Using Formal Concept Analysis to Extract a Greatest Common Model

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Elaborating data models is a recurrent activity

Usually, building a domain model requires several expertises
- Example: the study of pesticides impact needs hydrology, agronomy, chemistry... specialists

A gathering activity is needed to design a consolidated model

Issue

Extract common elements from two different yet close models.
Introduction
A short introduction to Formal Context Analysis
Use Formal Concept Analysis to extract core-concept candidates

Results

Conclusion

Two close yet different models - simplified versions

Transfer team:

Practice team:

Note: Association and features details are removed on this figure
Two close yet different models - simplified versions

Note: Association and features details are removed on this figure
Transfer team:

Practice team:

Note: Association and features details are removed on this figure
Proposition

<table>
<thead>
<tr>
<th>Common Elements</th>
<th>Specific Elements from M1</th>
<th>Specific Elements from M2</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Proposition

FCA Based analysis

M1

Common Elements

Specific Elements from M1

from M2

M2

Specific Elements
1. Introduction

2. A short introduction to Formal Context Analysis

3. Use Formal Concept Analysis to extract core-concept candidates
   - Apply Formal Concept Analysis on the two models
   - Concept Classification

4. Results

5. Conclusion
Formal Concept Analysis

- A method of data analysis based on lattice theory
- Used to group entities according to their characteristics
- Many ways to describe entities \(\Rightarrow\) many ways to apply FCA
- UML Classes can be described by:
  - their name
  - their owned attributes
  - their owned roles
  - ...
# From Model to Formal Context

<table>
<thead>
<tr>
<th>cl_PET</th>
<th>att_MeasuringHour</th>
<th>att_Value</th>
<th>att_WaterAmount</th>
<th>att_MeasuringDate</th>
<th>att_CodeQuality</th>
</tr>
</thead>
<tbody>
<tr>
<td>cl_Temperature</td>
<td>×</td>
<td>×</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cl_Rainfall</td>
<td>×</td>
<td>×</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cl_HydraulicHead</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>cl_PET</td>
<td>×</td>
<td>×</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### From Model to Formal Context

<table>
<thead>
<tr>
<th>Concept</th>
<th>MeasuringHour</th>
<th>Value</th>
<th>WaterAmount</th>
<th>MeasuringDate</th>
<th>CodeQuality</th>
<th>WaterHeight</th>
</tr>
</thead>
<tbody>
<tr>
<td>cl_PET</td>
<td></td>
<td></td>
<td></td>
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</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Extent
- cl_Rainfall: MeasuringHour, WaterAmount, MeasuringDate, CodeQuality
- cl_HydraulicHead: MeasuringHour, WaterHeight
- cl_Temperature: MeasuringHour, Value
- cl_PET: MeasuringHour, Value
A short introduction to Formal Context Analysis

Use Formal Concept Analysis to extract core-concept candidates

Results

Conclusion

From Model to Formal Context

<table>
<thead>
<tr>
<th>cl_Rainfall</th>
<th>att_CodeQuality</th>
<th>att_MeasuringDate</th>
<th>att_WaterAmount</th>
<th>att_MeasuringHour</th>
</tr>
</thead>
<tbody>
<tr>
<td>cl_HydraulicHead</td>
<td>att_WaterHeight</td>
<td>att_MeasuringDate</td>
<td>att_WaterAmount</td>
<td>att_MeasuringHour</td>
</tr>
<tr>
<td>cl_Temperature</td>
<td>att_CodeQuality</td>
<td>att_MeasuringDate</td>
<td>att_WaterHeight</td>
<td>att_MeasuringHour</td>
</tr>
<tr>
<td>cl_PET</td>
<td>att_Value</td>
<td>att_MeasuringDate</td>
<td>att_CodeQuality</td>
<td>att_MeasuringHour</td>
</tr>
<tr>
<td>Concept_16</td>
<td>att_MeasuringDate</td>
<td>att_Value</td>
<td>att_MeasuringDate</td>
<td>att_CodeQuality</td>
</tr>
</tbody>
</table>

Concepts:
- cl_PET
- cl_Temperature
- cl_Rainfall
- cl_HydraulicHead
From Formal Context to Concept Lattice
From Formal Context to Concept Lattice

