

The ISO 15926 4D approach

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With examples of the use of OWL DL inferencing

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- Instantiation to support inferencing of inheritance by spatial and temporal parts
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- Installation of pump equipment as a pump facility
- Instantiation to support inferencing of inheritance by temporal parts of the equipment and of the facility

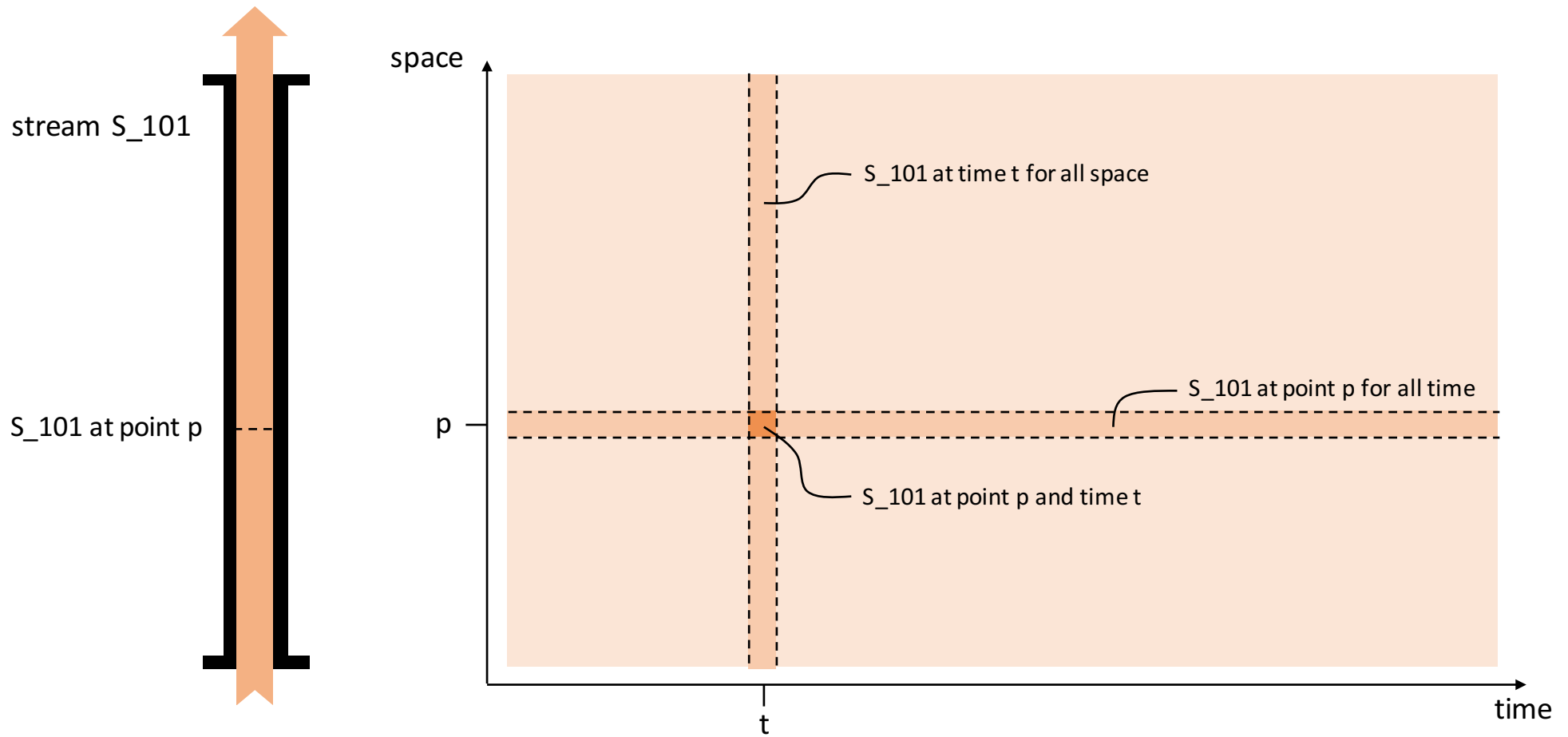
3. Role of installed equipment and model of equipment

