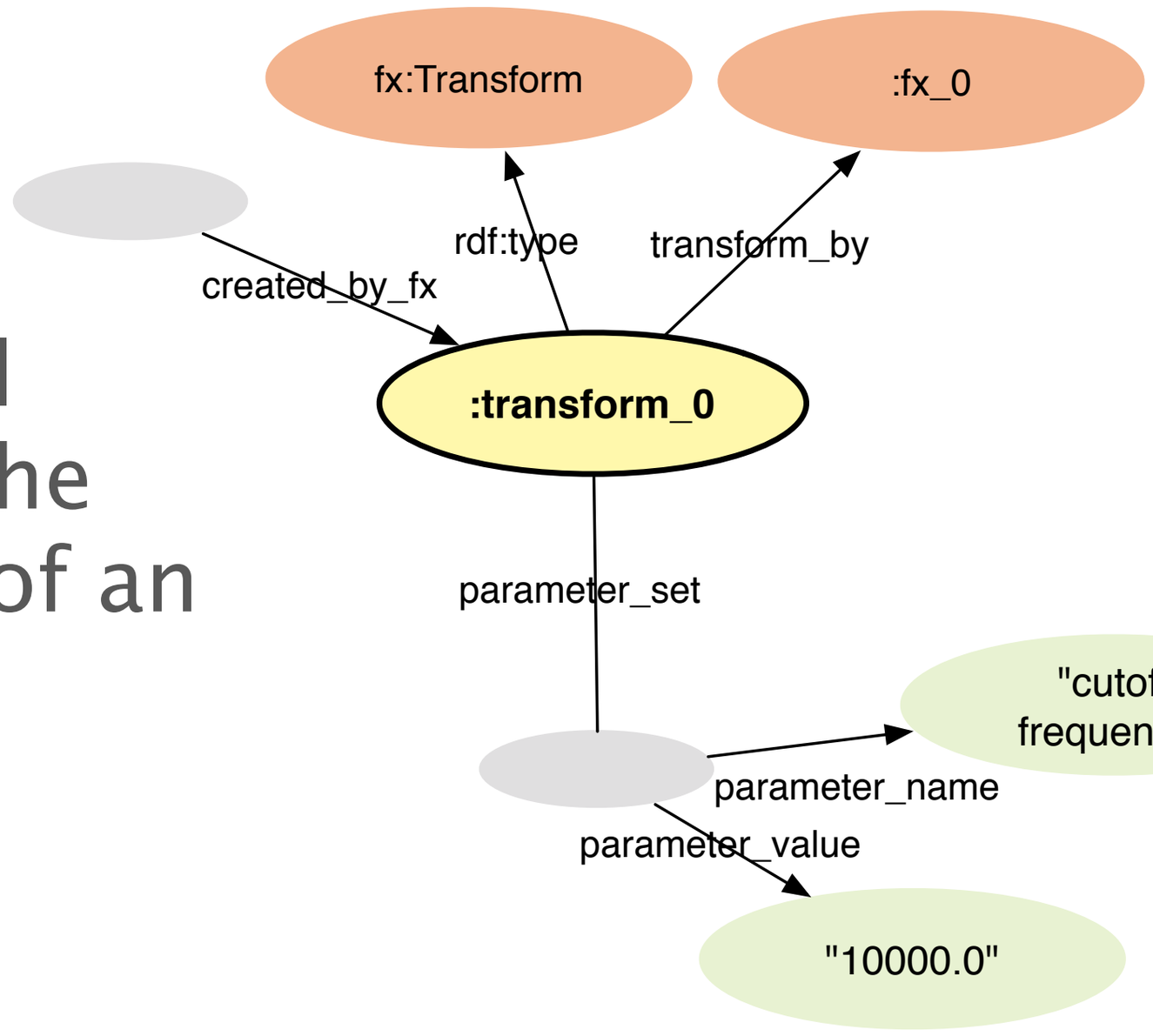
Audio FX Description



- link to classification system
- e.g. perceptual (fxp)

