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 considered 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:

\[ D_1^2 U_2 + (2w^2 - D_2^2)U = D_2^2 V \]

The wake velocity is found by the expression

\[ V/U = 1 - 2\gamma(1 + 2w/d)^2 \]

\( \gamma \) is defined as the initial velocity deficit \( 1 - U_2/U \), but can also be expressed as

\[ \gamma = (1 - \sqrt{1 - C_T})/2 \]

where \( C_T \) is the thrust coefficient of the turbine. Hence, the velocity deficit of the wake at a given position \( X \) is

\[ 1 - U_2/U = (1 - \sqrt{1 - C_T})(1 + 2w/d)^2 \]

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.
Overview

Goal Why do we want to build a graph database for the offshore wind farm domain?
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**Content** What do we put into the database?
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**Querying**  How do we add and extract data?
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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
Goal – context within EUROS program

Project 3  Wind Farm Design Optimization
Work Package 3.2  Uncertainty Model of Wind Farms

Challenge  Develop a model for the accumulation of uncertainty from multiple sources in performance and cost of an entire OWF.
Goal – context within EUROS program

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Work Package 3.2 Uncertainty Model of Wind Farms

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

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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Work Package 3.2  Uncertainty Model of Wind Farms

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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.

⇒ Conclusion  Create a structured description of the domain
Content – concept types

The physical world  Objects, Procedures, Attributes, and Phenomena

$\text{match } (o:\text{Object}) \text{ return } o, \text{ rand()} \text{ as } r \text{ order by } r \text{ limit 3}$

$\text{Object(3)}$

- support
- struct...
- active
- yaw
- syst...
- rotor
- bearing

$\text{match } (a:\text{Attribute}) \text{ return } a, \text{ rand()} \text{ as } r \text{ order by } r \text{ limit 3}$

$\text{Attribute(3)}$

- shunt
- reactor
- struct...
- monop...
- OWES
- state

$\text{match } (o:\text{Procedure}) \text{ return } o, \text{ rand()} \text{ as } r \text{ order by } r \text{ limit 3}$

$\text{Procedure(3)}$

- RNA
- assem...
- wind
- turbine
- main...
- OWF
- install...

$\text{match } (p:\text{Phenomenon}) \text{ return } p$

(no rows)
Content – concept types

The physical world  Objects, Procedures, Attributes, and Phenomena

$\text{match (o:Object) return o, rand() as r order by r limit 3}$

*(3) Object(3)

support struct...  active yaw syst...  rotor bearing

$\text{match (a:Attribute) return a, rand() as r order by r limit 3}$

*(3) Attribute(3)

shunt reactor struct...  monop...  OWES state

$\text{match (p:Phenomenon) return p}$

(no rows)

The mathematical world  Variables and Models

$\text{match (v:Variable) return v, rand() as r order by r limit 3}$

*(3) Mbz13(3) Variable(3)

kinem...  thrust coeffic...  wave period

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

*(3) GravityLoading(1)  Internal(1)  Maintenance(1)  Mbz13(2)  Mode(3)

rotor sweep area  wind turbine failure rate  gravity force
Structure – Graph representation

*Graph representation* as structured domain knowledge representation:

- *concepts* as nodes;
- *interrelations* as edges.
**Structure – Graph representation**

*Graph representation* as structured domain knowledge representation:
- **concepts** as nodes;
- **interrelations** as edges.

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 – Graph representation

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- **interrelations** as edges.