- Roles and models within an equipment class hierarchy
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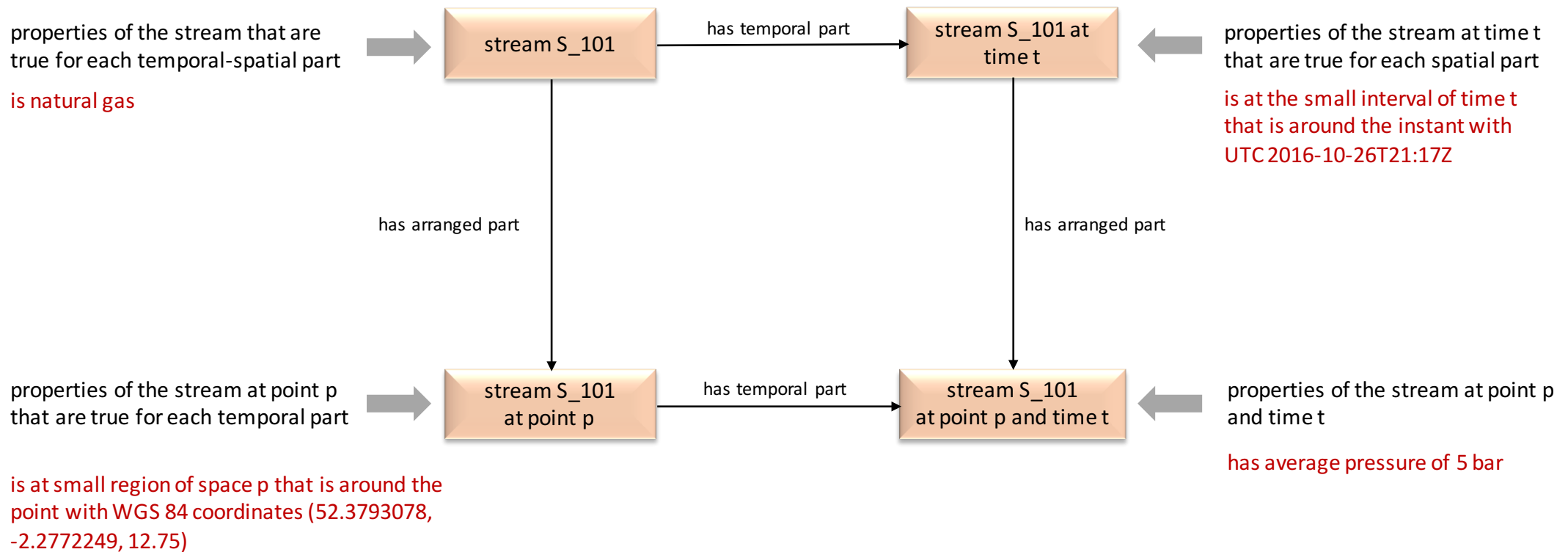
4. Physical property, quantity and scale

- Physical quantity as an object to support multiple units of measure
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4D - Stream - in space and time



4D - Stream – in space and time



4D - Stream – in space and time

lci:Individual

```
rdf:type owl:Class ;  
rdfs:subClassOf owl:Thing .
```

lci:PhysicalObject

```
rdf:type owl:Class ;  
rdfs:subClassOf lci:Individual .
```

lci:Stream

```
rdf:type owl:Class ;  
rdfs:subClassOf lci:PhysicalObject .
```

lci:partOf

```
rdf:type owl:ObjectProperty , owl:TransitiveProperty ;  
rdfs:domain lci:Individual ;  
rdfs:range lci:Individual .
```

lci:arrangedPartOf

```
rdf:type owl:ObjectProperty ;  
rdfs:subPropertyOf lci:partOf .
```

lci:temporalPartOf

```
rdf:type owl:ObjectProperty ;  
rdfs:subPropertyOf lci:partOf .
```

:S_101

```
rdf:type lci:Stream , rdl:NaturalGas .
```

:S_101AtPointP

```
rdf:type lci:Stream ;  
lci:partOf :PointP ;  
lci:arrangedPartOf :S_101 .
```

:S_101AtTimeT

```
rdf:type lci:Stream ;  
lci:partOf :TimeT ;  
lci:temporalPartOf :S_101 .
```

:S_101AtPointPAndTimeT

```
rdf:type lci:Stream ;  
lci:temporalPartOf :S_101AtPointP ;  
lci:arrangedPartOf :S_101AtTimeT ;  
rdl:averageStreamPressure  
[ rdl:bar "5"^^xsd:float ] .
```

4D - Stream – in space and time

Notes on previous slide:

1. The left box contains an extract from the OWL representation of ISO 15926-2. The right box contains an OWL representation of information about the spatial and temporal parts of the stream.
2. Spatial and temporal parts are treated in exactly the same way.
3. A small interval of time is an individual that has all individual existing within that interval as parts. A small region of space is an individual that has all individuals existing in that region as parts.
4. Natural gas is a class that has all physical objects that are natural gas, whether streams or quantities in storage, as members.

