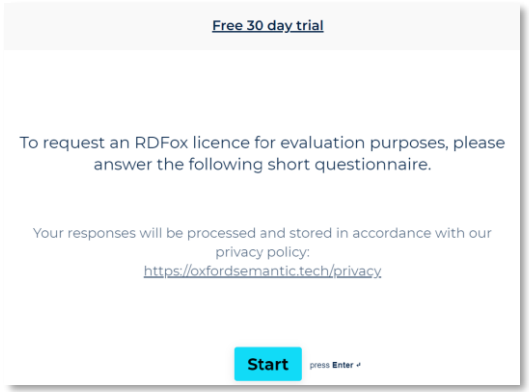
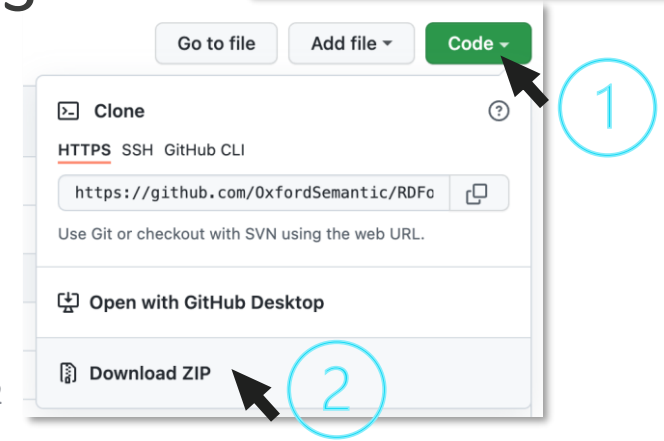
RDFox Reasoning Workshop

The world’s most performant knowledge graph and semantic reasoning engine.

Requirements

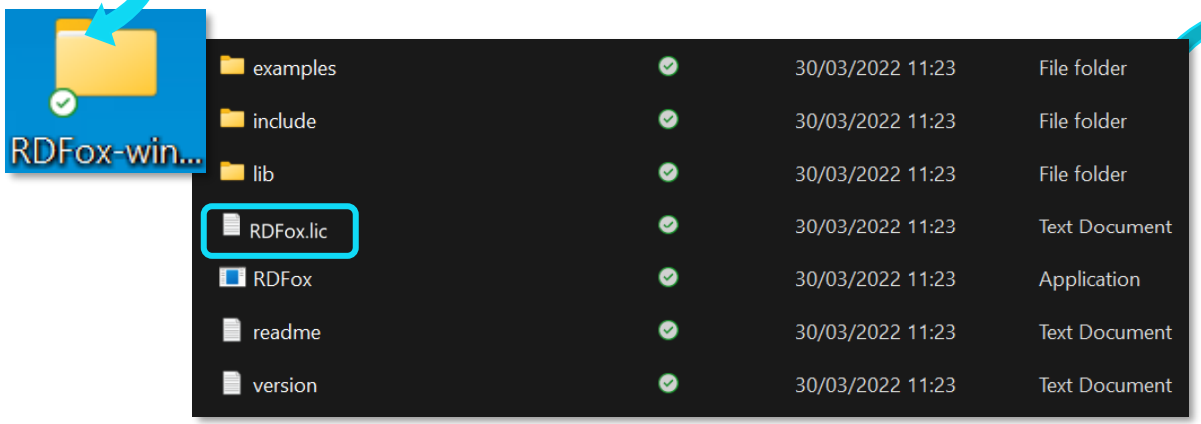
A. Get an RDFox License
   https://www.oxfordsemantic.tech/tryrdfoxforfree
B. Download RDFox (& unzip)
   https://www.oxfordsemantic.tech/downloads
C. Download the class materials from Github:
   https://github.com/OxfordSemantic/RDFoxWorkshop
D. *OPTIONAL* Get your IDE of choice ready (VS Code etc.)
   https://code.visualstudio.com/



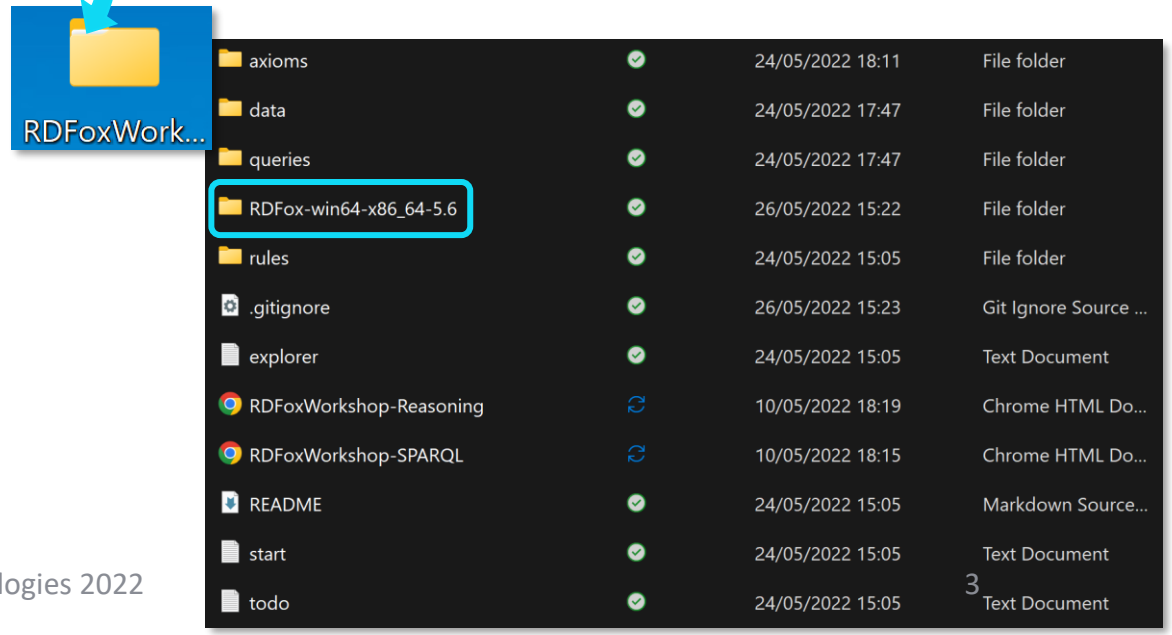


You should have…

1 Make sure to put your **license INSIDE** the **RDFox folder**.



2 Then drop your **RDFox folder INSIDE** the **Workshop folder**.



Without this setup you will need use different file paths in the commands we provide.

Setting up RDFox

- We recommend using an IDE (e.g. VS Code)
- Open a terminal, navigate to the workshop folder (or open it in VS Code)
  `cd path/to/RDFoxWorkshop`
- From there run:
  - MacOS ARM: `./RDFox-macOS-arm64-5.7/RDFox sandbox`
  - MacOS INTEL: `./RDFox-macOS-x86_64-5.7/RDFox sandbox`
  - Windows: `RDFox-win64-x86_64-5.7/RDFox.exe sandbox`
- The RDFox server should now be running.

```
Source code for RDFox v1.0 Copyright 2013 Oxford University Innovation Limited and subsequent improvements Copyright 2017-2021 by Oxford Semantic Techn
ologies Limited.
This copy of RDFox is licensed for Developer use to Tom Vout (tom.vout@oxfordsemantic.tech) of OST until 07-Jun-2022 16:01:44
This system is equipped with 16.9 GB of RAM, and RDFox is configured to use at most 15.2 GB (89.9% of the total).
Currently, 2.8 GB (18.4% of the amount allocated to RDFox) appear to be available on the system.
Since RDFox is a RAM-based system, its performance can suffer when other running processes use a lot of memory.


A new server connection was opened as role 'guest' and stored with name 'sc1'.
>
```

Loading Data into RDFox

First we need to create a data store…

```
dstore create f1
```

Then to set it as active.

```
active f1
```

Then specify a prefix. We'll need it later.

```
prefix : <http://www.oxfordsemantic.tech/f1demo/>
```

Now import the race data up to the year 2020.

```
import data/upTo2020.ttl
```

Setting the output
In the Web Console and the shell

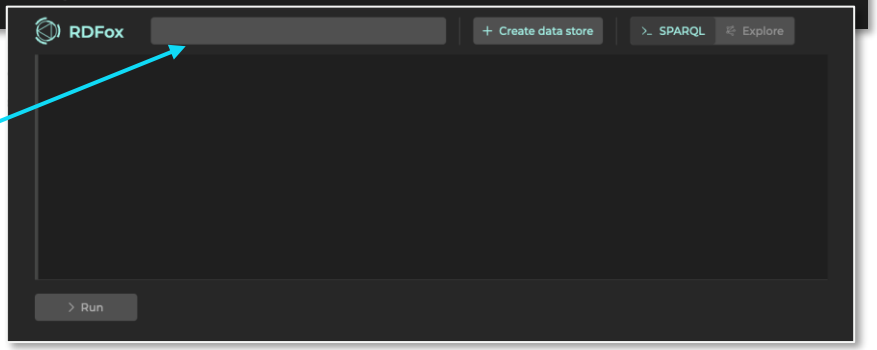
To use the Web Console:

