Formal Concept Analysis, A framework for knowledge structuring and exploration. Applications to service directories and product lines.
Marianne Huchard

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Formal Concept Analysis

A framework for knowledge structuring and exploration

Applications to service directories and product lines

Marianne Huchard
Montpellier University, LIRMM, France

13th IEEE Joint Conferences and workshops
CCR2019, MHBDT2019, WREHE2019, SeTM2019
San Francisco East Bay, USA
April 5th, 2019
Introduction

Formal Concept Analysis

FCA in Knowledge Engineering

Relational Concept Analysis

Focus 1: Product Lines

Focus 2: Service Workflows

Conclusion
Introduction

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FCA in Knowledge Engineering

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Focus 2: Service Workflows

Conclusion
Introduction

Fields: symbolic AI, symbolic knowledge engineering

- lattice theory, Galois connections  
  (Birkhoff, 1940; Barbut & Monjardet, 1970)
- concept lattices  
  (Wille, 1982, Ganter & Wille, 1999)

Formal concepts are “a natural feature of information representation which is as fundamental to hierarchies and object/attribute structures as set theory or relational algebra are for relational databases”.

Uta Priss. 40th anniv. vol. of Annual Review of Inf. Sc. and Tech., 2006
Knowledge structuring and exploration

- data analysis, data mining, hierarchical multi-clustering
- knowledge representation (e.g. ontology construction)
- classification, indexation (information retrieval)
- unsupervised learning (based on examples description)
- supervised learning (adding classes in description)

Credit to U. Priss, G. Greene, K. Bertet, A. Napoli, M. Alam, T. Tilley, ... et al.
Sommaire

Introduction

Formal Concept Analysis

FCA in Knowledge Engineering

Relational Concept Analysis

Focus 1: Product Lines

Focus 2: Service Workflows

Conclusion
# Formal Concept Analysis

**Formal Context:** Simplest form: entities with characteristics

<table>
<thead>
<tr>
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https://www.thedronechart.com  
Hum, typo, here. Typton in World of Warcraft? Teaspoon?
A maximal group of objects (object closed set, **extent**) sharing a maximal group of attributes (attribute closed set, **intent**)

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### Concept_Drone_8

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## Concept

### Concept_Drone_6

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Concept lattice: specialization
Concept lattice: top $\rightarrow$ bottom attribute inheritance

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Concept_Drone_8
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Parrot Bebop
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Aosenma CG035 GPS FPV

Concept_Drone_6
Altitude Hold
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GPS
Parrot Bebop
Hubsan X4 H502S
Aosenma CG035 GPS FPV
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Concept lattice: top → bottom attribute inheritance
### Concept lattice: top → bottom attribute inheritance

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**Sommaire**

- Introduction
- FCA
- FCA-KE
- RCA
- PL
- WS
- Conclusion
Concept lattice: bottom → top object inheritance

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Concept lattice: bottom $\rightarrow$ top object inheritance
Concept lattice: bottom → top object inheritance
Concept lattice: simplified through inheritance
AOC-poset: restricted to Attributes and Objects introducers

- Concept_Drone_12
- Concept_Drone_11
  - Headless
- Concept_Drone_10
  - Altitude Hold
- Concept_Drone_9
  - GPS
- Concept_Drone_8
  - FT ge 10
  - DJI Ryze Tello
- Concept_Drone_7
- Concept_Drone_6
  - Parrot Bebop
- Concept_Drone_5
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- Concept_Drone_2
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  - Avoidance
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- Concept_Drone_1
  - Aosenma CG035 GPS FPV
- Concept_Drone_0
AOC-poset: restricted to Attributes and Objects introducers
**Sommaire**

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</table>

- Introduction
- Formal Concept Analysis
- FCA in Knowledge Engineering
- Relational Concept Analysis
- Focus 1: Product Lines
- Focus 2: Service Workflows
- Conclusion
Knowledge engineering: Class discovery, concept extraction

Knowledge engineering: Implication rules extraction

Index construction

Decision tree

Ontology engineering

FCA for various data types

- Multi-valued attributes: integers, double, terms, structures, symbolic objects, etc. (Ganter et Wille, Polaillon, ...)
- Fuzzy (Belohlavek, Yahia et al., ...)
- Values taxonomies (Godin et al., Carpineto et Romano, ...)
- Logical description (Chaudron et al., Ferré et al., ...)
- Graphs (Ganter and Kuznetsov, Liquière, Prediger et Wille, Kötters et al., Ferré et al....)
- Relations (Priss, Rouane et al., ...)
- Polyadic (Sacarea, Tronca et al.)
- Pattern Structures (Kuznetsov, Napoli et al.)
- ....
Ressources