4D - Stream – inferring position and time of a temporal part

```
lci:Individual
  rdf:type owl:Class ;
  rdfs:subClassOf owl:Thing .

lci:PhysicalObject
  rdf:type owl:Class ;
  rdfs:subClassOf lci:Individual .

lci:Stream
  rdf:type owl:Class ;
  rdfs:subClassOf lci:PhysicalObject .

lci:partOf
  rdf:type owl:ObjectProperty, owl:TransitiveProperty ;
  rdfs:domain lci:Individual ;
  rdfs:range lci:Individual .

lci:arrangedPartOf
  rdf:type owl:ObjectProperty ;
  rdfs:subPropertyOf lci:partOf .

lci:temporalPartOf
  rdf:type owl:ObjectProperty ;
  rdfs:subPropertyOf lci:partOf .
```

```
:S_101
  rdf:type lci:Stream, rdl:NaturalGas .

:S_101AtPointP
  rdf:type lci:Stream ;
  lci:partOf :PointP ;
  lci:arrangedPartOf :S_101 .

:S_101AtTimeT
  rdf:type lci:Stream ;
  lci:partOf :TimeT ;
  lci:temporalPartOf :S_101 .

:S_101AtPointPAndTimeT
  rdf:type lci:Stream ;
  lci:temporalPartOf :S_101AtPointP ;
  lci:arrangedPartOf :S_101AtTimeT .
```

Inferred:

```
:S_101AtPointPAndTimeT
  lci:partOf :S_101, :PointP, :TimeT .
```

4D - Stream – inferring position and time of a temporal part

Notes on previous slide:

1. Because “part of” is transitive, it can be inferred that “S_101 at point p and time t” is:
 - a part of the small region of space p;
 - a part of the small interval of time t;
 - a part of stream S_101 .

4D – Quantity of Natural Gas – a part is also natural gas

```
rdl:NaturalGas
  rdf:type owl:Class ;
  rdfs:subClassOf lci:PhysicalObject .

:PartOfANaturalGasPhysicalObject
  owl:equivalentClass
    [ owl:onProperty lci:partOf ;
      owl:someValuesFrom rdl:NaturalGas ] ;
  rdfs:subClassOf rdl:NaturalGas .
```

```
:S_101
  rdf:type lci:Stream, rdl:NaturalGas .

:S_101AtPointP
  rdf:type lci:Stream ;
  lci:partOf :PointP ;
  lci:arrangedPartOf :S_101 .

:S_101AtTimeT
  rdf:type lci:Stream ;
  lci:partOf :TimeT ;
  lci:temporalPartOf :S_101 .

:S_101AtPointPAndTimeT
  rdf:type lci:Stream ;
  lci:temporalPartOf :S_101AtPointP ;
  lci:arrangedPartOf :S_101AtTimeT .
```

Inferred:

```
:S_101AtPointPAndTimeT
  rdf:type rdl:NaturalGas .
```

4D – Quantity of Natural Gas – a part is also natural gas

Notes on previous slide:

1. It is necessary to state that a part of a physical object that is natural gas is itself natural gas.
 - This statement is only true for reasonable scales. A very small scales a single atom could be a part.
2. It can be inferred that “S_101 at point p and time t”, which is a part of S_101 is natural gas.

4D – Quantity of Natural Gas – dangerous stream state

```
rdl:InvalidStreamState
  rdf:type owl:Class ;
  rdfs:subClassOf lci:Stream .

:NaturalGasStreamWithPressureGreaterThan4Bar
  owl:equivalentClass
    [ owl:intersectionOf (
      rdl:NaturalGas
      :StreamWithPressureGreaterThan4Bar
    ) ];
  rdfs:subClassOf rdl:DangerousStreamState .
```

The definition of **:StreamWithPressureGreaterThan4Bar** is shown on a later slide.

```
:S_101
  rdf:type lci:Stream, rdl:NaturalGas .

:S_101AtPointP
  rdf:type lci:Stream ;
  lci:partOf :PointP ;
  lci:arrangedPartOf :S_101 .

:S_101AtTimeT
  rdf:type lci:Stream ;
  lci:partOf :TimeT ;
  lci:temporalPartOf :S_101 .

:S_101AtPointPAndTimeT
  rdl:averageStreamPressure
    [ rdl:bar "5"^^xsd:float ] .
```

Inferred:

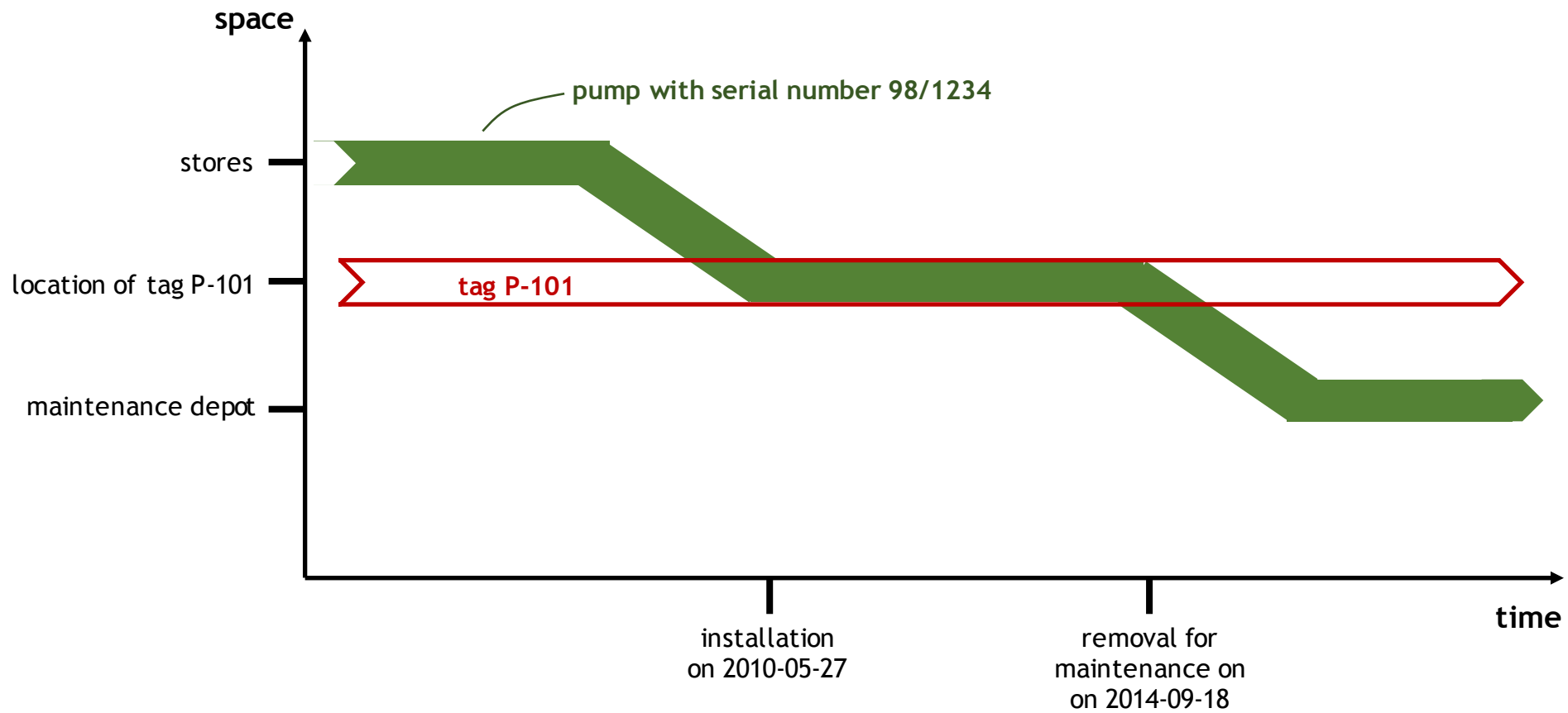
```
:S_101AtPointPAndTimeT
  rdf:type rdl:DangerousStreamState .
```

4D – Quantity of Natural Gas – dangerous stream state

Notes on previous slide:

1. A stream is in a dangerous state if:
 - it is natural gas;
 - it has a pressure greater than 4 bar.
2. It can be inferred that “S_101 at point p and time t”, is in a dangerous state.
 - Inferencing about numeric values within ranges is shown in later slides.

4D – Installation – functional and materialized physical objects



4D – Installation – functional and materialized physical objects

Notes on previous slide:

1. The pump with tag P_101 has a functional definition. It is that pump that has a particular role within the process plant. Different pumps can be installed to provide the role from time to time.
2. The pump with serial number 98/1234 has a material definition. It can be installed to provide different roles from time to time, or it can be stored as a spare.
3. Between the installation on 2010-05-27 and the removal on 2014-09-18, the temporal part of P_101 and the temporal part of pump 98/1234 are the same object.

4D – Installation – functional and materialized physical objects

```
lci:FunctionalPhysicalObject
    rdf:type owl:Class ;
    rdfs:subClassOf lci:PhysicalObject .

lci:MaterializedPhysicalObject
    rdf:type owl:Class ;
    rdfs:subClassOf lci:PhysicalObject .

rdl:Pump
    rdf:type owl:Class ;
    rdfs:subClassOf lci:PhysicalObject .
```

```
:P_101
    rdf:type lci:FunctionalPhysicalObject ,
            rdl:Pump .

:P_98_1234
    rdf:type lci:MaterializedPhysicalObject ,
            rdl:Pump .

:P_98_1234InstalledAsP_101FromMay2010
    rdf:type lci:PhysicalObject ;
    lci:temporalPartOf :P_98_1234 , :P_101 .
```

4D – Installation – functional and materialized physical objects

Notes on previous slide:

1. The left box contains an extract from the OWL representation of ISO 15926-2 and the class “pump” from a RDL.
 - A pump can be either a functional physical object or a materialized physical object.
2. The right box contains an OWL representation of information about the functional and materialized pumps, and about “Pump 98/1234 installed as P_101 from May 2010” which is a temporal part of both.