- In the terminal, run:
  endpoint start
- Open a browser and go to:
  localhost:12110/console
- This will show an empty console
  - Select your data store at the top

```
> endpoint start

WARNING: The RDFox endpoint is running with no transport layer security (TLS). This could allow attackers to
steal information including role passwords.
        See the endpoint.channel variable and related variables in the description of the RDFox endpoint for
 details of how to set up TLS.

The REST endpoint was successfully started at port number/service name 12110 with 7 threads.
>
```



To see the output in the shell:

set output out

```
> set output out
output = "out"
>
```

You will need to use both of these through this tutorial

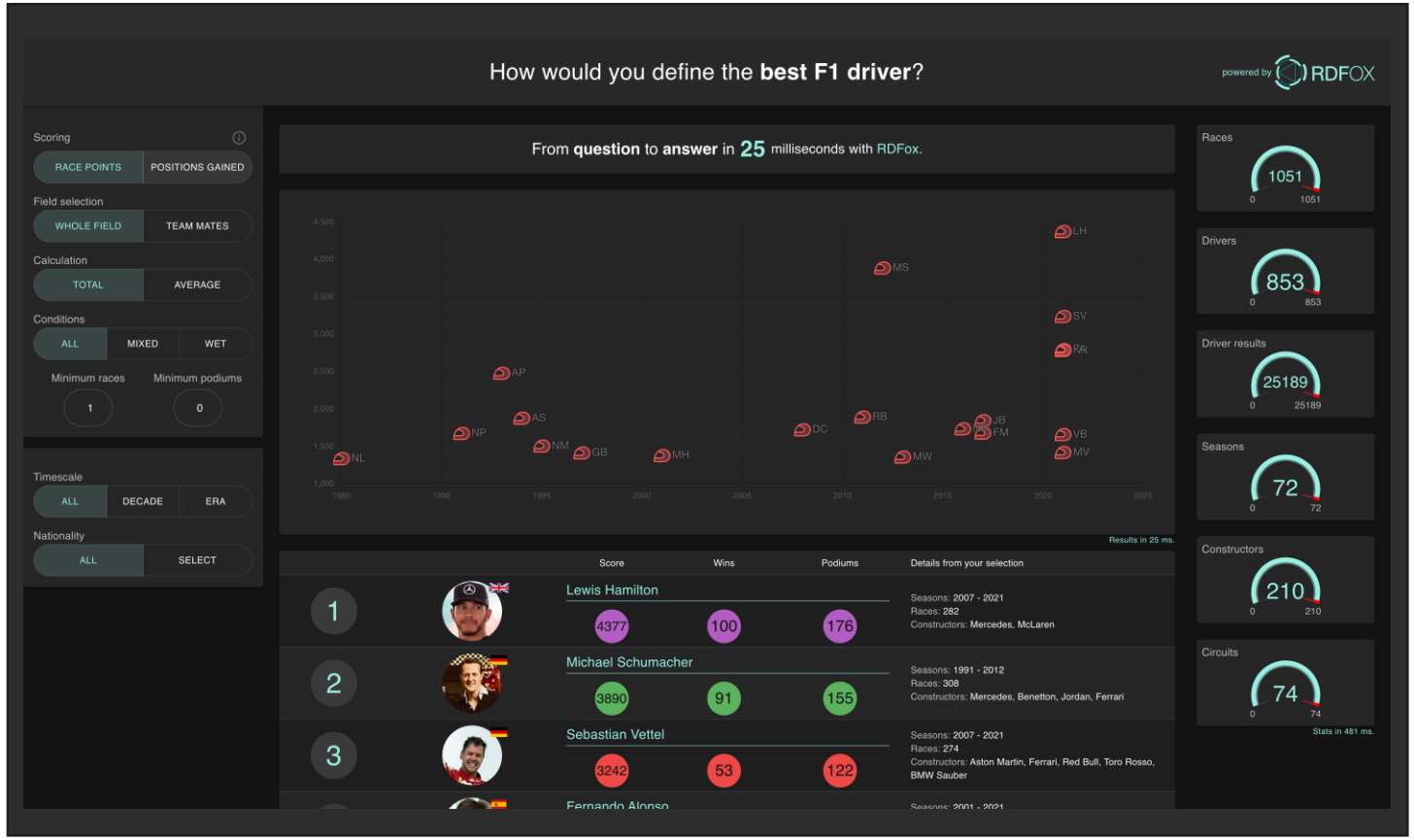
Objectives

By the end of the class everyone will:

- know how to write OWL axioms in Turtle syntax
- know how to add OWL axioms to RDFox datastores
- know how to write and import Datalog rules
- understand how RDFox performs reasoning
- know common uses of rules

Who is the Greatest Formula One Driver of All Time?

Controls and filters for the scoring system.



Statistics about the data used to form the results.

This matches the filters.

http://f1.rdfox.tech

Try it for yourself!

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What can Reasoning do for you?

```
#Query 11
PREFIX : <http://www.oxfordsemantic.tech/f1demo/>

# Drivers with their win percentage, ordered by win percentage
SELECT ?forename ?surname ?raceCount ?raceWins ?percentage
WHERE {
# First get the drivers
?driver :driver_forename ?forename ;
        :driver_surname ?surname .

# Then get the race count for each driver with an innery query...
    {SELECT ?driver (COUNT(?race) AS ?raceCount)
    WHERE {
    ?result :result_driver ?driver ;
            :result_race ?race .
    }
    GROUP BY ?driver}

# ... and get the *win* count for each driver with another inner query.
    {SELECT ?driver (COUNT(?race) AS ?raceWins)
    WHERE {
    ?result :result_driver ?driver ;
            :result_race ?race ;
            :result_positionOrder 1 .
    }
    GROUP BY ?driver}

# Finally use the two aggregate variables to compute a percentage
# with the BIND keyword.
BIND(?raceWins/?raceCount AS ?percentage)

}
ORDER BY DESC(?percentage)
```

Fetched 108 answers in 0.011 s.

Datalog Rules

```
#Query 19
PREFIX : <http://www.oxfordsemantic.tech/f1demo/>

SELECT ?forename ?surname ?percentage
WHERE {
    ?driver :driver_forename ?forename;
        :driver_surname ?surname;
        :hasWinPercentage ?percentage;
        :hasRaceCount ?count .
}
ORDER BY DESC(?percentage)
```

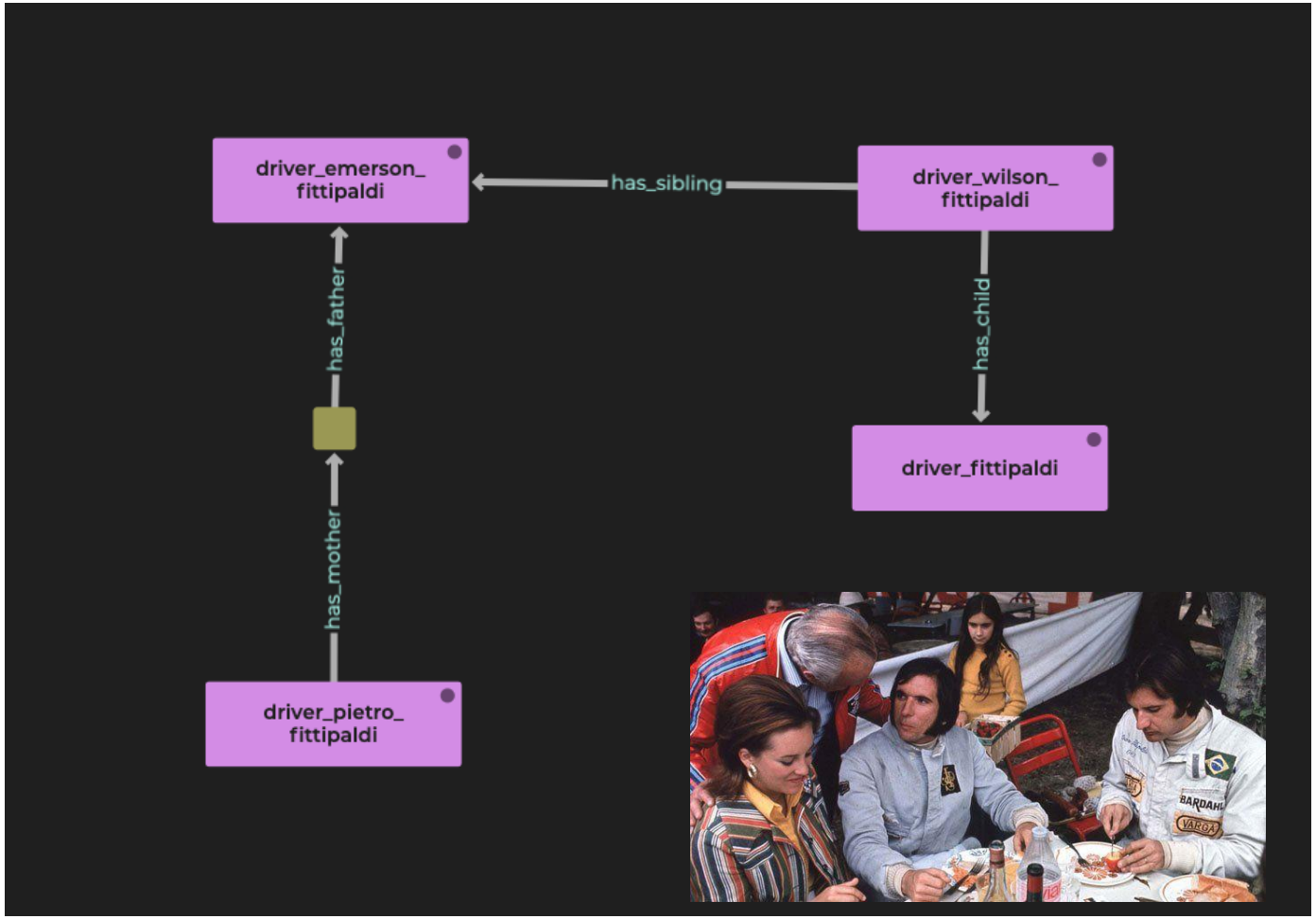
Fetched 108 answers in 0.003 s.