Books


Web page of Uta Priss

links to FCA software http://www.upriss.org.uk/fca/fca.html
Sommaire

Introduction

Formal Concept Analysis

FCA in Knowledge Engineering

Relational Concept Analysis

Focus 1: Product Lines

Focus 2: Service Workflows

Conclusion
A Flavor of Relational Concept Analysis

- Extends the purpose of FCA for taking into account object categories and links between objects
- Main principles:
  - a relational model based on an entity-relationship model
  - integrate relations between objects as relational attributes
  - iterative process
- RCA provides a set of interconnected lattices
- Produced structures can be represented as ontology concepts within a knowledge representation formalism such as description logics (DLs)

Joint work with:
A. Napoli, C. Roume, M. Rouane-Hacène, P. Valtchev
### Drone fleet (Formal context)

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# Drone fleet 2 Drone (Relational Context)

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</table>
rescueDF2 and rescueDF3 do not share concrete drone types, but they share the fact that all their drones with GLONASS, GPS, FT ≥ 20, etc.

**Relational attribute:** $\exists \forall$ contains($\text{Concept\_Drone\_1}$)
Drone fleet extended by relations to their drones

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<th>mission:rescue</th>
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<th>control:behaviorBased</th>
<th>( \exists \forall \geq 60% \text{ contains(Concept} _0) )</th>
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Drone fleets extended by relations to their drones (AOC-posets)

Rescue fleets have a majority of drones with GLONASS, Avoidance system and Flight Time $\geq 20\text{mn}$
RCA in the general case

An iterative process

- Complex model with paths and cycles of any length
- Objects groups (concepts) are propagated along the paths and the cycles, step after step
- The process stops when no new concept appears

Tool

- [http://dataqual.engees.unistra.fr/logiciels/rcaExplore](http://dataqual.engees.unistra.fr/logiciels/rcaExplore)
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Relational Concept Analysis

Focus 1: Product Lines

Focus 2: Service Workflows

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Focus 1: Product Line Engineering

Feature model

Assets Variable Architecture

Derived Products
Building a product

Feature selection

Selected Assets

Implemented Architecture

Product
Product Line Reverse Engineering

Similar Products developed in undisciplined manner

Which Feature model?

Which Assets?
Which Architecture?
Variability extraction with FCA and RCA

Implications
- GLONASS -> Gimbal
- FT ≥ 10 -> Headless
- Gimbal -> GPS
- Gimbal -> Headless
- FT ≥ 10 -> Altitude Hold
- GPS -> Altitude Hold

Coverage (candidate groups)
- FT ≥ 20, FT ≥ 10, FT ≥ 10

Co-occurrences
- GLONASS <-> Avoidance
- GLONASS <-> FT ≥ 20

Mutex
- FT ≥ 10 → not T ≥ 10
- FT ≥ 10 → not GLONASS
- Gimbal → not FT ≥ 10
- FT ≥ 10 → not GLONASS
Feature Model
Theoretical variability

AOC-poset: Realized variability

Theoretical variability vs. realized variability

Implications
- GLONASS → Gimbal
- FT ≥ 10 → Headless
- Gimbal → GPS
- Gimbal → Headless
- FT ≥ 10 → Altitude Hold
- GPS → Altitude Hold

Coverage (candidate groups)
- FT ≥ 20, FT ≥ 10, FT ≤ 10

Co-occurrences
- GLONASS ↔ Avoidance
- GLONASS ↔ FT ≥ 20

Mutex
- FT ≥ 10 → not T ≤ 10
- FT ≥ 10 → not GLONASS
- Gimbal → not FT ≤ 10
- FT ≤ 10 → not GLONASS
Contributions to Product Lines

- Assist the construction of variability representations, e.g. Feature Models
- Assist the composition by union and intersection
- Exploring a product family
- Using RCA to represent interconnected product lines (like Drone fleets vs. Drones)