4D – Pump – a temporal part is also a pump

```
:TemporalPartOfAPump
  owl:equivalentClass
    [ owl:onProperty lci:temporalPartOf ;
      owl:someValuesFrom rdl:Pump ] ;
  rdfs:subClassOf rdl:Pump .
```

```
:P_101
  rdf:type lci:FunctionalPhysicalObject ,
          rdl:Pump .
:P_98_1234
  rdf:type lci:MaterializedPhysicalObject ,
          rdl:Pump .
:P_98_1234InstalledAsP_101FromMay2010
  rdf:type lci:PhysicalObject ;
  lci:temporalPartOf :P_98_1234 , :P_101 .
```

Inferred:

```
:P_98_1234InstalledAsP_101FromMay2010
  rdf:type rdl:Pump .
```

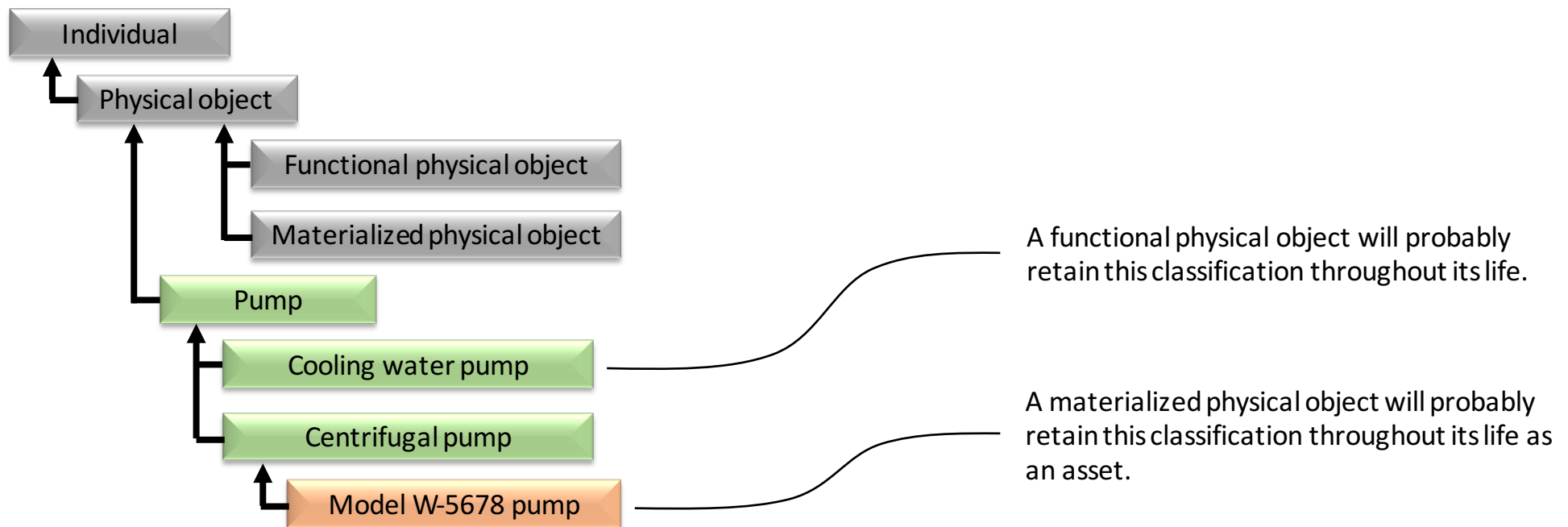
4D – Pump – a temporal part is also a pump

Notes on previous slide:

1. A temporal part of a pump is also a pump. This is true for many classes, but not all. It has to be stated explicitly for inferencing to work.
2. It can be inferred that “Pump 98/1234 installed as P_101 from May 2010” is a pump.

4D – Pump role and pump model

- Tag P_101 is a cooling water pump
- P-98-1234 is a centrifugal pump and a model W-5678 pump



4D – Pump role and pump model

Notes on previous slide:

1. “Cooling water pump” is a subclass of pump defined by role. A functional physical object usually has the same role throughout its life.
2. “Centrifugal pump” is a subclass of pump defined by physical principal. A materialized physical object usually has the same physical principal throughout its life.
3. All pumps of model W-5678 are centrifugal pumps, therefore model W-5678 is a subclass.
 - A pump usually remains a member of the same model class throughout its life, but not always. There may be a conversion kit to upgrade a pump from model W-5678 to model W-5679.

4D – Pump role and pump model

```
rdl:CoolingWaterPump
  rdf:type owl:Class ;
  rdfs:subClassOf rdl:Pump .

rdl:CentrifugalPump
  rdf:type owl:Class ;
  rdfs:subClassOf rdl:Pump .

man:ModelW_5678
  rdf:type owl:Class ;
  rdfs:subClassOf rdl:CentrifugalPump .
```

```
:P_101
  rdf:type rdl:CoolingWaterPump .

:P_98_1234
  rdf:type man:ModelW_5678 .

:P_98_1234InstalledAsP_101FromMay2010
  rdf:type lci:PhysicalObject ;
  lci:temporalPartOf :P_98_1234 , :P_101 .
```

4D – Pump role and pump model

Notes on previous slide:

1. The left hand box contains an extract from an RDL that defines the classes “Cooling water pump” and “Centrifugal pump”. The left hand block also contains the class “model W-5678” which would be in a manufacturer’s catalogue.
2. The right hand box classifies the functional physical object pump P_101 and the materialized physical object pump 98/1234.