OWL reasoning

- ❑ Sub Properties
- ❑ Object & Datatype Properties
- ❑ Domain & Range
- ❑ Inverse Properties
- ❑ Symmetry & Transitivity
- ❑ Property Chains
- ❑ Class Equivalence
- ❑ Unions
- ❑ Class Intersections

Meet the Fittipaldis

- Data is often irregular.
- Is there something that can help us make it regular?
- As it happens, there is…

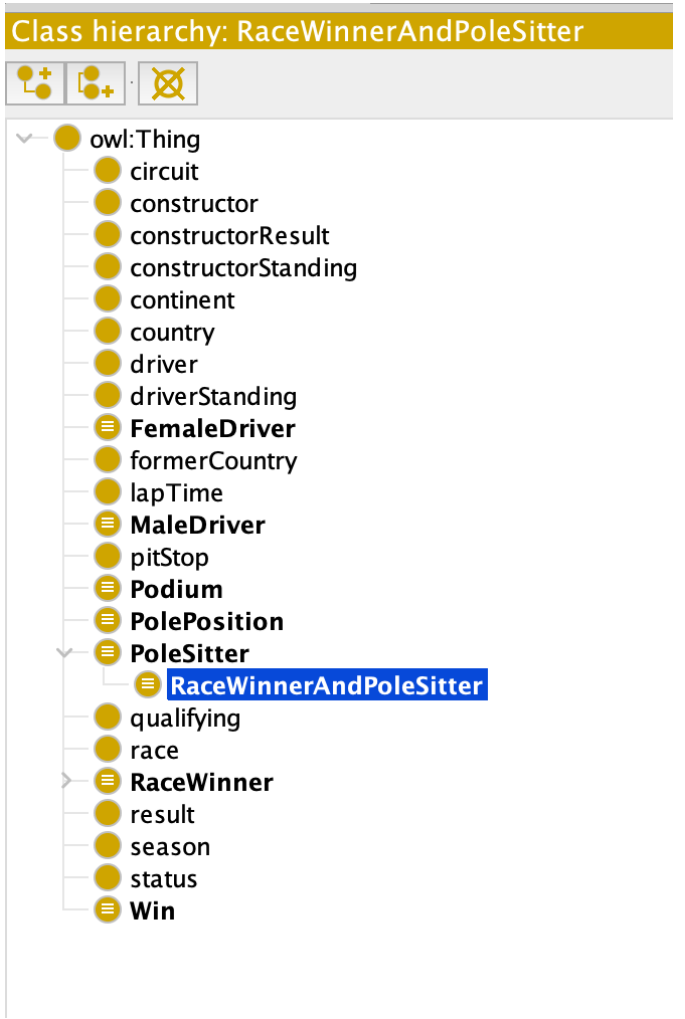


Web Ontology Language (OWL)

- standard created by W3C, RDFox supports the profile OWL 2 RL
- axioms are assertions about classes, properties or individuals
- ontology are collection of axioms
- ontologies are themselves graphs and can be written in many different syntaxes - we will use Turtle

Protégé

- useful program for managing ontologies
- free and open source
- before writing an ontology, it is often better to have some data first and to consider the queries you want to facilitate

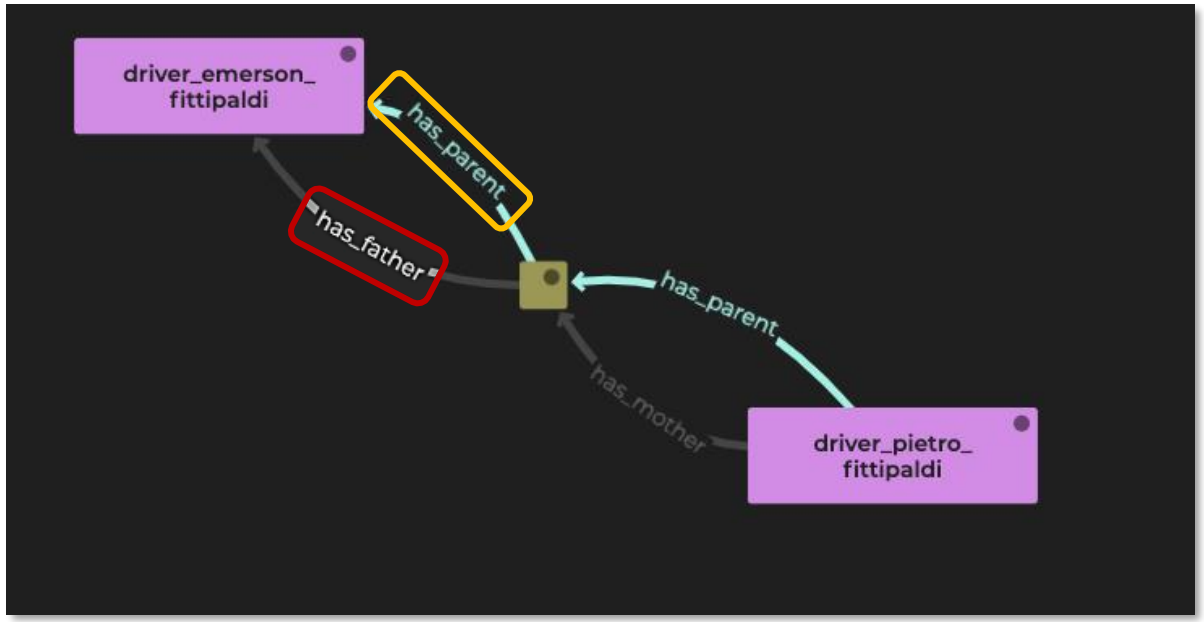


Axiom Set 1
Sub Properties

```
:has_father a owl:ObjectProperty ;
rdfs:subPropertyOf :has_parent .

:has_mother a owl:ObjectProperty ;
rdfs:subPropertyOf :has_parent .

:has_parent a owl:ObjectProperty ;
owl:inverseOf :has_child ;
rdfs:subPropertyOf :has_relative .
```



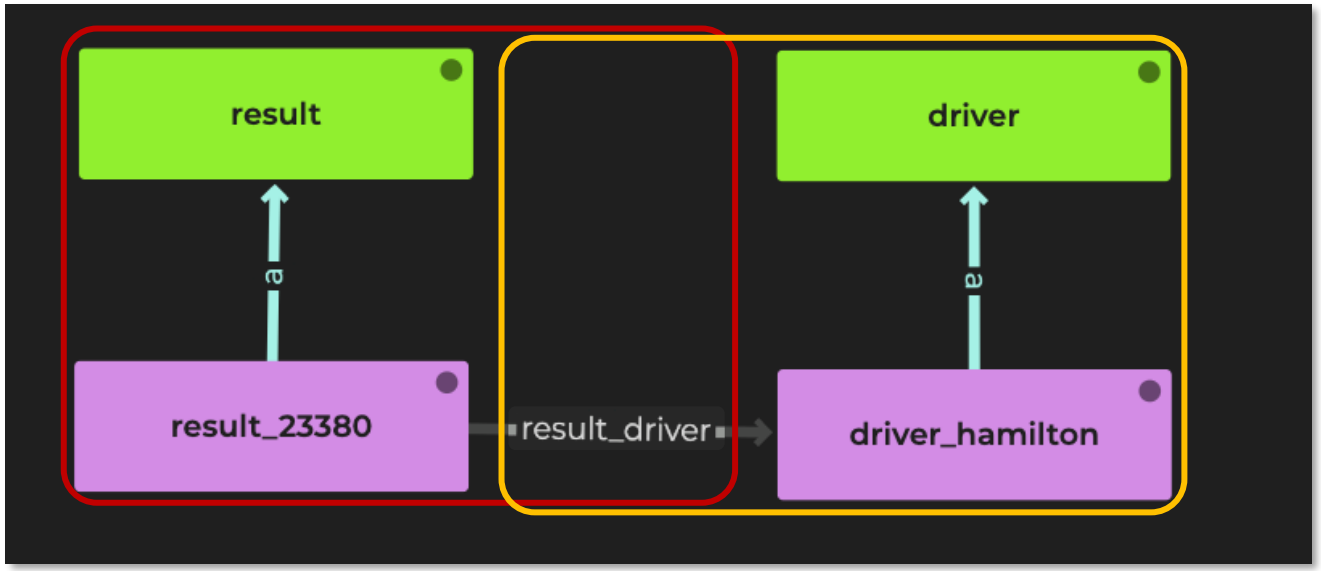
Axiom Set 2
Object & Datatype Properties

```
:result_driver rdf:type owl:ObjectProperty ;
rdfs:domain :result ;
rdfs:range :driver ;
owl:inverseOf :driver_result .

:driver_dob rdf:type owl:DatatypeProperty ;
rdfs:domain :driver ;
rdfs:range xsd:string .
```

