OWFgraph

a graph database for the off-shore wind farm domain

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joint work with Sebastian Sanchez & Michiel Zaaijer

TU Delft Wind Energy Presentation

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2.1 Wake description

The wake behind a turbine is assumed to have a start diameter equal to the turbine diameter, and to spread linearly as a function of downwind distance. This simplification means that the wake velocity cannot be found very accurately at all downwind positions, but by adjusting the spread angle to fit data at distances larger than about four diameters, only the calculation of the near-wake zone will involve large errors. As wind turbines are seldom put closer together than this distance, it is not necessary to make accurate calculations here.

Inside the wake the velocity is consideted constant, instead of using the commonly seen Gaussian distribution. This simplification is made because the aim of the model is to give an estimate of the energy content in the wind field seen by the downwind turbines, rather than to describe the velocity field accurately.

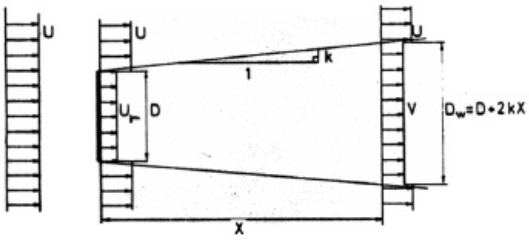


Fig. 2. Schematic view of wake description

With symbols defined in Fig. 2, a balance of momentum gives:

$$D^2U_r + (Dw^2 - D^2)U = D_w^2 V$$

The wake velocity is found by the expression

$$V/U = 1 - 2a/(1 + 2kX/D)^2 \quad ,$$

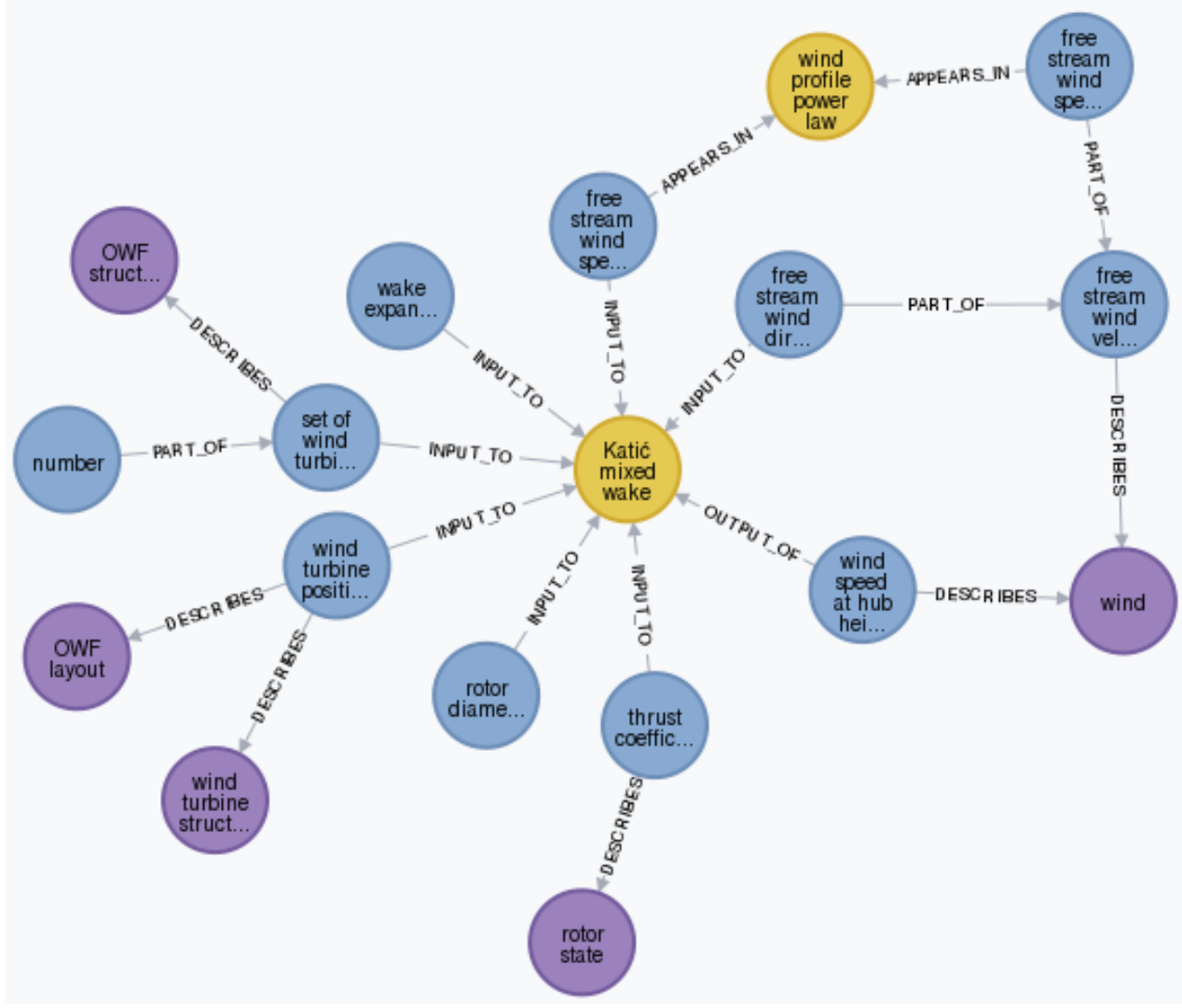
a is defined as the initial velocity deficit $1-U_r/U$ but can also be expressed as