- Concept_12
  - Concept_13
    - att_MeasuringHour
    - att_Value
    - cl_PET
    - cl_Temperature
  - Concept_14
    - att_MeasuringDate
    - att_CodeQuality
  - Concept_15
    - att_WaterAmount
    - cl_Rainfall
  - Concept_16
    - att_MeasuringDate
    - att_CodeQuality
  - Concept_17
    - att_WaterHeight
    - cl_HydraulicHead

- Perennial
- Merged
- New
From Formal Context to Concept Lattice

Intent
Extent
Concept_12
att_MeasuringHour
att_Value
cl_PET
cl_Temperature
Concept_13
att_MeasuringHour
att_Value
cl_PET
cl_Temperature
Concept_14
att_MeasuringDate
att_CodeQuality
Concept_15
att_WaterAmount
cl_Rainfall
Concept_16
att_MeasuringDate
att_CodeQuality
Concept_17
att_WaterHeight
cl_HydraulicHead

Perennial
Merged
New
From Formal Context to Concept Lattice

- **Concept_13**
  - **att_MeasuringHour**
  - **att_Value**
  - **cl_PET**
  - **cl_Temperature**

- **Concept_17**
  - **att_WaterHeight**
  - **cl_HydraulicHead**

- **Concept_15**
  - **att_WaterAmount**
  - **cl_Rainfall**

- **Concept_16**
  - **att_MeasuringDate**
  - **att_CodeQuality**

- **Concept_12**

**Cl_Rainfall**
- **att_WaterAmount**: real
- **att_MeasuringDate**: string
- **att_CodeQuality**: string

**Cl_HydraulicHead**
- **att_WaterHeight**: real
- **att_MeasuringDate**: string
- **att_CodeQuality**: string

**Perennial**
- Merged
- New
From Formal Context to Concept Lattice
A methodology based on FCA
A methodology based on FCA
A methodology based on FCA

- Concept 12
  - att_MeasuringDate
  - att_CodeQuality

- Concept 13
  - att_MeasuringHour
  - att_Value
  - cl_PET
  - cl_Temperature

- Concept 14
  - att_WaterAmount
  - cl_Rainfall

- Concept 15
  - att_WaterAmount
  - cl_Rainfall

- Concept 16
  - att_MeasuringDate
  - att_CodeQuality

- Concept 17
  - att_WaterHeight
  - cl_HydraulicHead
A methodology based on FCA
A methodology based on FCA

Decision Tree
A methodology based on FCA
Two close yep different models (simplified version)
Formal Contexts

- We look for common parts in the class diagram
- Formal contexts are used to describe classes
- There are many ways to describe classes, we will focus on three options:
  - describe classes by their name
  - describe classes by their attributes
  - describe classes by their roles
Formal Contexts

- We look for common parts in the class diagram
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From Formal Contexts to lattices

- Apply Formal Concept Analysis on the two models

- Concept Classification

- Decision Tree

- FCA

- From Formal Contexts to lattices

- Introduction
  - A short introduction to Formal Context Analysis
  - Use Formal Concept Analysis to extract core-concept candidates

- Results

- Conclusion
The class/attribute name concept lattice
The class/attribute name concept lattice
Introduction
A short introduction to Formal Context Analysis

Use Formal Concept Analysis to extract core-concept candidates

Results

Conclusion

Apply Formal Concept Analysis on the two models

Concept Classification

The class/attribute name concept lattice
Classify Formal Concepts

- FCA
- Decision Tree

Concept_13
- att_MeasuringHour
- att_Value
- cl_PET
- cl_Temperature

Concept_17
- att_WaterHeight
- cl_HydraulicHead

Concept_14
- att_MeasuringDate
- att_CodeQuality

Concept_15
- att_WaterAmount
- cl_Rainfall

Concept_16
- att_MeasuringDate
- att_CodeQuality

Concept_12
- att_MeasuringHour
- att_Value
- cl_PET
- cl_Temperature

Decision Tree
Six classification lists

The analysis of the concept extent allows to classify it in one of the following lists:

- \( L_{GCM} \) is the list of core-concepts (△)
- \( L_{pGCM} \) is the list of potential new core-concepts (▲)
- \( L_{M_1} \) and \( L_{M_2} \) are the lists of specific concepts (▲, ■)
- \( L_{nM_1} \) and \( L_{nM_2} \) are the lists of potential new specific concepts (▲, ●)
A decision tree to classify each concept

\[\begin{align*}
Merged \ Concept & \quad 1 \rightarrow E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset \\
& \quad 2 \rightarrow |E_k \cap C_{M_i}| = 1 \land |E_k \cap C_{M_j}| = 1 \rightarrow \triangleleft \\
& \quad 3 \rightarrow |E_k \cap C_{M_i}| = 1 \land |E_k \cap C_{M_j}| > 1 \rightarrow \triangleleft \\
& \quad 4 \rightarrow |E_k \cap C_{M_i}| > 1 \land |E_k \cap C_{M_j}| > 1 \rightarrow \triangleleft \\
& \quad 5 \rightarrow E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow \square \bullet \\
& \quad 6 \rightarrow E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow Inconsistent
\\
New \ Concept & \quad 8 \rightarrow E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset \rightarrow \triangleleft \\
& \quad 9 \rightarrow E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow \square \bullet \\
& \quad 10 \rightarrow E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow Bottom
\\
Perennia\ Concept & \quad 12 \rightarrow E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset \rightarrow \triangleleft \\
& \quad 13 \rightarrow E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow \square \bullet \\
& \quad 14 \rightarrow E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow Inconsistent
\end{align*}\]

\(E_k\): Extent of \(k\)

\(C_{M_i}\): Classes of \(M_i\)
A decision tree to classify each concept

1. **Merged Concept**
   - $E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset$
   - $|E_k \cap C_{M_i}| = 1 \land |E_k \cap C_{M_j}| = 1 \rightarrow \uparrow$
   - $|E_k \cap C_{M_i}| = 1 \land |E_k \cap C_{M_j}| > 1 \rightarrow \uparrow$
   - $|E_k \cap C_{M_i}| > 1 \land |E_k \cap C_{M_j}| > 1 \rightarrow \uparrow$
   - $E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow \downarrow$
   - $E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow \text{Inconsistent}$

2. **New Concept**
   - $E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset \rightarrow \uparrow$
   - $E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow \downarrow$
   - $E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow \text{Bottom}$

3. **Perennial Concept**
   - $E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset \rightarrow \uparrow$
   - $E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow \downarrow$
   - $E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset \rightarrow \text{Inconsistent}$

---

$E_k$: Extent of $k$
$C_{M_i}$: Classes of $M_i$
A decision tree to classify each concept

- **Merged Concept**
  - \(E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset\)
  - \(\left|E_k \cap C_{M_i}\right| = 1 \land \left|E_k \cap C_{M_j}\right| = 1\) → \(\triangle\)
  - \(\left|E_k \cap C_{M_i}\right| = 1 \land \left|E_k \cap C_{M_j}\right| > 1\) → \(\triangle\)
  - \(\left|E_k \cap C_{M_i}\right| > 1 \land \left|E_k \cap C_{M_j}\right| > 1\) → \(\triangle\)

- **New Concept**
  - \(E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset\) → \(\triangle\)
  - \(E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} = \emptyset\) → \(\triangle\)
  - \(E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset\) → \(\triangle\)
  - \(E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset\) → \(\triangle\)

- **Perennial Concept**
  - \(E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset\) → \(\triangle\)
  - \(E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} = \emptyset\) → \(\triangle\)
  - \(E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset\) → \(\triangle\)

**E_k**: Extent of k
**C_{M_i}**: Classes of Mi

Concept_47
- Concept_48
  - att_Date
  - cl_PesticideMeasurement

Concept_49
- att_Quantity
  - cl_WindMeasurement

Concept_48
- att_Quantity
  - cl_PesticideMeasurement

Concept_49
- att_Velocity
  - cl_WindMeasurement

Conclusion
A decision tree to classify each concept

1. **Merged Concept**
   - \( E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset \)
   - \(|E_k \cap C_{M_i}| = 1 \land |E_k \cap C_{M_j}| = 1\) →
   - \(|E_k \cap C_{M_i}| > 1 \land |E_k \cap C_{M_j}| > 1\) →
   - \(E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} = \emptyset\) →
   - \(E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset\) → Inconsistent

2. **New Concept**
   - \(E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset\) →
   - \(E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} = \emptyset\) →
   - \(E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset\) → Bottom

3. **Perennial Concept**
   - \(E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} \neq \emptyset\) →
   - \(E_k \cap C_{M_i} \neq \emptyset \land E_k \cap C_{M_j} = \emptyset\) →
   - \(E_k \cap C_{M_i} = \emptyset \land E_k \cap C_{M_j} = \emptyset\) → Inconsistent

\(E_k\): Extent of \(k\)
\(C_{M_i}\): Classes of \(M_i\)
GCM Construction

Apply Formal Concept Analysis on the two models

Concept Classification

Decision Tree
Two close yet different models (reminder)