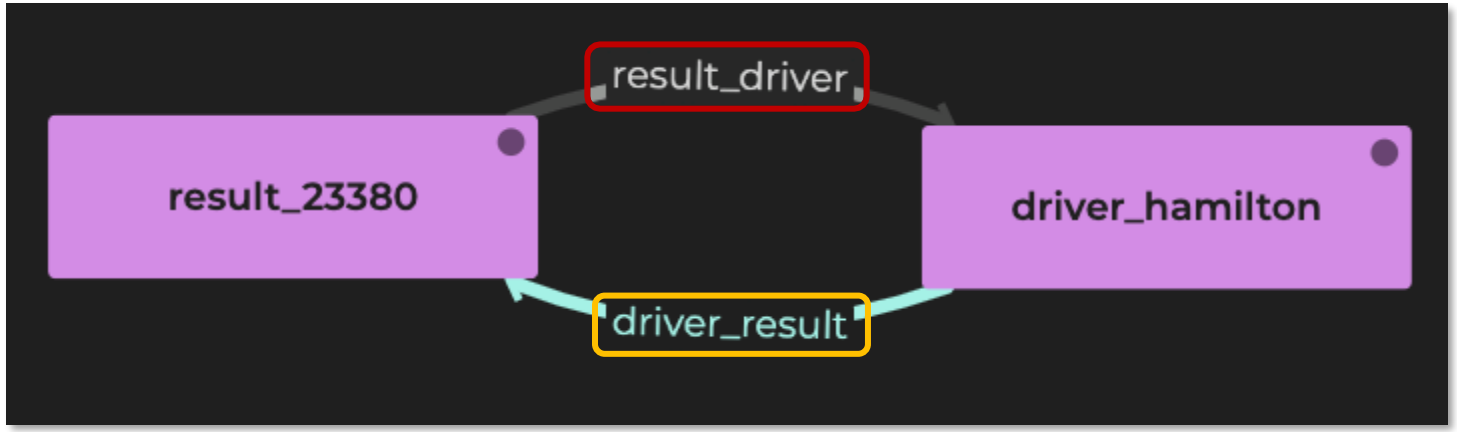
Axiom Set 3
Domain & Range

```
:result_driver rdf:type owl:ObjectProperty ;
rdfs:domain :result ;
rdfs:range :driver ;
owl:inverseOf :driver_result .
```

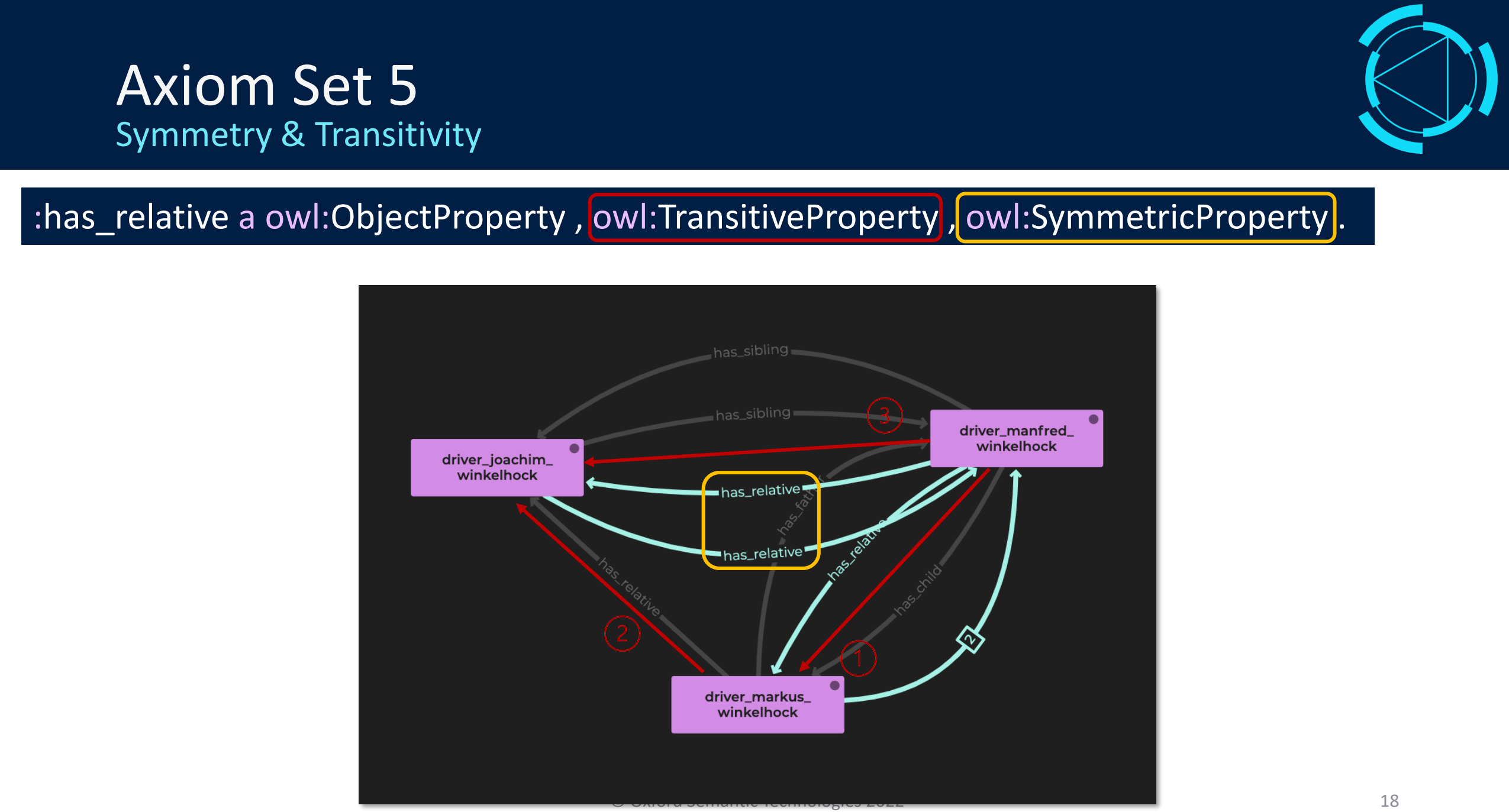


Axiom Set 4
Inverse Properties

```
:result_driver rdf:type owl:ObjectProperty ;
    rdfs:domain :result ;
    rdfs:range :driver ;
    owl:inverseOf :driver_result .
```



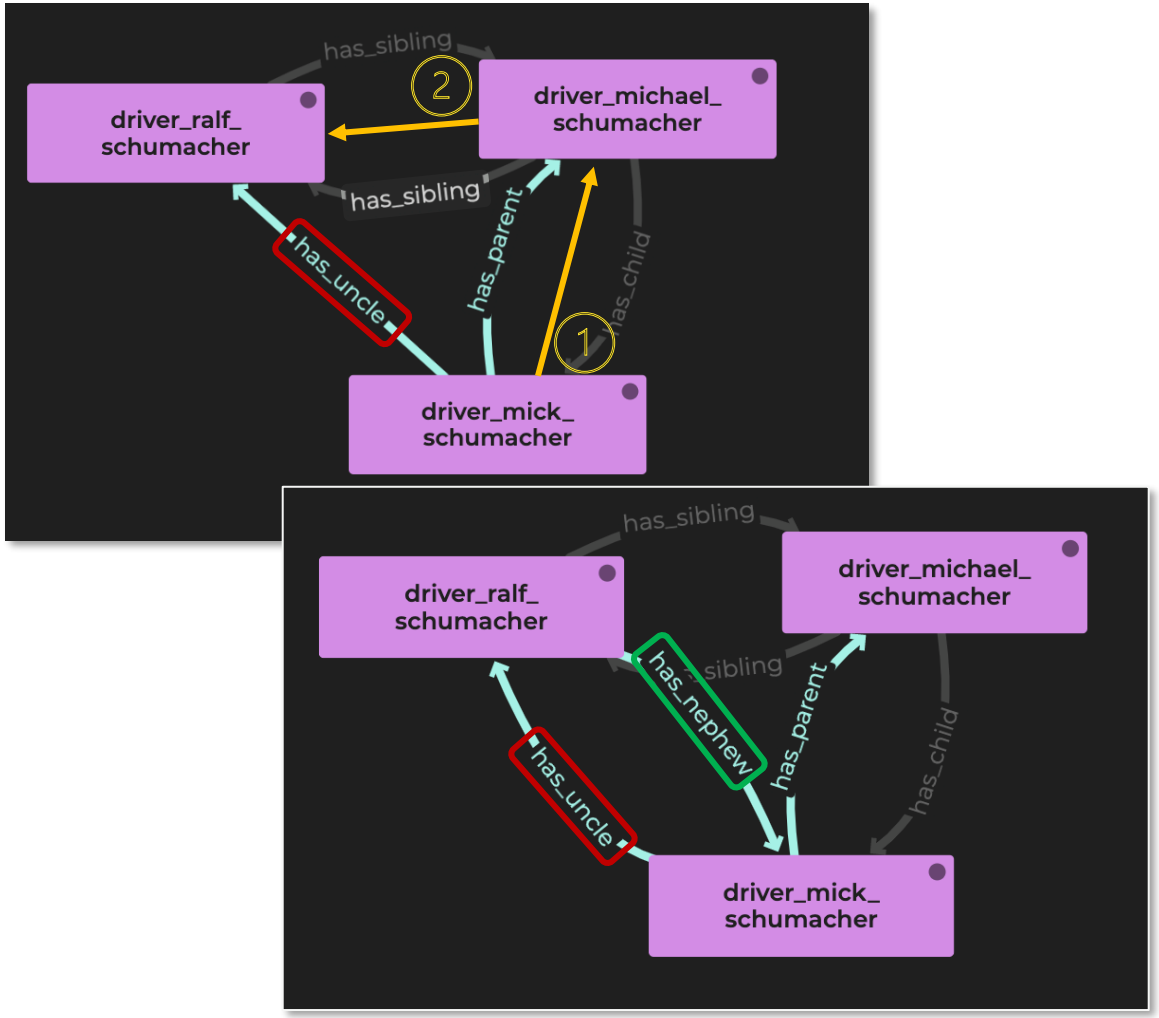
Axiom Set 5
Symmetry & Transitivity



:has_relative a owl:ObjectProperty , owl:TransitiveProperty , owl:SymmetricProperty .