$$a = (1 - \sqrt{1 - C_t})/2$$

where Ct is the thrust coefficient of the turbine. Hence, the velocity deficit of the wake at a given position X is:

$$1 - V/U = (1 - \sqrt{1 - C_t})/(1 + 2kX/D)^2 \ .$$

The problem of interacting wakes is solved by assuming the kinetic energy deficit of a mixed wake to be equal to the sum of the energy deficits for each wake at the calculated downwind position.



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Lessons learned	What is different from what we expected?

Goal – context within EUROS program

Project 3 Wind Farm Design Optimization

Work Package 3.2 Uncertainty Model of Wind Farms

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Challenge Develop a model for the accumulation of uncertainty from multiple sources in performance and cost of an entire OWF.

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Activities

- make inventory of sources of uncertainty;
- create causal map of uncertainty propagation;
- assessment of uncertainty contributions to OWF CoE;
- select uncertainty propagation approach.

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⇒ Conclusion Create a structured description of the domain

Content – concept types

The physical world Objects, Procedures, Attributes, and Phenomena

```
$ match (o:Object) return o, rand() as r order by r limit 3
```

*(3) **Object**(3)


```
$ match (o:Procedure) return o, rand() as r order by r limit 3
```

*(3) **Procedure**(3)


```
$ match (a:Attribute) return a, rand() as r order by r limit 3
```

*(3) **Attribute**(3)


```
$ match (p:Phenomenon) return p
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(no rows)

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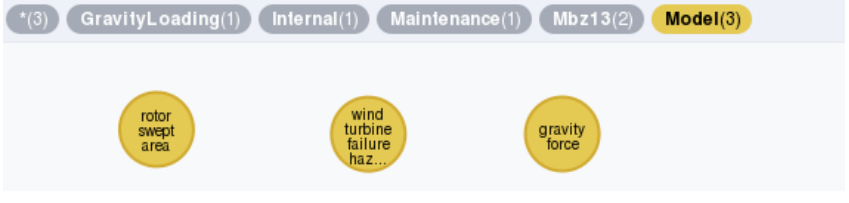
```

(no rows)

The mathematical world Variables and Models

```
$ match (v:Variable) return v, rand() as r order by r limit 3
```


```
$ match (m:Model) where exists(m.name) return m, rand() as r order by r limit 3
```



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Graph representation as structured domain knowledge representation:

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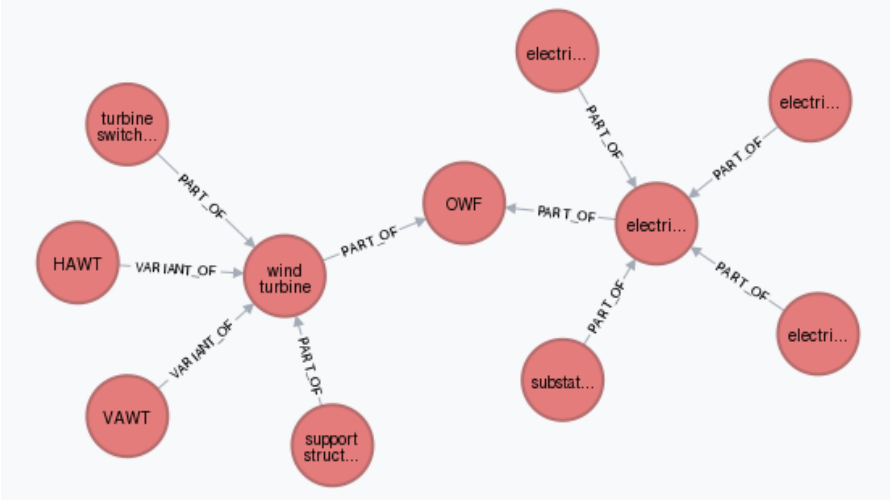