Note: Association details are removed on this figure.
**The Greatest Common Model**

<table>
<thead>
<tr>
<th>Class</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>cl_MeasuringStation</td>
<td>att_StationName : string, att_AdministrativeInstitute : string</td>
</tr>
<tr>
<td>cl_Piezometer</td>
<td>att_TubeDiameter : real, att_WaterHeight : real, att_TubeHeight : real</td>
</tr>
<tr>
<td>cl_HydraulicHead</td>
<td>att_WaterHeight : real, att_WaterAmount : real</td>
</tr>
<tr>
<td>cl_Rainfall</td>
<td>att_WaterAmount : real</td>
</tr>
<tr>
<td>cl_RainGauge</td>
<td>att_TubeHeight : real</td>
</tr>
</tbody>
</table>

Diagram showing relationships and attributes of classes and their interactions.
The Greatest Common Model

- **Groundwater Instrumentation**
  - **cl_Piezometer**
    - `att_TubeDiameter : real`
  - **cl_HydraulicHead**
    - `att_WaterHeight : real`

- **Rainfall Instrumentation**
  - **cl_RainGauge**
    - `att_TubeHeight : real`

- **Groundwater Monitoring**
  - **cl_Data**
    - `att_MeasuringDate : string`
    - `att_CodeQuality : string`

- **Rainfall Monitoring**
  - **cl_Rainfall**
    - `att_WaterAmount : real`

**Attributes**:
- `att_AdministrativeInstitute : string`
- `att_DeviceNumber : integer`
- `att_DeviceType : string`
- `att_WaterHeight : real`
- `att_TubeDiameter : real`
- `att_WaterAmount : real`
- `att_TubeHeight : real`

**Relationships**:
- `ro_Station`
- `ro_Device`
- `ro_Measure`
- `ro_Piezometer`
- `ro_Piezometer`
- `ro_HydraulicHead`
- `ro_HydraulicHead`
- `ro_RainGauge`
- `ro_RainGauge`
Experiences

The Measuring Station model
- \( \approx 20 \) classes
- Each class owns \( \approx 2 \) or \( 3 \) attributes
- The GCM has 5 classes

The complete IES-Pesticides model
- Design to study the pesticides impact on the environment
- UML classes model
- \( \approx 170 \) classes
- Each class owns about 5 attributes
## Results

**TABLE**: Result of our approach on the MeasuringStation model

<table>
<thead>
<tr>
<th></th>
<th>△</th>
<th>▲</th>
<th>▽</th>
<th>●</th>
<th>▼</th>
<th>□</th>
</tr>
</thead>
<tbody>
<tr>
<td>class/class name</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>class/attribute name</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>class/attribute-role name</td>
<td>4</td>
<td>7</td>
<td>1</td>
<td>1</td>
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</tr>
</tbody>
</table>

**TABLE**: Result of our approach on the complete EIS-Pesticides model

<table>
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<tr>
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<tbody>
<tr>
<td>class/class name</td>
<td>111</td>
<td>34</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>class/attribute name</td>
<td>43</td>
<td>39</td>
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<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>class/attribute-role name</td>
<td>68</td>
<td>119</td>
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<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

**Table**: Result of our approach on the complete EIS-Pesticides model

<table>
<thead>
<tr>
<th>class/class name</th>
<th>△</th>
<th>▲</th>
<th>□</th>
<th>◊</th>
<th>□</th>
<th>△</th>
</tr>
</thead>
<tbody>
<tr>
<td>class/attribute name</td>
<td>111</td>
<td>34</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>class/attribute-role name</td>
<td>43</td>
<td>39</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>class/attribute-role name</td>
<td>68</td>
<td>119</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>
Introduction
A short introduction to Formal Context Analysis
Use Formal Concept Analysis to extract core-concept candidates
Results
Conclusion

Concept_13
att_MeasuringHour
att_Value
cl_PET
cl_Temperature

Concept_17
att_WaterHeight
cl_HydraulicHead

Concept_14
att_WaterAmount
cl_Rainfall

Concept_16
att_MeasuringDate
att_CodeQuality

Decision Tree
Control the quantity of new generated concepts
  119 concepts with the Attribute/Role configuration

Add semantic aspects in our approach with natural language processing
  to generate new formal contexts
  to name new concepts

Use Relational Concept Analysis, an extension to FCA