Axiom Set 6
Property Chains

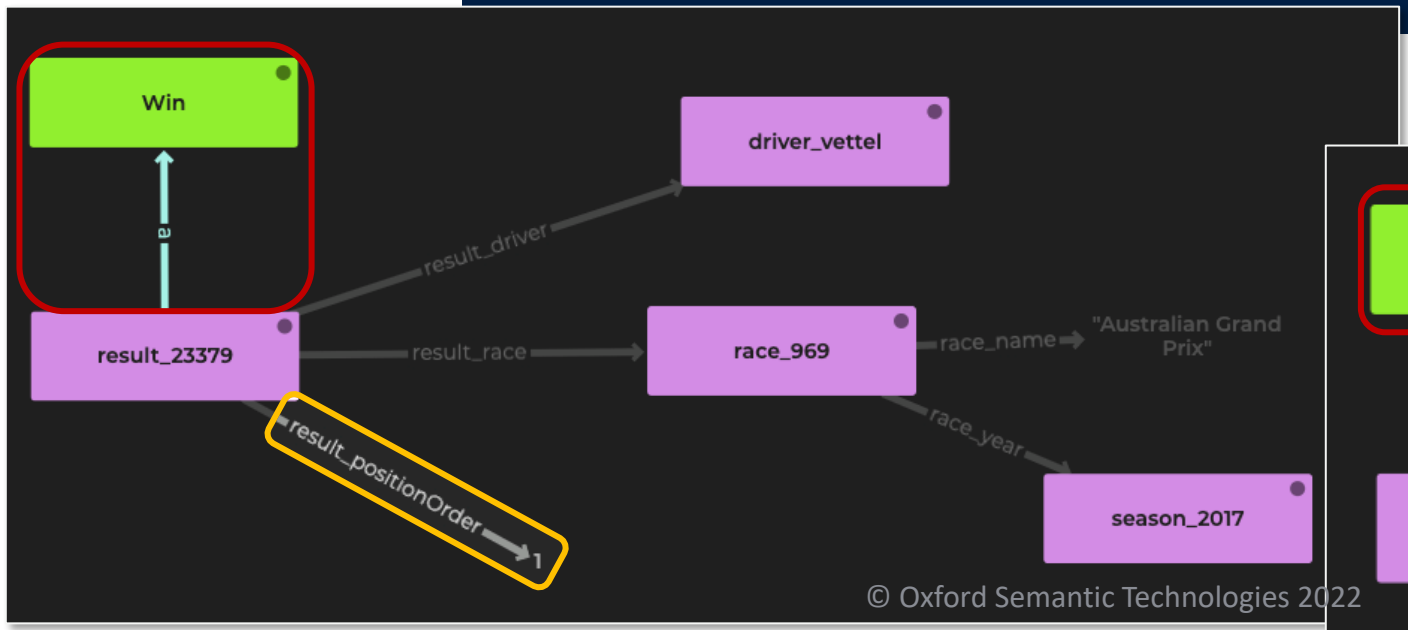
```
:has_uncle a owl:ObjectProperty ;
        rdfs:subPropertyOf :has_relative ;
        owl:propertyChainAxiom (
                :has_parent
                :has_sibling
        );
        owl:inverseOf :has_nephew .
```

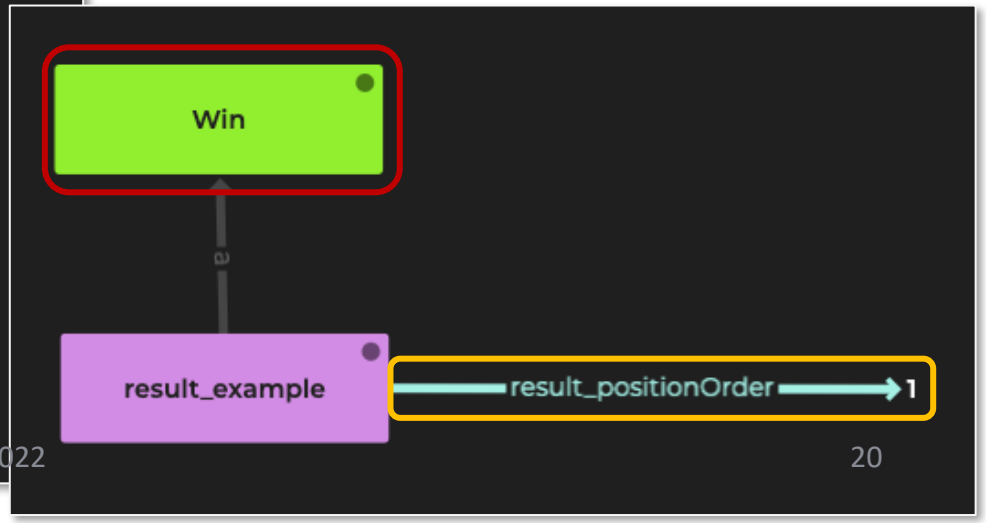


Axiom Set 7

Class Equivalence - hasValue

```
:Win a owl:Class ;
    owl:equivalentClass [
            a owl:Restriction ;
            owl:onProperty :result_positionOrder ;
            owl:hasValue "1"^^xsd:integer
    ] .
```