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)... 
```

<table>
<thead>
<tr>
<th>t</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>APPEARS_IN</td>
<td>1328</td>
</tr>
<tr>
<td>DESCRIBES</td>
<td>542</td>
</tr>
<tr>
<td>PART_OF</td>
<td>408</td>
</tr>
<tr>
<td>INPUT_TO</td>
<td>168</td>
</tr>
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<td>150</td>
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Content – Types, Labels, and Properties

Content is added to the graph by
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- giving nodes zero or more labels, and

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\$ \text{match } ()-[r:()-] \text{ with type}(r)...
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```
\$ \text{match } (n) \text{ with labels}(n) \text{ as } l, \text{ count}(n)...
```

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<td>124</td>
</tr>
<tr>
<td>[Attribute]</td>
<td>102</td>
</tr>
<tr>
<td>[Object]</td>
<td>93</td>
</tr>
<tr>
<td>[Model, Maintenance, Mbz13, Internal]</td>
<td>40</td>
</tr>
<tr>
<td>[Model]</td>
<td>42</td>
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<tr>
<td>[Model, Hydrology, Mbz13]</td>
<td>6</td>
</tr>
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<td>[Procedure]</td>
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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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$\text{match \{[r]\} with type(r)...}$

$\text{match \{n\} with labels(n) as l, count(n) ...}$

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$\text{match \{s:Model \{name: 'Katz mixed wake model'\}--\{v:Variable\} where v.name contains 'wake'...}$

<table>
<thead>
<tr>
<th>m</th>
<th>v</th>
</tr>
</thead>
<tbody>
<tr>
<td>author</td>
<td>sebastian,equaeghebier</td>
</tr>
<tr>
<td>domain</td>
<td>real</td>
</tr>
<tr>
<td>name</td>
<td>wake expansion factor</td>
</tr>
<tr>
<td>description</td>
<td>Linear coefficient with which the wake diameter increases downstream according to the Jensen model. Also called wake decay coefficient. Denoted k.</td>
</tr>
<tr>
<td>note</td>
<td>We have not described the model for determining the upstream wind turbines nor mentioned mirror turbines to take into account the ground effect.</td>
</tr>
<tr>
<td>author</td>
<td>sebastian,equaeghebier</td>
</tr>
<tr>
<td>name</td>
<td>Katz mixed wake model</td>
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Content & Structure – Representation challenges

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

$\text{match } p = \text{(:Model \{name:"bending moment normal stress in monopile"\})..(:Variable) return } p$
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?

\[
\text{match } p = \{(\text{name} : \text{"MM"})\} \rightarrow 
\rightarrow \{v : \text{Variable} : \text{Internal}\} \text{ return } p \text{ limit } 10
\]

\[
\text{match } p = \{(\text{name} : \text{"MM"})\} \leftarrow 
\rightarrow \{v : \text{Variable}\} \text{ where not } v : \text{Internal} \text{ return } p \text{ limit } 10
\]
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

- **VPS**
  - ubuntu®
  - TU Delft

- **Cluster**
  - neo4j
  - read-only slave

- **Read-write master**
  - neo4j

- **Proxy/webserver**
  - NGiNX
  - Let's Encrypt

- **Server access**
  - OpenSSH

- **Export**
  - git

- **URLs**
  - https://owfgraph.lr.tudelft.nl
  - https://rw.owfgraph.lr.tudelft.nl
Querying

- Queries—questions asked or instructions given—are formulated using Cypher.

- All screenshots are output resulting from queries.
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- My interest is to query the database for possible paths between variables of interest.

- Such questions require manual query tweaking:
Querying

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- My interest is to query the database for possible *paths between variables of interest*.

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

```
$ match p = shortestPath((ws:Variable {name:"wind speed at hub height"})-[*..6]-(fp:Variable {name:"OWF power output"})) where all(n in nodes(p) where n:Variable or n:Model) return p
```

(via ‘set of wind turbines’)
Querying

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- Such questions require manual query tweaking:

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

```
$ match p = shortestPath((w:Variable {name:'wind speed at hub height'}), ('OWP').{(f:Variable {name:'OWF power output'})}) where all(n in nodes(p)) where (n:Variable or n:Model) and not id(n)=278) return p
```

(via ‘available power’)
Querying

- Queries—questions asked or instructions given—are formulated using Cypher.