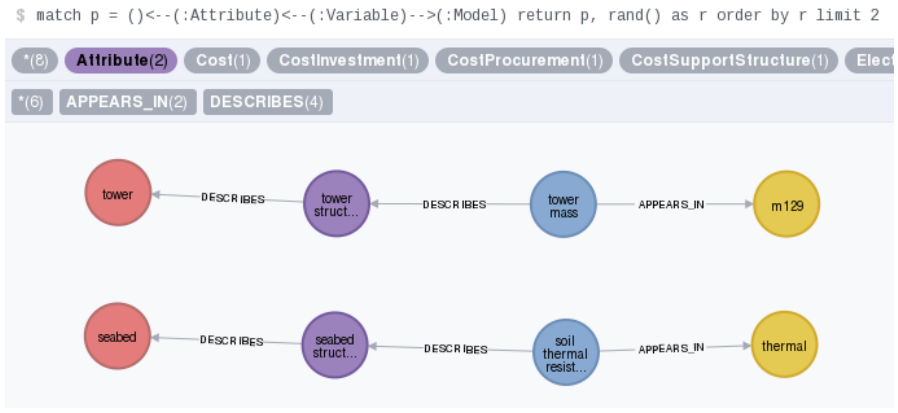

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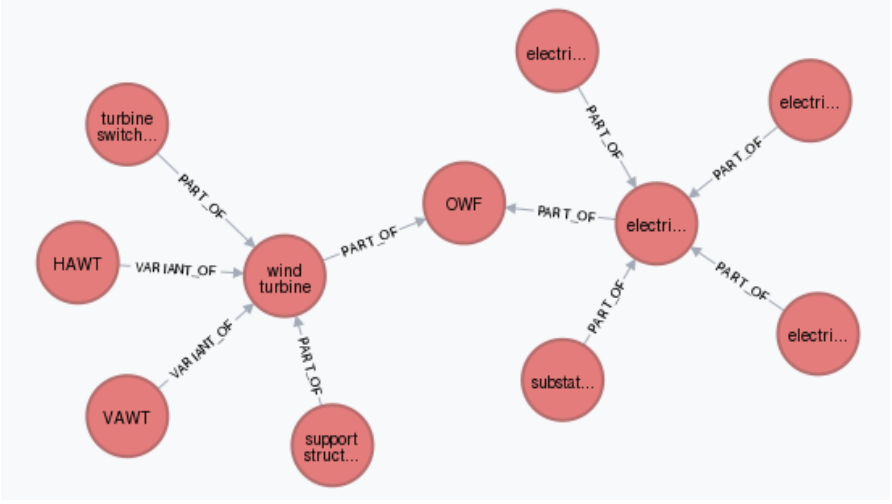
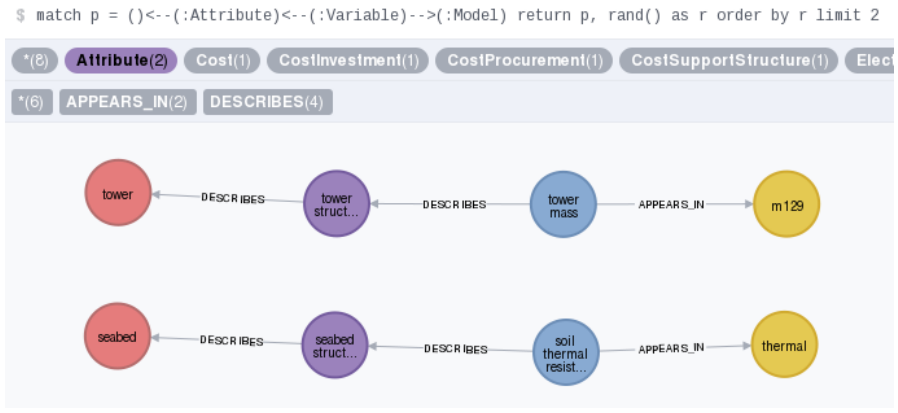
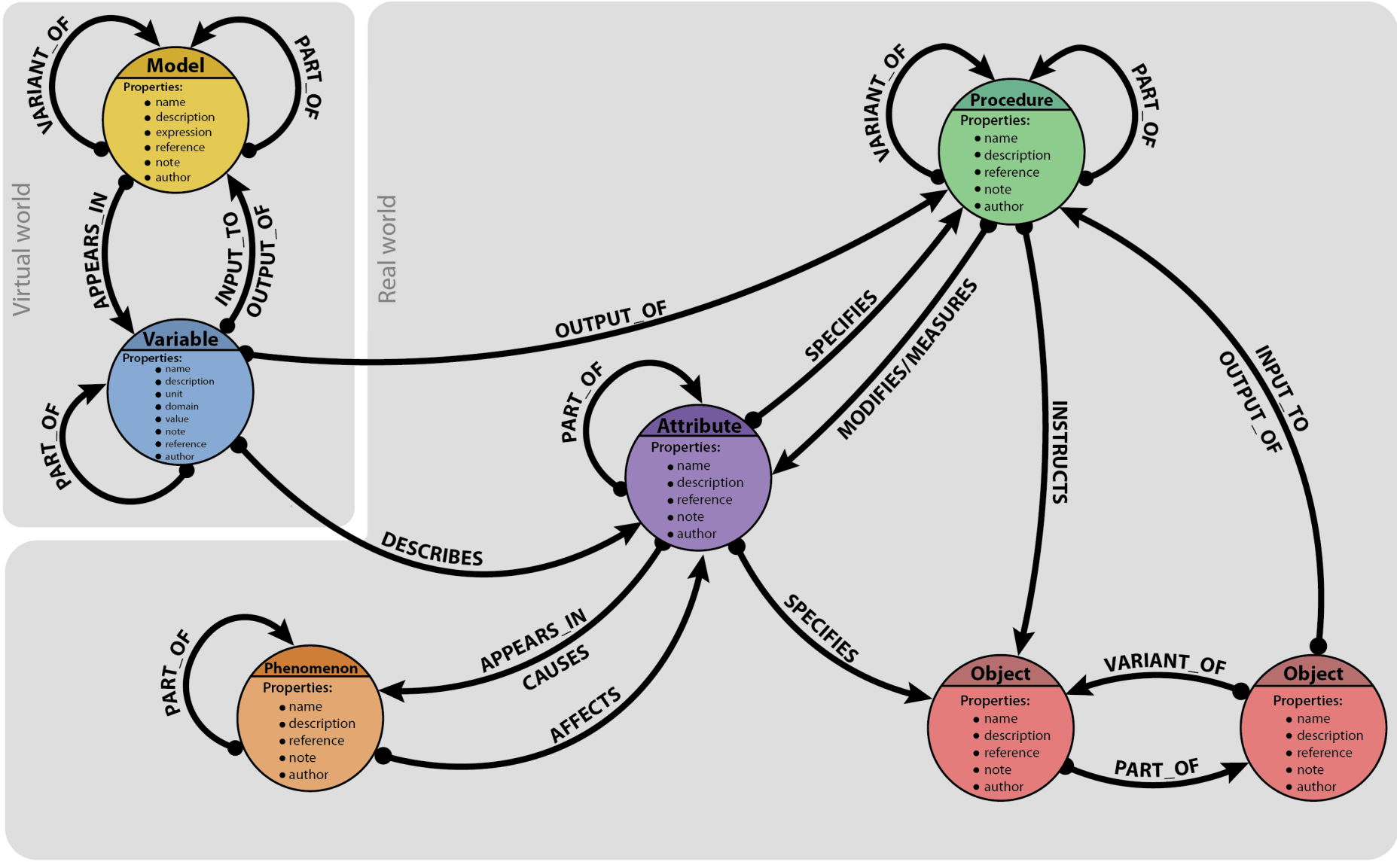