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Introduction

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Focus 1: Product Lines

Focus 2: Service Workflows

Conclusion
Focus 2: Services, Service Workflows

Approaches

- Select one Web service for a particular task
- Planning approaches to build a workflow satisfying a given input/output
- Instantiating an abstract workflow by mining Web services for each task

Issues

- Satisfy the expected functionality
- Satisfy QoS (Quality of Service) attributes
- Keep alternative choices (for backup concern)
Hypotheses

Context

• Service is one functionality
  • complex WS can be considered as several services
• Semantic Web services: service input and output are described by concepts of an ontology
  • OWL-S, SAWSDL, WSMO, ...
• QoS: quality of service attributes are known
  • availability, response time, reputation, ...
Instantiating an abstract task workflow

Abstract task workflow (credit Z. Azmeh)

Alternative concrete web services

Alternative concrete workflows
Web Service Description

Ontology concepts for input/output

QoS attributes

• availability: very low, low, medium, high, very high *(best)*
• response time: very low *(best)*, low, medium, high, very high
Service connection

Ontology concepts

Connection principle
Service replacement

Ontology concepts

Replacement principle (require less, provide more)
WS Classification guided by Replacement
Formal context: IPCN

A query object `query_IPCN` is classified to identify easily the potential answers.

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WS Classification guided by Replacement
Formal context: CNAC

A query object `query_CNAC` is classified to identify easily the potential answers

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WS Classification guided by Replacement

Formal context: ACPF

A query object `query_ACPF` is classified to identify easily the potential answers

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Concept Lattices of Web Services
Services introduced below Concept_ACPF_7 are below query_ACPF, they satisfy the query

Concept Lattices of Web Services
Using the classification for workflow instantiation

Abstract task workflow (credit Z. Azmeh)

Relational Data Model (scaling quantifier $\exists$)
Relational contexts: connects to (reverse relation is not shown)

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Relational contexts: connects to (reverse relation is not shown)

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</table>
Lattice Family after RCA process
WS 13, 14, 15 satisfy query (with improved availability, response time or input); each connects to at least one service of Concept CNAC 8
WS 23, 25, 26 satisfy query (with improved availability and response time); 25, 26 almost equivalent; each connects to at least one service from Concept ACPF 11
WS 32, 33, 35 satisfy query (with improved availability for 32); 35 more specific than 33 (gives more precision on weather)
Candidate concrete workflows

Specialization (replacement and improvement) on services

Specialization (replacement and improvement) between candidate concrete workflows (excerpt)
The approach provides web services that:

- satisfy QoS properties; can connect properly

Besides, several opportunities are:

- highlighted; classified along QoS properties and functionalities

Tracks for future research

- Encoding more information (e.g. various details on functionalities)
- Tools for visualization and navigation in and between lattices are needed
- Need for aligning ontologies for different web service sets
- Can be used to organize results of planning-based approaches
References

• Software component classification

• Web service composition with backups
  • Zeina Azmeh, Marianne Huchard, Fady Hamoui, Naouel Moha: From Abstract to Executable BPEL Processes with Continuity Support. ICWS 2012: 368-375

• Querying RCA results
  • Zeina Azmeh, Marianne Huchard, Amedeo Napoli, Mohamed Rouane Hacene, Petko Valtchev: Querying Relational Concept Lattices. CLA 2011: 377-392

• Classifying semantic web services for workflow instantiation
  • Sara El Hassad, Master thesis, June 2013, Montpellier University (supervised by N. Moha, C. Tibermacine, M. Huchard)
Sommaire

Introduction

Formal Concept Analysis

FCA in Knowledge Engineering

Relational Concept Analysis

Focus 1: Product Lines

Focus 2: Service Workflows

Conclusion
FCA

- Objects + Attributes = Concept hierarchy
- Many extensions to take into account many data types

RCA

- Objects + Attributes + Relations = Interconnected Concept hierarchies
- Integrate information of complex entity-relationships
- Iterative process for concept propagation
- Tunable (algorithms, steps, quantifiers, excerpt of ER diagram)
Perspectives

Methodology

• On-demand algorithms
• Visualization
• Assistive tool for data exploration

On-going applications

• Product Lines + service workflows
• Data exploration (e.g., environmental domain)

⇒ Exploring FCA and statistical ML

• as a pre-processing, as a post-processing
• in other combinations of methodological patterns, see inspiring lectures of Frank van Harmelen
Thank you!