4D – Pump role and pump model – temporal parts

```
:TemporalPartOfACoolingWaterPump
  owl:equivalentClass
    [ owl:onProperty lci:temporalPartOf;
      owl:someValuesFrom rdl:CoolingWaterPump ];
  rdfs:subClassOf rdl:CoolingWaterPump .

:TemporalPartOfAModelW_5678
  owl:equivalentClass
    [ owl:onProperty lci:temporalPartOf;
      owl:someValuesFrom man:Model_5678 ];
  rdfs:subClassOf man:Model_5678 .
```

```
:P_101
  rdf:type rdl:CoolingWaterPump .

:P_98_1234
  rdf:type man:ModelW_5678 .

:P_98_1234InstalledAsP_101FromMay2010
  rdf:type lci:PhysicalObject ;
  lci:temporalPartOf :P_98_1234 , :P_101 .
```

Inferred:

```
:P_98_1234InstalledAsP_101FromMay2010
  rdf:type rdl:CoolingWaterPump , man:Model_5678 .
```

4D – Pump role and pump model – temporal parts

Notes on previous slide:

1. A temporal part of a cooling water pump is also a cooling water pump. A temporal part of a model W-5678 pump is also a W-5678 pump.
2. It can be inferred that “Pump 98/1234 installed as P_101 from May 2010” is a cooling water pump and a model W-5678 pump.

4D – Pump role and pump model – invalid role for model

```
rdl:InvalidEquipmentModelForRole
  rdf:type owl:Class ;
  rdfs:subClassOf lci:PhysicalObject .

:UseOfModel_5678AsCoolingWaterPump
  owl:equivalentClass
    [ owl:intersectionOf (
      rdl:CoolingWaterPump
      man:Model_5678
    ) ];
  rdfs:subClassOf rdl:InvalidEquipmentModelForRole .
```

```
:P_101
  rdf:type rdl:CoolingWaterPump .

:P_98_1234
  rdf:type man:ModelW_5678 .

:P_98_1234InstalledAsP_101FromMay2010
  rdf:type lci:PhysicalObject ;
  lci:temporalPartOf :P_98_1234 , :P_101 .
```

Inferred:

```
:P_98_1234InstalledAsP_101FromMay2010
  rdf:type rdl:InvalidEquipmentModelForRole .
```

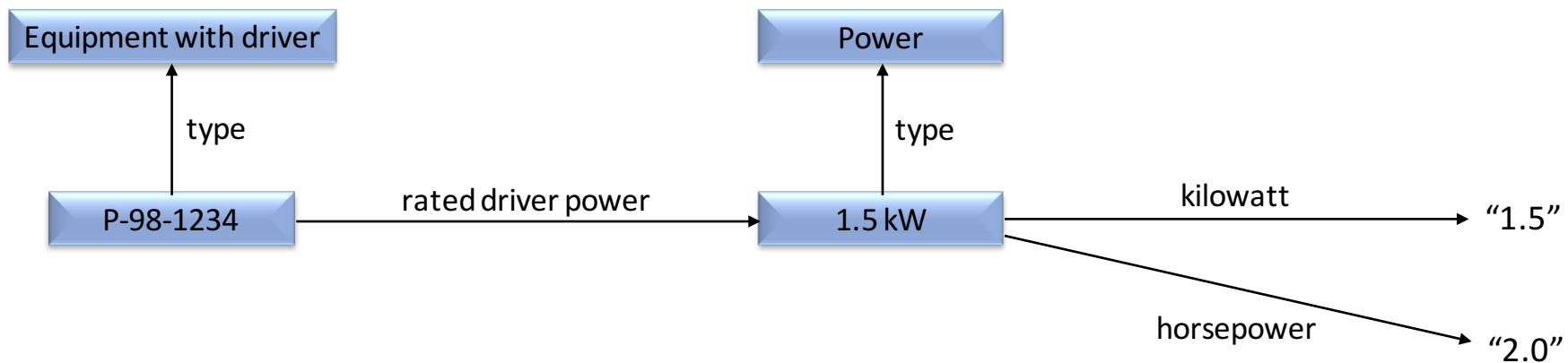
4D – Pump role and pump model – invalid role for model

Notes on previous slide:

1. If it is known that a model W-5678 pump is not suitable for cooling water, then the intersection of “cooling water pump” and “model W-5678” is a subclass of “invalid by role for equipment model”.
2. It can be inferred that “Pump 98/1234 installed as P_101 from May 2010” is a member of “invalid equipment model for role”.