We need a 'foundational ontology' for our knowledge graph:

- classification of the domain's concepts and relationships,
- small enough to be manageable,
- large enough to be sufficiently expressive.

Structure – The foundational ontology



(Drawing courtesy of Sebastian Sanchez.)

Content – Types, Labels, and Properties

Content is added to the graph by

- giving edges a *type*,

```
$ match ()-[r]-() with type(r)...
```

t	c
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INPUT_TO	168
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```
$ match (n) with labels(n) as l, count(n) ...
```

l	c
[Variable, Mbz13]	293
[Variable]	124
[Attribute]	102
[Object]	93
[Model, Maintenance, Mbz13, Internal]	48
[Model]	42
[Variable, Mbz13, Internal]	40
[Model, Electricity, Mbz13]	24
[Model, Mechanics, Mbz13]	15
[Model, SiteConditions, Mbz13]	8
[Model, Hydrology, Mbz13]	6
[Model, Cost, CostOperationMaintenance, CostMaintenance, Mbz13]	6
[Procedure]	6

Content – Types, Labels, and Properties

Content is added to the graph by

- giving edges a *type*,
- giving nodes zero or more *labels*, and
- attaching any number of *properties*—key-value pairs—to nodes.

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```
$ match (m:Model {name:"Katić mixed wake model"})--(v:Variable) where v.name contains "wake"...
```

m

reference	I. Katić, J. Højstrup, and N. O.Jensen. A simple model for cluster efficiency. In Proceedings of EWEC'86, volume 1, pages 407–410. Rome, 1987. John Twidell (ed.) Offshore Wind Power, Chapter 4, Eq. 21. PhD thesis Michiel Zaaijer, p.237.
note	We have not described the model for determining the upstream wind tubines nor mentioned mirror turbines to take into account the ground effect.
author	sebastian,equaeghebeur
name	Katić mixed wake model

v

author	sebastian,equaeghebeur
domain	real
name	wake expansion factor
description	Linear coefficient with which the wake diameter increases downwind according to the Jensen model. Also called wake decay coefficient. Denoted k.

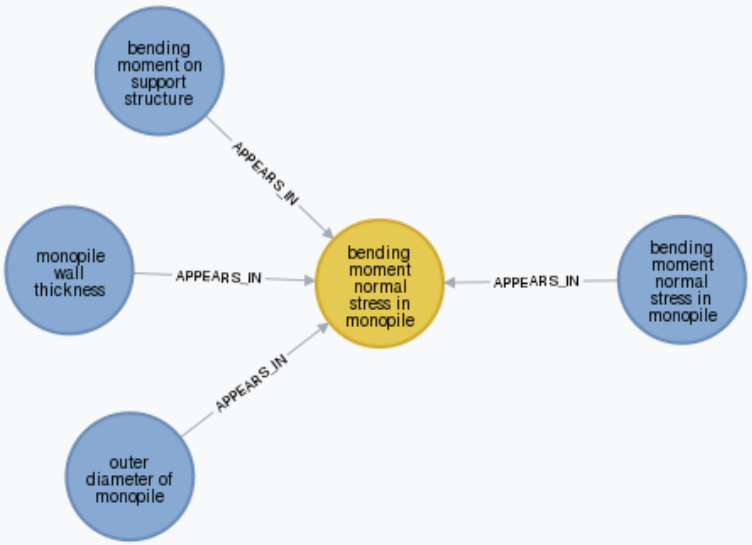
Content & Structure – Representation challenges

When is variable an input to a model, an output, or both?

```
$ match p = (:Model {name:"bending moment normal stress in monopile"})--(:Variable) return p
```