Audio Transformation

- event/signal created by the application of an effect



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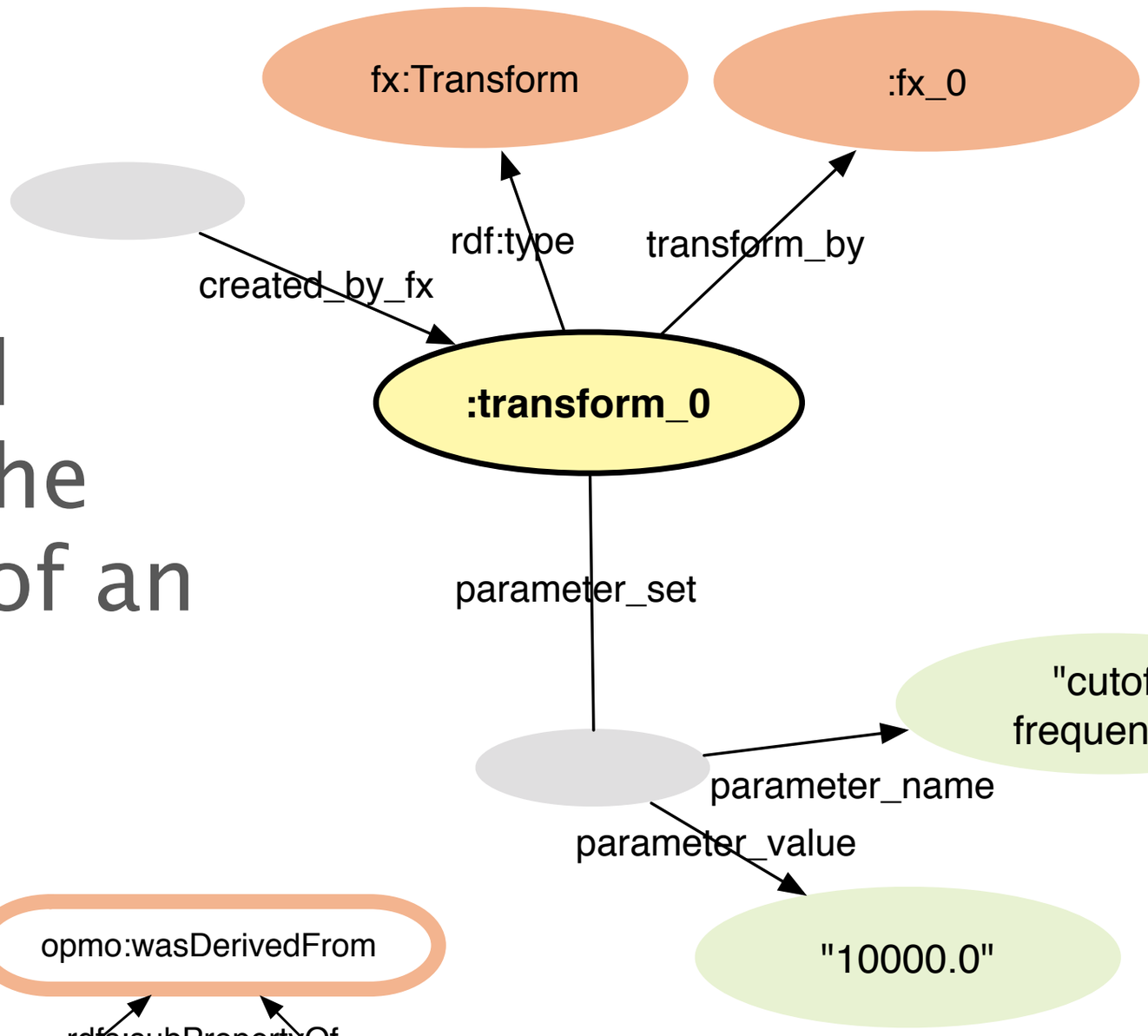