4D – Physical property, quantity and scale

- P-98-1234 has a rated driver power of 1.5 kW
- Each pump of model W-5678 has a rated driver power of 1.5 kW



4D – Physical property, quantity and scale

Notes on previous slide:

1. “Rated driver power” is a **physical property**. A **physical property** has a range that is a **physical quantity kind**.
2. “Power” is a **physical quantity kind**. “1.5 kilowatts” is a member of “power”.
3. A member of power is identified by a number with respect to the kilowatt **scale**, the horse power **scale**, or both.

4D – Physical property – property of an individual

- P-98-1234 has a rated driver power of 1.5 kW

```
rdl:EquipmentWithDriver
  rdf:type owl:Class ;
  rdfs:subClassOf rdl:PhysicalObject .

rdl:Power
  rdf:type owl:Class .

rdl:ratedDriverPower
  rdf:type owl:ObjectProperty, owl:FunctionalProperty ;
  rdfs:domain rdl:EquipmentWithDriver ;
  rdfs:range rdl:Power .

rdl:kilowatt
  rdf:type owl:DatatypeProperty, owl:FunctionalProperty ;
  rdfs:domain rdl:Power ;
  rdfs:range xsd:float .
```

```
:P_98_1234
  rdl:ratedDriverPower
    [ rdl:kilowatt "1.5"^^xsd:float ] .
```

4D – Physical property – property of an individual

Notes on previous slide:

1. The left box shows the OWL representation of the RDL for “rated driver power”, “power” and “kilowatt”. The class “equipment with driver” is defined as the domain of “rated driver power”.
2. The right box shows the OWL representation of the rated power for pump P-98-1234.

4D – Physical property – property of a class

- Each pump of model W-5678 has a rated driver power of 1.5 kW

```
:EquipmentWithDriverRatedAt1_5kW
  owl:equivalentClass
    [ owl:onProperty rdl:ratedDriverPower ;
      owl:hasValue [ rdl:kilowatt "1.5"^^xsd:float ] ] .

man:ModelW_5678
  rdfs:subClassOf :EquipmentWithDriverRatedAt1_5kW .
```

```
:P_98_1234
  rdf:type man:ModelW_5678 .

:P_98_1234InstalledAsP_101FromMay2010
  lci:temporalPartOf :P_98_1234 .
```

Inferred:

```
:P_98_1234InstalledAsP_101FromMay2010
  rdl:ratedDriverPower
    [ rdl:kilowatt "1.5"^^xsd:float ] .
```

4D – Physical property – property of a class

Notes on previous slide:

1. The left box defines the class “equipment with driver rated at 1.5kW”, and states that pumps of model W-5678 are members of it.
2. The right box shows the statements that pump P-98-1234 is of model W-5678, and that “Pump 98/1234 installed as P_101 from May 2010” is a temporal part of it.
3. From this it can be inferred that:
 - “Pump 98/1234 installed as P_101 from May 2010” is of model W-5678; and hence that:
 - “Pump 98/1234 installed as P_101 from May 2010” has a rated driver power of 1.5 kW.

4D – Physical property – invalid installation by rating

- An installation of a pump for P_101 with a rated driver power less than 2 kW is invalid

```
:EquipmentWithDriverRatedLessThan2kW
  owl:equivalentClass
    [ owl:onProperty rdl:ratedDriverPower ;
      owl:allValuesFrom :LessThan2kW ] .

:LessThan2kW
  owl:equivalentClass
    [ rdf:type owl:Restriction ;
      owl:onProperty rdl:kilowatt ;
      owl:someValuesFrom
        [ rdf:type rdfs:Datatype ;
          owl:onDatatype xsd:float ;
          owl:withRestrictions (
            [ xsd:maxExclusive "2"^^xsd:float ] ;
          )
        ]
    ] .
```

```
:TemporalPartOfP_101
  owl:equivalentClass
    [ owl:onProperty lci:temporalPartOf ;
      owl:someValuesFrom :P_101 ] .

:TemporalPartOfP_101WithDriverRatedLessThan2kW
  owl:equivalentClass
    [ owl:intersectionOf (
      :TemporalPartOfP_101
      :EquipmentWithDriverRatedLessThan2kW
    ) ] ;
  rdfs:subClassOf rdl:InvalidEquipmentInstallationByRating .
```

4D – Physical property – invalid installation by rating

Notes on previous slide:

1. The left box defines the class “less than 2 kW” and the class “equipment with driver rated at less than 2kW” that depends on it.
2. The right box defines the class “temporal part of P-101” and says that any “temporal part of P-101” that is also an “equipment with driver rated at less than 2kW” is an “invalid equipment installation by rating”.