- All screenshots are output resulting from queries.

- My interest is to query the database for possible paths between variables of interest.

- Such questions require manual query tweaking:

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

```
$ match p = shortestPath({v:Variable (name:"wind speed at hub height")}:{n:7}<{fp:Variable (name:"OWF power output")}) where all(n in nodes(p)) where (n:Variable or n:Model) and not id(n) in [278, 269] return p
```

(via ‘power curve algorithm’)
Querying

- Queries—questions asked or instructions given—are formulated using Cypher.

- All screenshots are output resulting from queries.

- My interest is to query the database for possible paths between variables of interest.

- Such questions require manual query tweaking:

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

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

- Queries—questions asked or instructions given—are formulated using Cypher.
- All screenshots are output resulting from queries.
- My interest is to query the database for possible paths between variables of interest.
- Such questions require manual query tweaking:

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

(enter your cypher query here)

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

- Designing the foundational ontology takes quite a number of iterations and requires experience from adding content.
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- System administration also requires a non-negligible effort.
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- Even with the foundational ontology more-or-less settled, structuring content is often difficult.

- Adding well-curated content takes time.

- System administration also requires a non-negligible effort.

But overall very interesting and quite useful.
Current & Next Steps

- Focus shift from content entry to use.
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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

- Surf to https://owfgraph.lr.tudelft.nl; login ‘Euros’, password ‘…’.
- Interface: command line at the top, output canvas below, info & control pane at the left.
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- Basic query:

  ```
  match (n:Object) return (n) limit 3
  ```

  Explore neighborhood interactively.
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- Basic query:
  
  \[
  \text{match (n:Object) return (n) limit 3}
  \]

  Explore neighborhood interactively.

- Table output:
  
  \[
  \text{match (n:Object) with n limit 5}
  \text{return n.name, n.description, n.author}
  \]
Live demo – Read-Only

- Surf to https://owfgraph.lr.tudelft.nl; login ‘Euros’, password ‘…’.
- Interface: command line at the top, output canvas below, info & control pane at the left.
- Basic query:
  \[
  \text{match (n:Object) return (n) limit 3}
  \]
  Explore neighborhood interactively.
- Table output:
  \[
  \text{match (n:Object) with n limit 5 return n.name, n.description, n.author}
  \]
- More involved queries:
  \[
  \text{match p = (:Object \{name:"monopile"\})-[*]->() return p}
  \]
Live demo – Read-Write

- Surf to https://rw.owfgraph.lr.tudelft.nl. (Currently only Sebastian & I have access.)
- Same interface, but now also write—and delete—queries are enabled.
Live demo – Read-Write

- Surf to https://rw.owfgraph.lr.tudelft.nl. (Currently only Sebastian & I have access.)
- Same interface, but now also write—and delete—queries are enabled.
- Creation (merging):

  ```
  match (a:Attribute {name:"wind"})
  merge (a)<-[PART_OF]-(b {name:"wind color"})
  return a, b
  ```
Live demo – Read-Write

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  return a, b
  ```

- Setting and removing labels and properties:

  ```
  match (b {name:"wind color"})
  set b:Attribute, b.author="killroy"
  remove b.name
  return b
  ```
Live demo – Read-Write

- Surf to https://rw.owfgraph.lr.tudelft.nl.
  (Currently only Sebastian & I have access.)
- Same interface, but now also write—and delete—queries are enabled.
- Creation (merging):
  ```cyrillic
  match (a:Attribute {name:"wind"})
  merge (a)<-[PART_OF]-(b {name:"wind color"})
  return a, b
  ```

- Setting and removing labels and properties:
  ```cyrillic
  match (b {name:"wind color"})
  set b:Attribute, b.author="killroy"
  remove b.name
  return b
  ```

- Deleting nodes and edges:
  ```cyrillic
  match (b {author:"killroy"}) detach delete b
  ```
Questions?

Feedback?