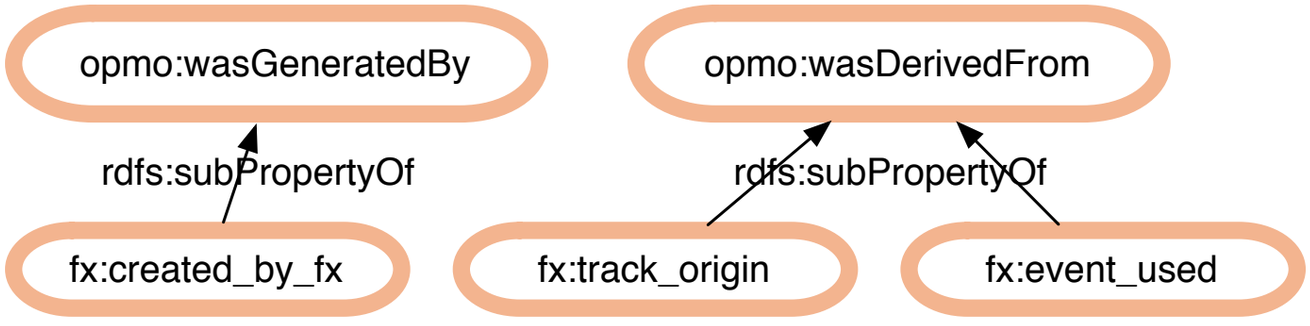

SPARQL Query Example

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- instead: predict and accumulate metadata (where possible)
- use RDF and the Audio Effects Ontology

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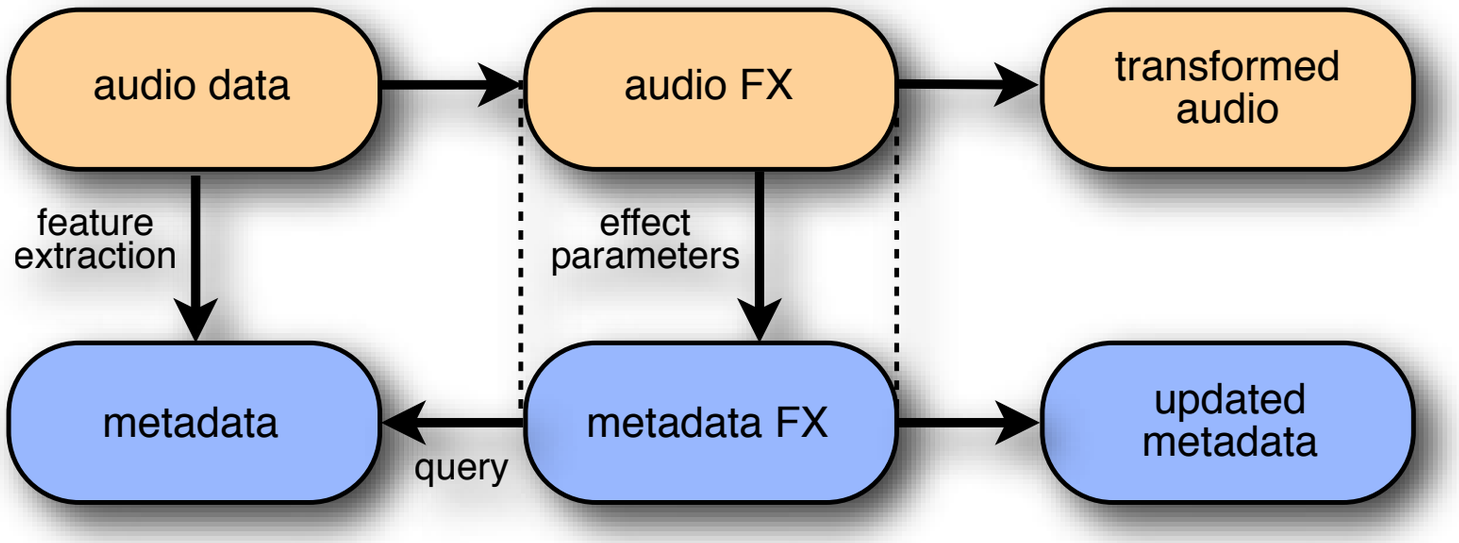
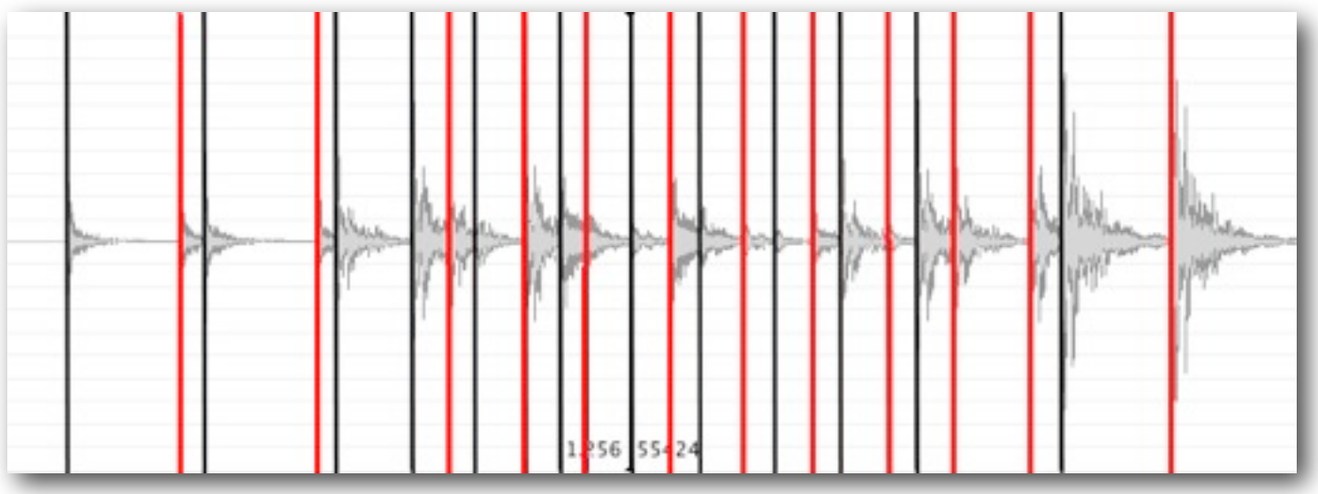