*(5) Mbz13(4) Mechanics(1) **Model**(1) **Variable**(4)

*(4) APPEARS_IN(4)

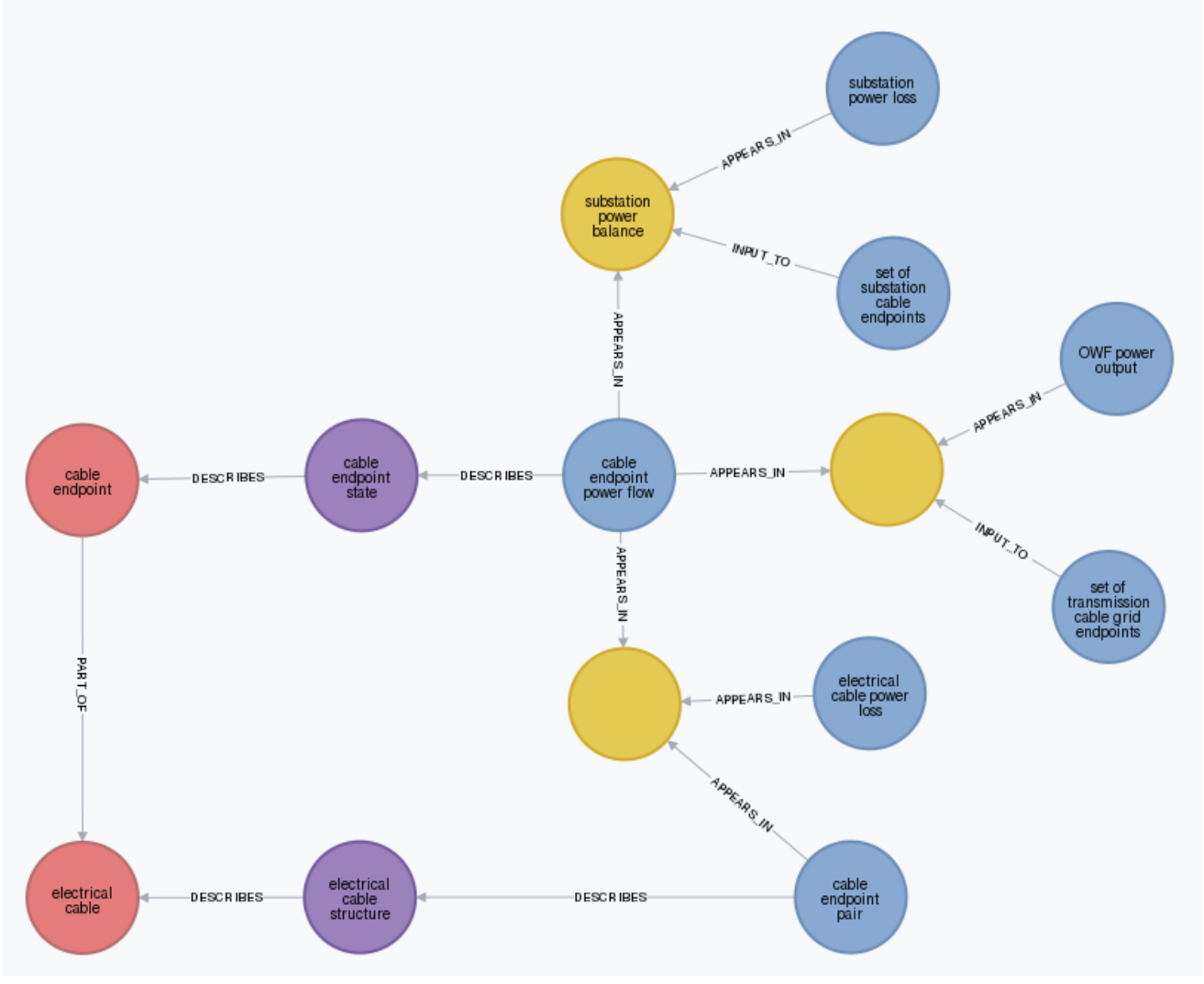



```
$ match (:Model {name:"bending moment normal...
```

v.name	r.output
bending moment normal stress in monopile	true
outer diameter of monopile	false
bending moment on support structure	false
monopile wall thickness	false