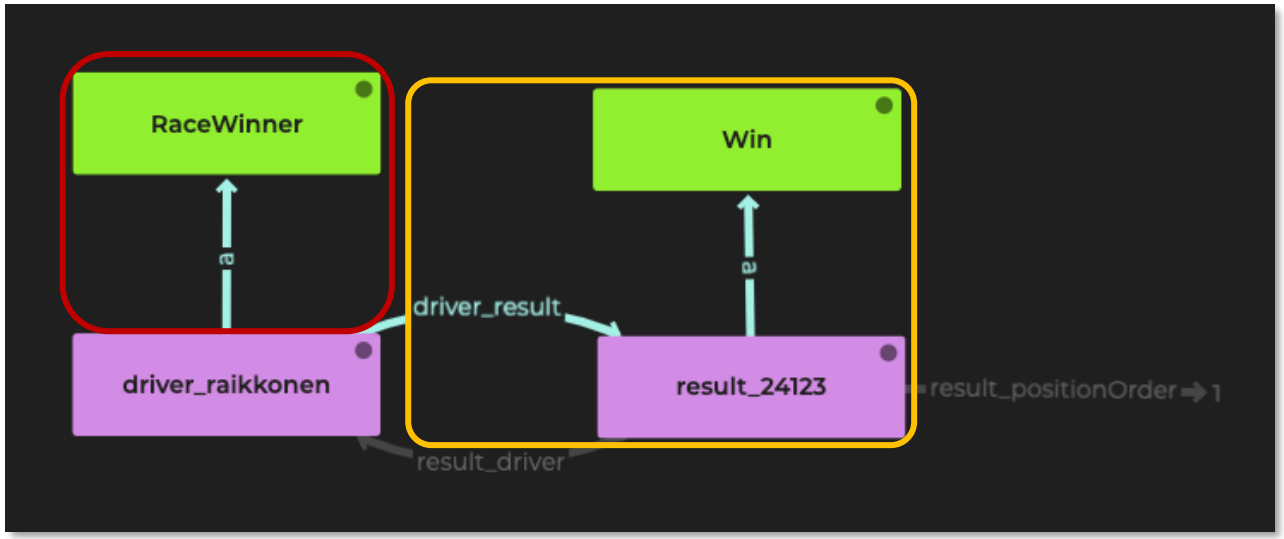




Axiom Set 8

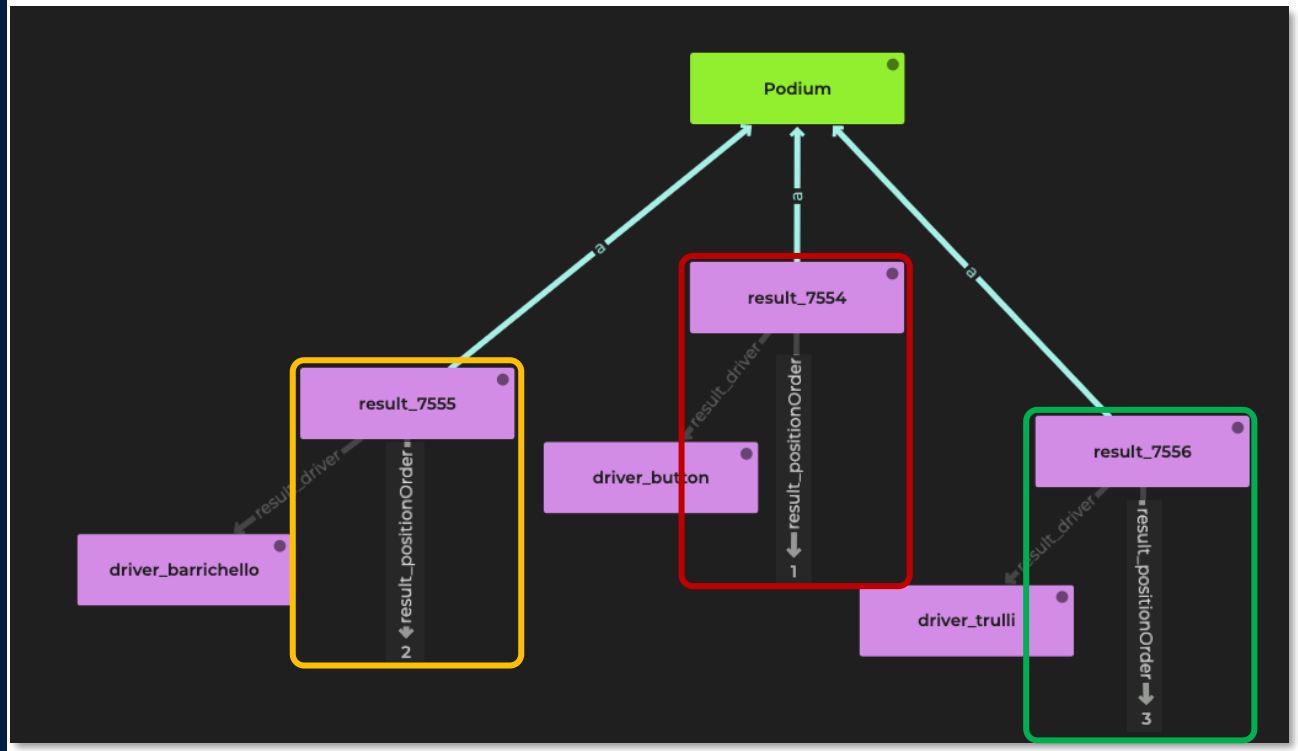
Class Equivalence - someValuesFrom

```
:RaceWinner a owl:Class ;
    owl:equivalentClass [
            a owl:Restriction ;
            owl:onProperty :driver_result ;
            owl:someValuesFrom :Win
    ] .
```



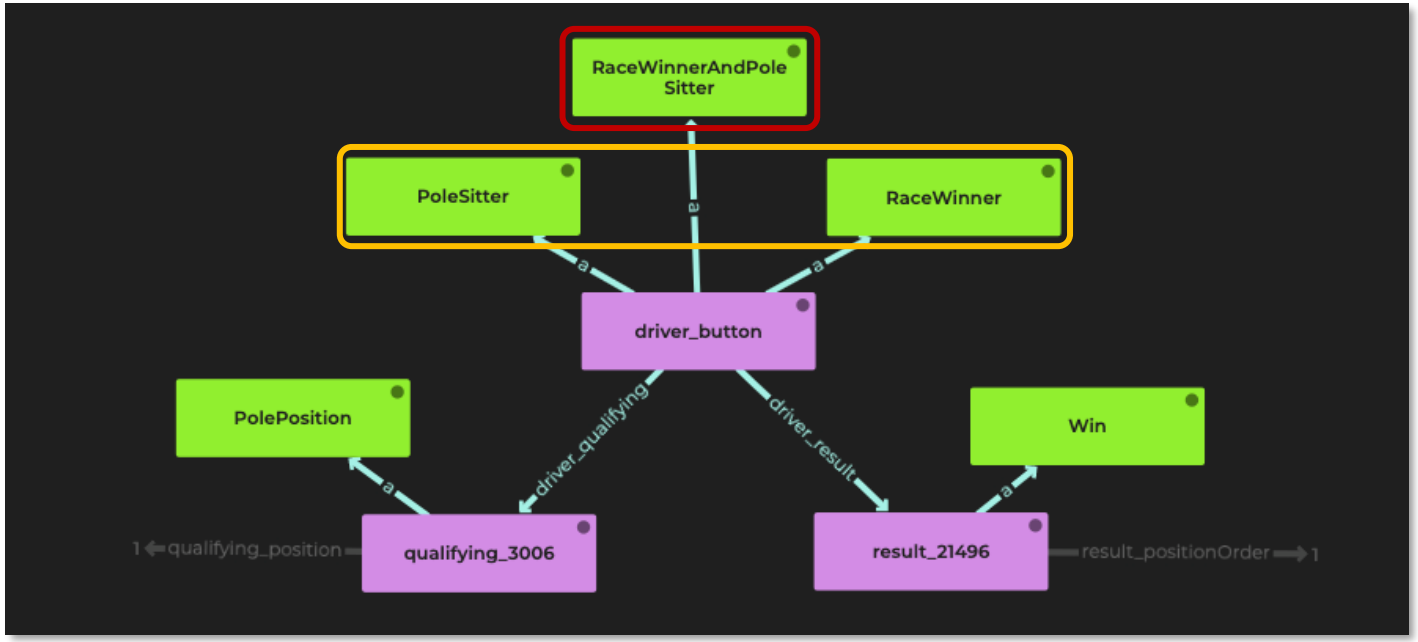
Axiom Set 9
Unions

```
:Podium a owl:Class ;
  owl:equivalentClass [
    a owl:Class ;
    owl:unionOf (
      [
      a owl:Restriction ;
      owl:onProperty :result_positionOrder ;
      owl:hasValue "1"^^xsd:integer
      ]
      [
      a owl:Restriction ;
      owl:onProperty :result_positionOrder ;
      owl:hasValue "2"^^xsd:integer
      ]
      [
      a owl:Restriction ;
      owl:onProperty :result_positionOrder ;
      owl:hasValue "3"^^xsd:integer
      ]
    )
  ] .
```



Axiom Set 10
Class Intersections

```
:RaceWinnerAndPoleSitter a owl:Class ;
        owl:equivalentClass [
                a owl:Class ;
                owl:intersectionOf (
                        :RaceWinner
                        :PoleSitter
                )
        ] .
```



Parsing the Ontology

Now we just need to import the axioms into a named graph, and then parse the graph for axioms:

```
import > :myAxioms axioms/axioms.ttl
```

```
importaxioms :myAxioms
```

OWL 2 RL Limitations

- The RL fragment of OWL has some limitations
- It does not support *existentials*
- This is why we see some warnings when parsing the axioms
- When asserting that a result is a podium, we have no way of knowing whether it's a P1, P2, or P3.
- Similarly, when declaring a race winner, we have no way of knowing which result of theirs is a win.

Fixing Mistakes

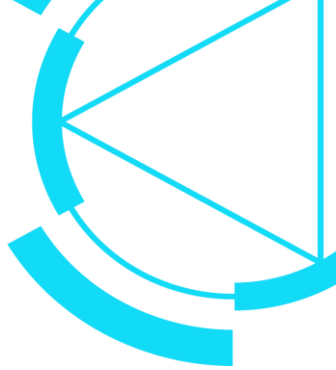
What should I do if I make a mistake?

```
importaxioms :myAxioms -
```

```
update ! clear graph :myAxioms
```

```
import > :myAxioms axioms/axioms.ttl
```

```
importaxioms :myAxioms
```



Datalog Reasoning with RDFox

- ❑ Basic rules
- ❑ Filters
- ❑ Aggregates
- ❑ Negation
- ❑ Binds
- ❑ Incremental reasoning

Datalog Rules

[*fact A*] :- [*fact B*]

“A is true whenever B is true”

Rule 1
Basic rules

```
[?driver, :hasRacedIn, ?race] :-
        [?result, :result_race, ?race],
        [?result, :result_driver, ?driver] .
```

This rule will add a direct link between drivers and the races they raced in. Notice this has the same effect as axiom 4, but expressed more clearly.

```
import rules/r1.dlog
```

The same could seemingly be achieved with an equivalent SPARQL update, but rules offer several advantages over write queries.

Check for inferred triples with query 14 – q14.rq

```
evaluate queries/q14.rq
```

Rule 2
Filters

```
[?driver, :hasPodiumInRace, ?race] :-
        [?result, :result_race, ?race],
        [?result, :result_driver, ?driver],
        [?result, :result_positionOrder, ?positionOrder],
        FILTER(?positionOrder < 4) .
```

We can use FILTERs in rules too, in this case to find the races in which a driver reached the podium.

```
import rules/r2.dlog
```

Check for inferred triples with query 15 – q15.rq

```
evaluate queries/q15.rq
```

Rule 3
Aggregates

```
[?driver, :hasRaceCount, ?raceCount] :-
        AGGREGATE(
                [?driver, :hasRacedIn, ?race]
                ON ?driver
                BIND COUNT(?race) AS ?raceCount
        ) .
```

This rule adds a count of races a driver has entered.