FX-Based Information Retrieval



```
:event_1 a af:Onset;
     event:time [ a tl:Instant;
             tl:at "PT2.194007S"^^xsd:duration;
             tl:onTimeLine :signal_timeline_0];
     fx:created_by_fx :transform_0;
     fx:event_used :event_0;
     fx:track_origin :drums.
```

FX-Database on the Semantic Web

FX-Database on the Semantic Web

- Large database on the Web: KVR Audio

Frohmage is a multi-band resonant filter. It can offer some unique sounds, from slow and deep filter sweeps to the most savage tones with high resonance setting and heavy distortion.

- Highly resonant low-pass filter.
- Cutoff frequency unit selection : Hz or musical note.

Product	**Frohmage**
Developer	**Ohm Force**
Price (MSRP)	Free
Type / Tags	Filter

Plug-in, App & Soundware Format(s)

Effect(s)	VST, RTAS, DX

Operating System Availability

Operating System	Latest Version	Download	Released
X64	1.60	Free Download	✓
64	1.60	Free Download	✓

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FX-Database on the Semantic Web

- KVR module for the FX Ontology

```
:fx_0 a owl:Class, fx:PlugIn ;
  fx:implementation_of fx:Reverberation, kvr:Reverb ;
  dc:title "VariVerb Pro"^^xsd:string ;
  dc:creator "Magix"^^xsd:string ;
  rdfs:seeAlso "http://www.samplitude.com/eng/vst/variverb.html";
  fx:available_as fx:Vst ;
    gr:hasPriceSpecification
    [ a gr:UnitPriceSpecification ;
      gr:hasCurrency "USD"^^xsd:string ;
      gr:hasCurrencyValue "199"^^xsd:float ;
      gr:validThrough "2012-02-13T20:16:40"^^xsd:dateTime ] .
```

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- **Music production**
  - detailed metadata creation

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    - perceptual/technical descriptors
    - link to data on the Semantic Web
  - semantic metadata as control input for adaptive audio effects

Applications of the FX Ontology

- **Musicological research**
  - production tendencies of genres/eras
  - more detailed descriptors due to retention of multitrack and transform-specific metadata

Summary

- The use of Semantic Web technologies enable Semantic Audio applications that link and scale like the Web itself.

- New applications using a mash-up of data sources

- Provide interoperability between tools in music information sciences and music production

Summary

- **Future work**
- Release large datasets using these ontologies
- Consider a broader set of use cases
- Harmonisation with standards
- Work towards a Semantic Audio Desktop