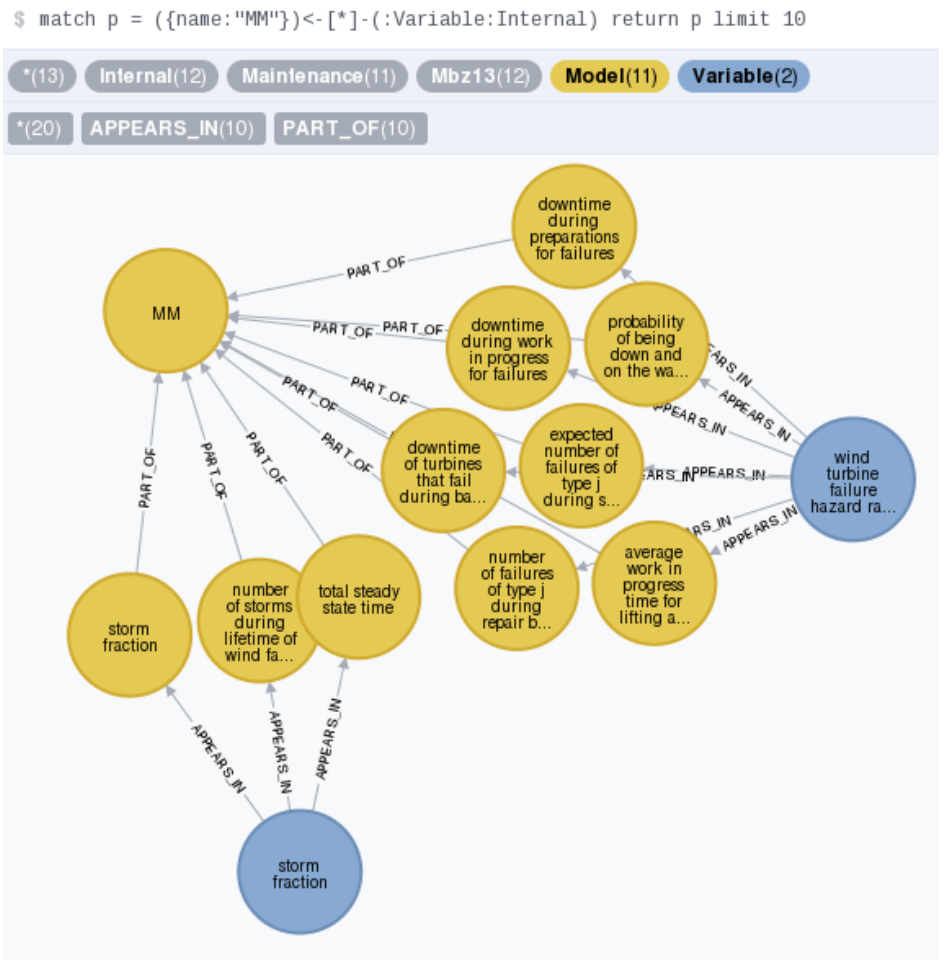
Content & Structure – Representation challenges

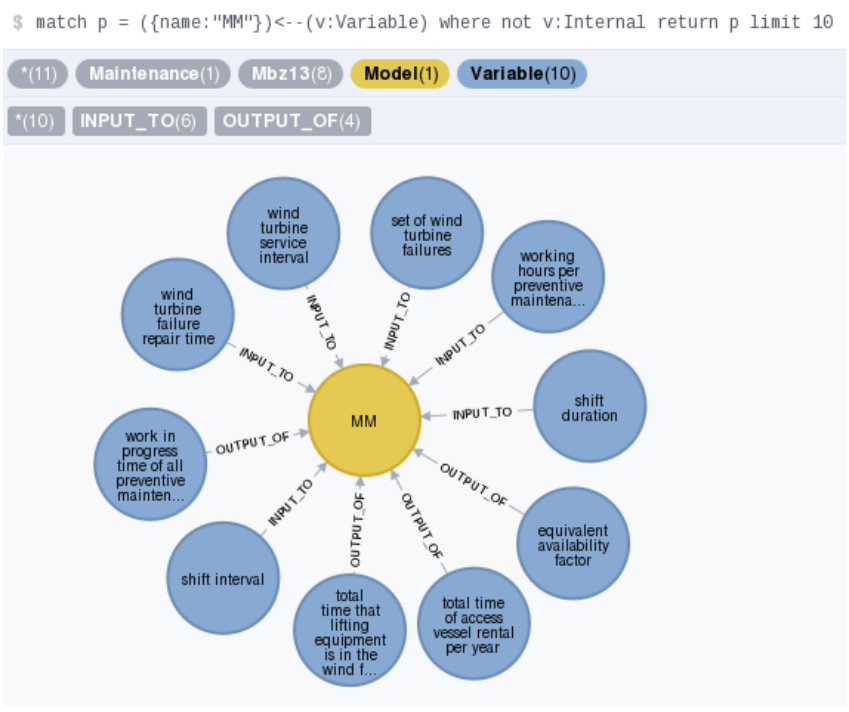
A concept should only be represented once; what about models that deal with multiple instances of a concept?



Content & Structure – Representation challenges

How to isolate sub-models of a larger model and deal with the variables involved?