Notice we use the previously inferred `:hasRacedIn` property. Rules can be composed together, and RDFox will automatically find the order in which to run them.

```
import rules/r3.dlog
```

Check for inferred triples with query 16 – q16.rq

```
evaluate queries/q16.rq
```

Rule 4 - exercise

Aggregates

```
[?___, :hasRaceWinCount, ?___] :-
        AGGREGATE(
                [?___, :result_driver, ?___],
                [?___, :result_positionOrder, 1] # Make sure the driver actually won
                ON ?driver
                BIND COUNT(?___) AS ?___
        ) .
```

This rule adds a count of races a driver has *won* (provided they won at least 1).

We can put more than one atom *inside* the AGGREGATE statement.

```
import rules/r4.dlog
```

Check for inferred triples with query 17 – q17.rq

```
evaluate queries/q17.rq
```

Rule 5
Negation

```
[?driver, a, :DriverWithoutPodiums] :-
        [?driver, a, :driver],
        NOT EXISTS ?race IN (
                [?driver, :hasPodiumInRace, ?race]
        ) .
```

This rule tells us that if a driver does not have a race where they were on the podium, then they are a `:DriverWithoutPodiums`.

So, we are looking for something that is **not** in the data (i.e. no race where the driver was on the podium).

```
import rules/r5.dlog
```

Check for inferred triples with query 18 – q18.rq

```
evaluate queries/q18.rq
```

Negation as Failure

Negation as failure is negation understood as the *absence* of a triple.

Using Negation as Failure leads to ‘non-monotonic reasoning’- the engine may need to retract some triples instead of just adding them. This adds another dimension to an already complicated problem of reasoning planning, but RDFox handles all of that automatically.

Example:
What if a driver without any podiums *so far* gets a podium next year? In 2021, for instance, George Russell got his first podium. In our data, which is accurate up to and including 2020, George Russell would be a `:DriverWithoutPodiums`. But if we add data from 2021, we will need to retract this fact.

- Exercise: Run the query “q18_1.rq”, then import the data from file “2021-22.ttl” and try again

```
evaluate queries/q18_1.rq
```

Rule 6 - exercise

Binds

```
[?driver, :hasWinPercentage, ?percentage] :-
        [?___, :hasRaceCount, ?___],
        [?___, :hasRaceWinCount, ?___],
        BIND(?raceWinCount/?raceCount AS ?percentage) .
```

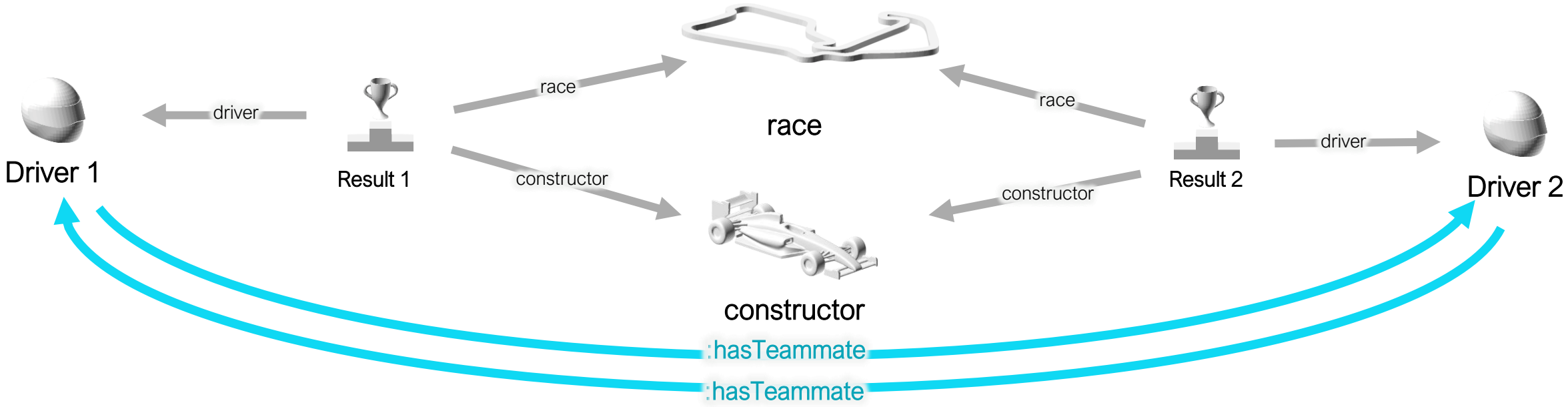
With `BIND` we can use various mathematical functions, string manipulation, regular expression matching, conditional binds, hashing and IRI creation.

```
import rules/r6.dlog
```

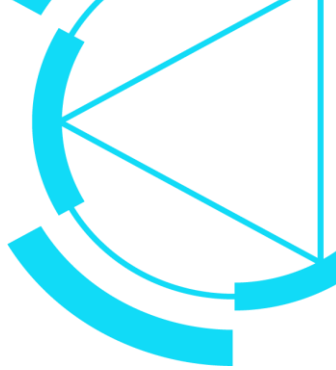
Check for inferred triples with query 19 – q19.rq

```
evaluate queries/q19.rq
```

Bonus Exercise

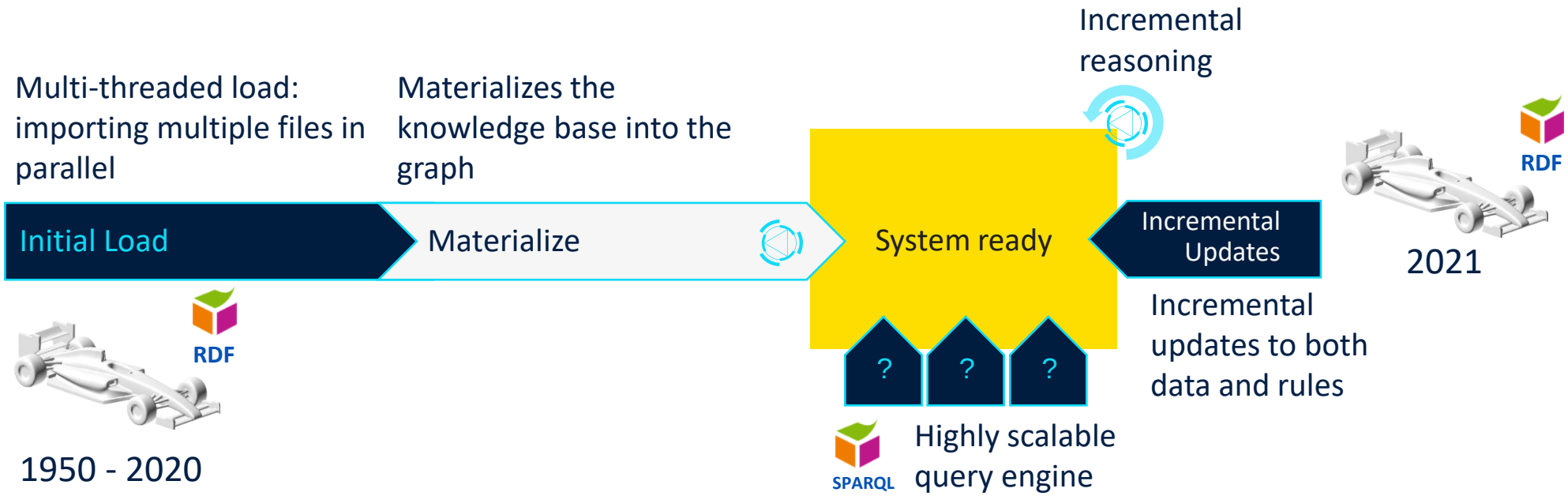


- Write and import a rule to find out if two drivers have been teammates (use the predicate `:hasTeammate`).



RDFox: How does it work?