4D – Physical property – invalid installation by rating

- An installation of a pump for P_101 with a rated driver power less than 2 kW is invalid

```
rdl:InvalidEquipmentInstallationByRating
  rdf:type owl:Class ;
  rdfs:subClassOf lci:PhysicalObject .
```

```
:P_98_1234InstalledAsP_101FromMay2010
  lci:temporalPartOf:P_101 .
```

Inferred:

```
:P_98_1234InstalledAsP_101FromMay2010
  rdf:type :EquipmentWithDriverRatedLessThan2kW .
```

```
:P_98_1234InstalledAsP_101FromMay2010
  rdf:type rdl:InvalidEquipmentInstallationByRating .
```

4D – Physical property – invalid installation by rating

Notes on previous slide:

1. “Pump 98/1234 installed as P_101 from May 2010” is of model W-5678; therefore has a rated driver power of 1.5 kW; and therefore is a member of the class “equipment with driver rated at less than 2kW”.
2. “Pump 98/1234 installed as P_101 from May 2010” is a member of the class “temporal part of P-101”, and therefore it is a member of “invalid equipment installation by rating”.

4D – Physical property – multiple units of measure

```
rdl:horsePower
  rdf:type owl:DatatypeProperty, owl:FunctionalProperty;
  rdfs:domain rdl:Power;
  rdfs:range xsd:float .

:LessThan2_7hp
  owl:equivalentClass
    [ rdf:type owl:Restriction;
      owl:onProperty rdl:horsePower;
      owl:someValuesFrom
        [ rdf:type rdfs:Datatype;
          owl:onDatatype xsd:float;
          owl:withRestrictions (
            [ xsd:maxExclusive "2.7"^^xsd:float ];
          )
        ]
    ];
  owl:equivalentClass :LessThan2kW .
```

```
:EquipmentWithDriverRatedAt2hp
  owl:equivalentClass
    [ owl:onProperty rdl:ratedDriverPower;
      owl:hasValue [ rdl:horsePower "2"^^xsd:float ] ];
  owl:equivalentClass
    :EquipmentWithDriverRatedAt1.5kW .
```

```
:P_98_1234
  rdl:ratedDriverPower
    [ rdl:kilowatt "1.5"^^xsd:float;
      rdl:horsepower "2"^^xsd:float ] .
```

4D – Physical property – multiple units of measure

Notes on previous slide:

1. The left box shows that the class “less than 2.7 hp” can be defined and stated to be equivalent to the class “less than 2 kW”.
2. The right box shows that the class “equipment with driver rated at 2 hp” can be defined and stated to be equivalent to the class “equipment with driver rated at 1.5 kW”.
3. A physical property of an individual can be stated using multiple units of measure.

4D – Physical property – stream example

- A natural gas stream with a pressure greater than 4 bar is in a dangerous state

```
rdl:Pressure
  rdf:type owl:Class .

rdl:averageStreamPressure
  rdf:type owl:ObjectProperty, owl:FunctionalProperty ;
  rdfs:domain rdl:Stream ;
  rdfs:range rdl:Pressure .

rdl:bar
  rdf:type owl:DatatypeProperty, owl:FunctionalProperty ;
  rdfs:domain rdl:Pressure ;
  rdfs:range xsd:float .
```

```
:StreamWithPressureGreaterThan4Bar
  owl:equivalentClass
    [ owl:onProperty rdl:averageStreamPressure ;
      owl:allValuesFrom :GreaterThan4Bar ] .

:GreaterThan4Bar
  owl:equivalentClass
    [ rdf:type owl:Restriction ;
      owl:onProperty rdl:bar ;
      owl:someValuesFrom
        [ rdf:type rdfs:Datatype ;
          owl:onDatatype xsd:float ;
          owl:withRestrictions (
            [ xsd:minExclusive "4"^^xsd:float ] ;
          )
        ]
    ] .
```

4D – Physical property – stream example

Notes on previous slide:

1. The left box shows the OWL representation of the RDL for “average stream pressure”, “pressure” and “bar”.
2. The right box defines the class “greater than 4 bar” and the class “stream with pressure greater than 4 bar” that depends on it.

4D – Physical property – stream example

- A natural gas stream with a pressure greater than 4 bar is in a dangerous state

```
:S_101
    rdf:type lci:Stream, rdl:NaturalGas .

:S_101AtPointP
    lci:arrangedPartOf :S_101 .

:S_101AtPointPAndTimeT
    lci:temporalPartOf :S_101AtPointP ;
    rdl:averageStreamPressure
        [ rdl:bar "5"^^xsd:float ] .
```

Inferred:

```
:S_101AtPointPAndTimeT
    rdf:type :NaturalGas .

:S_101AtPointPAndTimeT
    rdf:type :StreamWithPressureGreaterThan4Bar .

:S_101AtPointPAndTimeT
    rdf:type rdl:DangerousStreamState .
```

4D – Physical property – stream example

Notes on previous slide:

1. The left box shows statements about the stream and the measurement at point p and time t.
2. The right box shows what can be inferred about the stream at point p and time t:
 - it is of natural gas;
 - it is a member of “stream with pressure greater than 4 bar”;
 - it is a member of “dangerous stream state”.