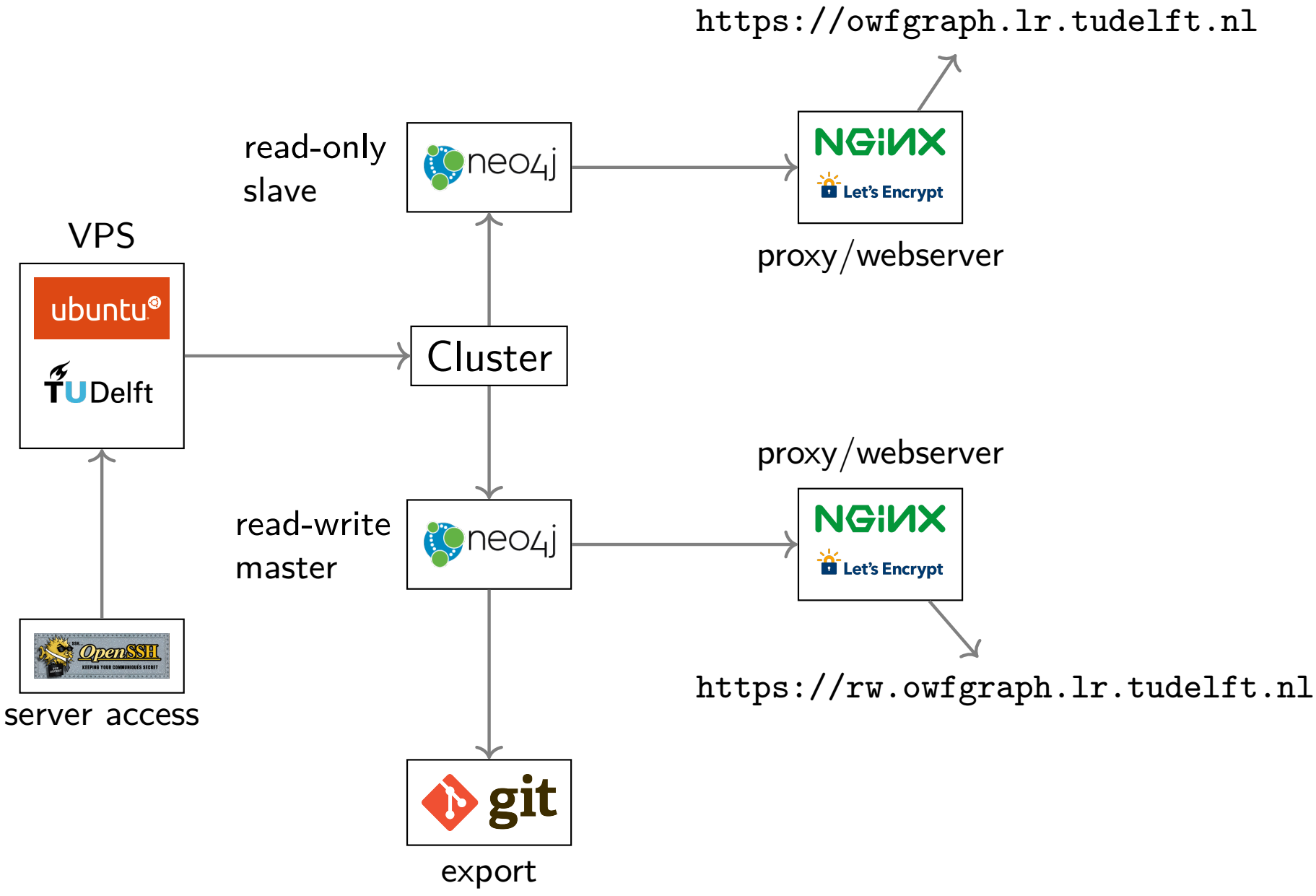




Implementation

- Native property graph database
- Java
- ‘driver’ (or wrapper) for many major languages (e.g., Python)
- Web interface for data entry and querying
- Shell access for importing and exporting data
- ‘Community edition’ (GPLv3) with limitations
- ‘Enterprise edition’ (AGLPv3) with clustering, live backups, etc.
- Mature and widely used (so free ‘forum-based’ support works)

Installation – Our setup



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- All screenshots are output resulting from queries.

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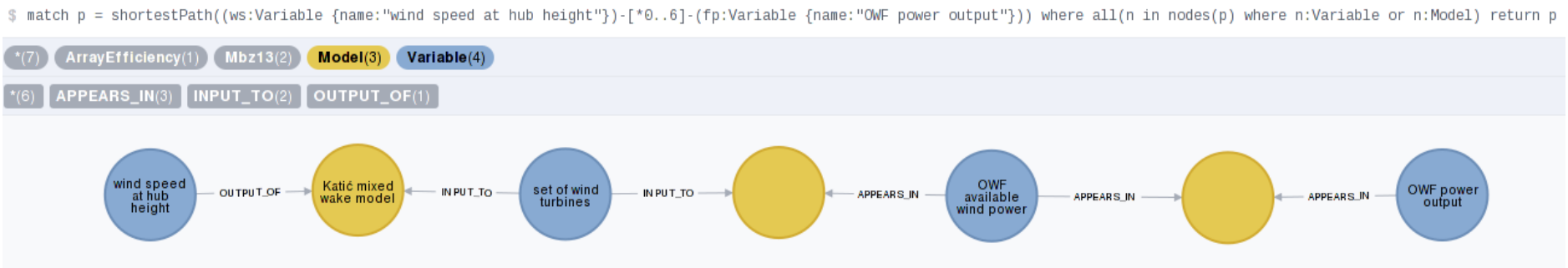
Example: path between ‘wind speed’ and ‘OWF power output’.