Incremental Reasoning



Incremental Reasoning

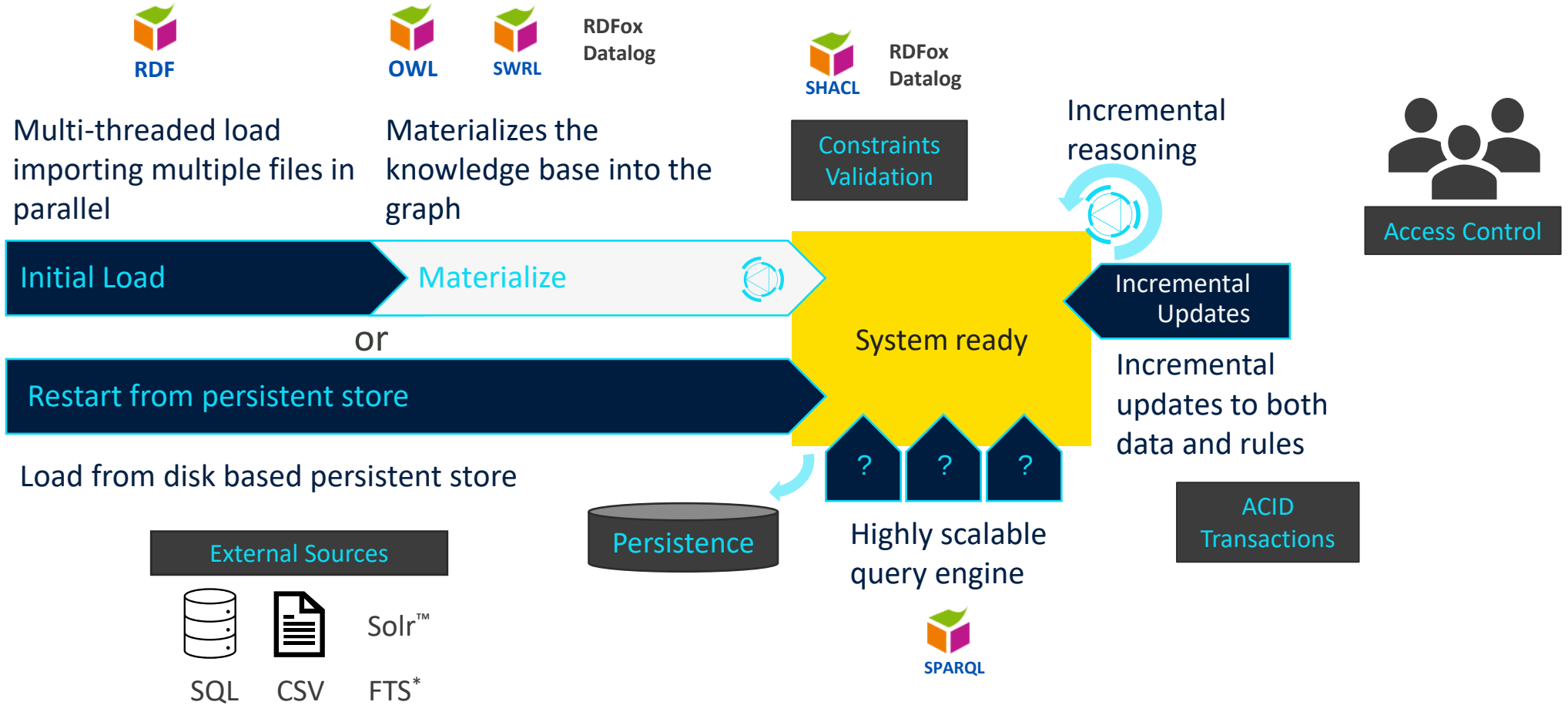
- One of the key strengths of RDFox.
- Data can be imported at any time, and RDFox will automatically compute the necessary inferences.
- This all happens *incrementally*, without the need to reboot.
- Incremental reasoning open the door to many novel use cases which were previously impractical.

RDFox vs. Other Solutions

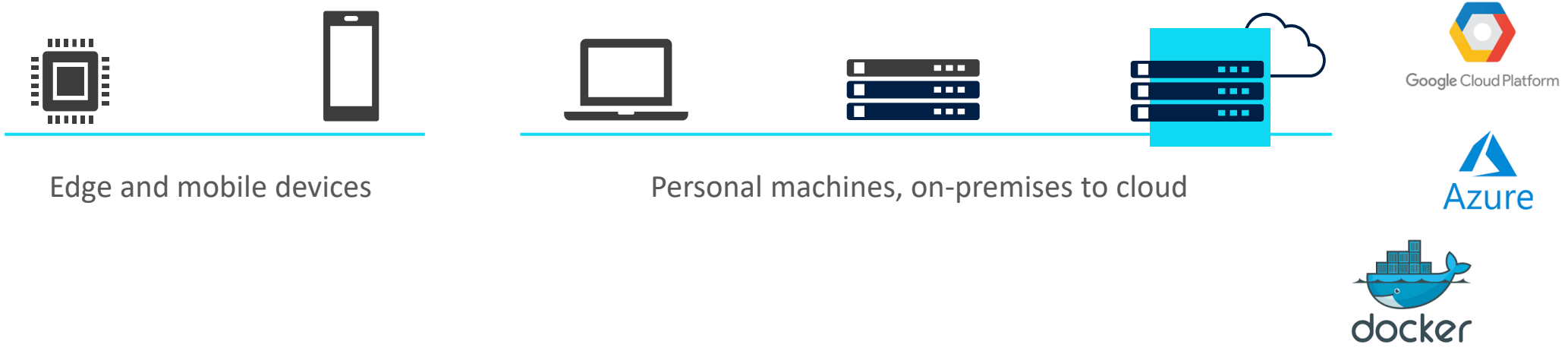
	Feature	Example	RDFox	Materialisation Competitors	Query Rewriting Competitors
	Ontological reasoning	“List all financial instruments / derivative instruments / futures.” [class inferencing]	✓	✓*	✓**
	Graph analytics	“What is the nearest electrical switch for a circuit?” [negation + recursion]	✓		
	Data Analytics	“What is the total volume and value of trades?” [aggregation + arithmetic]	✓		
	Local constraints validation	“No trades over a limit & no traders without trades!” [filters + negation]	✓	Partial (SHACL)	
	Global constraint validation	“Every component must be connected to a power source!” [negation + recursion]	✓		
	All of the above	“What is the total value of assets owned through holdings?”	✓		

* **many times slower** than RDFox
** **orders of magnitude slower** than RDFox

How does it work?



Deployment Options

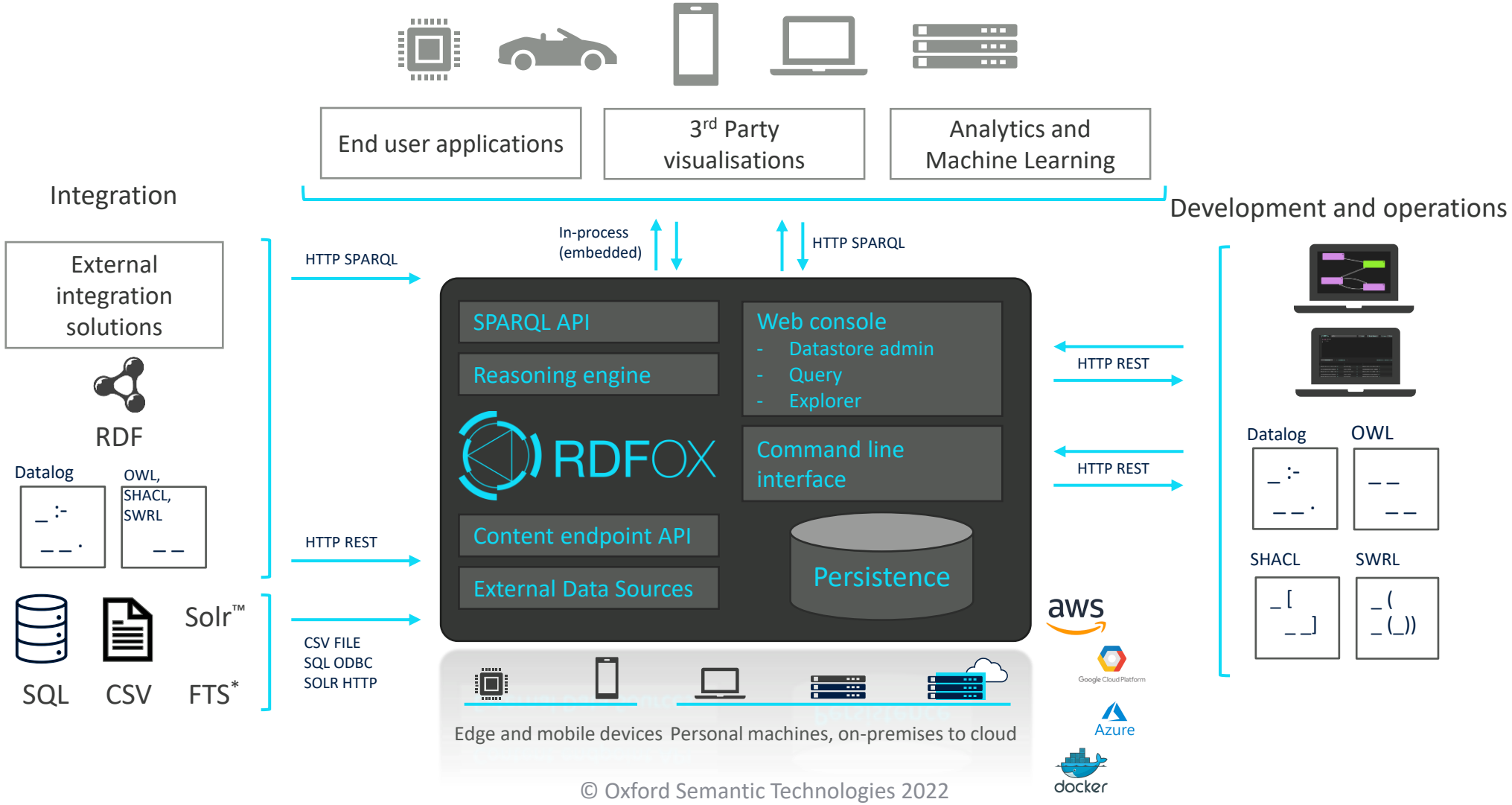


Edge and mobile devices

Personal machines, on-premises to cloud

Architecture

RDFox system context diagram



Your final exercise…

Click on the link below to start filling out our quick survey. It won't take you more than 3 minutes!

https://oxfordsemantictech.typeform.com/to/WuuNcFPm

Further resources

Our website
https://www.oxfordsemantic.tech

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Read the documentation
https://docs.oxfordsemantic.tech/

Our blog
https://www.oxfordsemantic.tech/the-blog