(via ‘set of wind turbines’)

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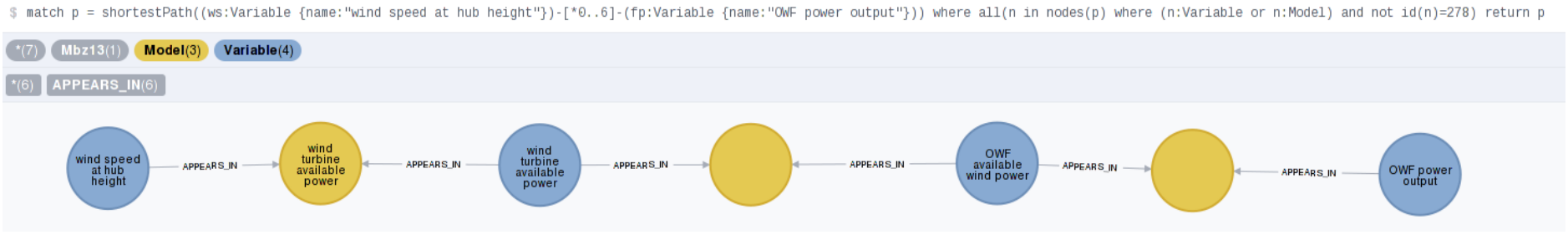

(via ‘available power’)

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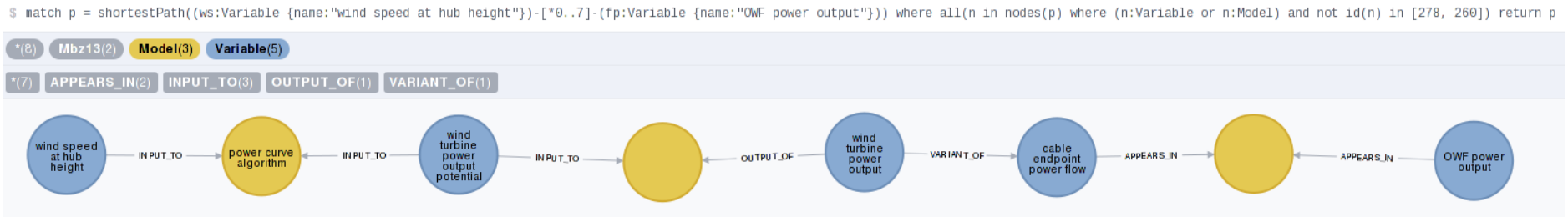

(via ‘power curve algorithm’)

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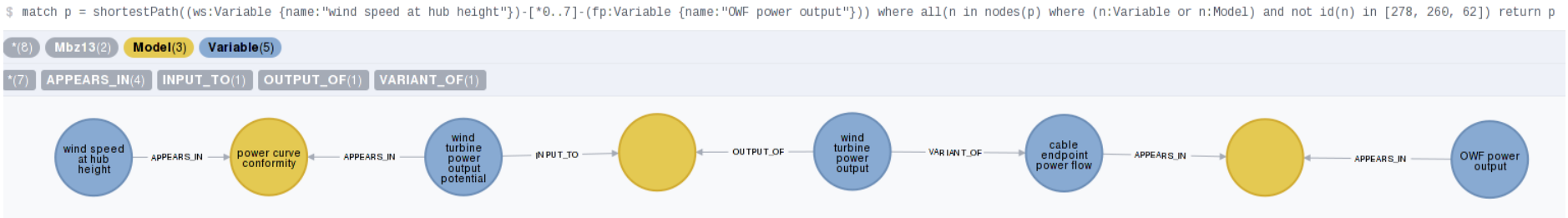

(looks good, but ‘wind speed’ is not free stream)

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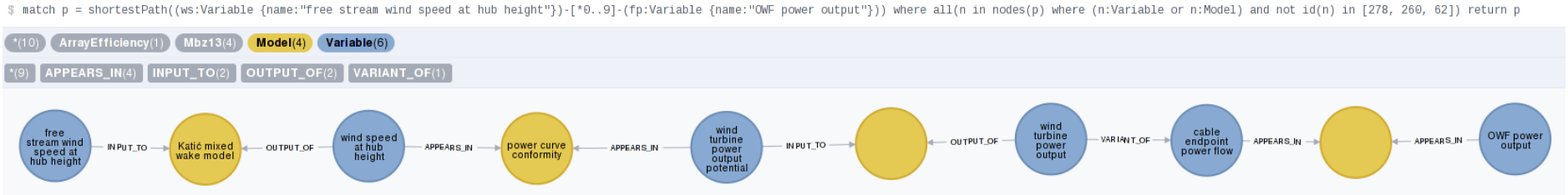

(ok, a good path, now tweak further to find alternatives. . .)

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- System administration also requires a non-negligible effort.

But overall very interesting and quite useful.

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- Make the database semi-public. (learning curve is an issue.)
- Open up and promote for other uses as well.

Live demo – Read-Only

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- Interface: command line at the top, output canvas below,
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- Table output:

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  match (n:Object) with n limit 5
  return n.name, n.description, n.author
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- More involved queries:

  ```
  match p = (:Object {name:"monopile"})-[*]->()
  return p
  ```

Live demo – Read-Write

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  (Currently only Sebastian & I have access.)
- Same interface, but now also write—and delete—queries are enabled.

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remove b.name
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set b:Attribute, b.author="killroy"
remove b.name
return b
```

- Deleting nodes and edges:

```
match (b {author:"killroy"}) detach delete b
```

Questions?

Feedback?