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

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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
Sommaire

Introduction

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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
Introduction

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

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## Formal Concept Analysis

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

<table>
<thead>
<tr>
<th>Drone</th>
<th>Gimbal</th>
<th>GPS</th>
<th>GLONASS</th>
<th>Avoidance</th>
<th>Headless</th>
<th>Altitude Hold</th>
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https://www.thedronechart.com  

*Hum, typo, here. Typoon in World of Warcraft? Teaspoon?*
## Concept

A maximal group of objects (object closed set, **extent**) sharing a maximal group of attributes (attribute closed set, **intent**)

<table>
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<tr>
<th>Drone</th>
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Concept

### Concept_Drone_8
- **Altitude Hold**
  - FT ge 10

### Concept Identifier
- Intent
- Extent

### Concept

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</table>
Concept lattice: specialization
Concept lattice: top → bottom attribute inheritance

![Concept lattice diagram]

- **Concept_Drone_8**
  - Altitude Hold
  - FT ge 10
  - DJI Ryze Tello
  - Parrot Bebop
  - Hubsan X4 H502S
  - Aosenma CG035 GPS FPV

- **Concept_Drone_6**
  - Altitude Hold
  - FT ge 10
  - GPS
  - Parrot Bebop
  - Hubsan X4 H502S
  - Aosenma CG035 GPS FPV
Concept lattice: top $\rightarrow$ bottom attribute inheritance

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<th>Concept_Drone_8</th>
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Concept lattice: top → bottom attribute inheritance
Concept lattice: bottom → top object inheritance
Concept lattice: bottom $\rightarrow$ top object inheritance

![Concept lattice diagram](image-url)
**Concept lattice: bottom → top object inheritance**

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</table>
Concept lattice: simplified through inheritance
AOC-poset: restricted to Attributes and Objects introducers
AOC-poset: restricted to Attributes and Objects introducers

- Concept_Drone_0
  - Aosenma CG035 GPS FPV

- Concept_Drone_1
  - DJI Mavic Air
  - Yuneec Typhoon H Pro

- Concept_Drone_2
  - Hubsan X4 H502S

- Concept_Drone_3
  - Syma X4S Assault
  - Syma X8G
  - FT ge 10
  - DJI Ryze Tello

- Concept_Drone_4
  - Gimbal

- Concept_Drone_5
  - Parrot Bebop

- Concept_Drone_6
  - FT ge 10
  - DJI Ryze Tello

- Concept_Drone_7
  - GPS

- Concept_Drone_8
  - Altitude Hold

- Concept_Drone_9
  - Headless
  - FT l 10

- Concept_Drone_10
  - GLONASS
  - Avoidance
  - FT ge 20
Sommaire

Introduction

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Conclusion
Knowledge engineering: Class discovery, concept extraction

Knowledge engineering: Implication rules extraction

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.)
- ....
Books


Web page of Uta Priss
links to FCA software http://www.upriss.org.uk/fca/fca.html
Sommaire

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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 (AOC-poset)

Concept_DroneFleet_0
  mission: Audiovisual
  audiovisualDF4

Concept_DroneFleet_1
  mission: agri
  control: leaderFollower
  agriDF1

Concept_DroneFleet_2
  mission: agri
  archi: centralized
  agriDF0

Concept_DroneFleet_3
  mission: rescue
  guidance: ML
  rescueDF2
  rescueDF3

Concept_DroneFleet_5
  control: behaviorBased
  archi: distributed

Concept_DroneFleet_6
  control: behaviorBased

Concept_DroneFleet_7
  guidance: human
## Drone fleet 2 Drone (Relational Context)

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<th>Syma X8G</th>
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<th>Hubsan X4 H502S</th>
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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($Concept\_Drone\_1$)
Drone fleet extended by relations to their drones

<table>
<thead>
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<th>mission:rescue</th>
<th>mission:Audiovisual</th>
<th>archi:centralized</th>
<th>archi:distributed</th>
<th>guidance:human</th>
<th>guidance:ML</th>
<th>control:leaderFollower</th>
<th>control:behaviorBased</th>
<th>( \exists \forall \geq 60% \text{ contains(Concept}_{i}\text{Drone$_k$}) )</th>
<th>( \exists \forall \geq 60% \text{ contains(Concept}_{i}\text{Drone$_k$}) )</th>
<th>( \exists \forall \geq 60% \text{ contains(Concept}_{i}\text{Drone$_k$}) )</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
Introduction

Formal Concept Analysis

FCA in Knowledge Engineering

Relational Concept Analysis

Focus 1: Product Lines

Focus 2: Service Workflows

Conclusion
Focus 1: Product Line Engineering

Feature model

M. Potatoe
- Head
  - Face
    - Eyes
    - Nose
  - Ears
- FiveSenses
  - Touch
  - Sight
  - Taste
  - Hearing
- Walk
- Top
  - Hair
  - Hat
  - Glasses
- Handbag
- Assets
  - Red nose
  - Muzzle
  - Pink nose
- Variable Architecture

Derived Products

- Ms. Potatoe
- Mr. Potatoe
- Mr. Potatoe Jr.
- Mr. Potatoe Costume
- Mr. Potatoe Toy
- Mr. Potatoe Game
- Mr. Potatoe Mascot

Focus on the evolution of the Mr. Potatoe product line through feature modeling and variable architecture.
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
Theoretical variability vs. realized variability
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)

Sommaire

Introduction

Formal Concept Analysis

FCA in Knowledge Engineering

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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

may be connected to

AreaCode

ZipCode

is-a

LocalNetwork

AreaCode

FrPostalCode

WeatherInfo

PrecipitationForecast

WeatherHistory

PrecipWindForecast

PrecipTempWindForecast

is-a

IPAddress

ZipCode
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
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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<th>out:Zip</th>
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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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<th>out:PTW</th>
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Concept Lattices of Web Services
Concept Lattices of Web Services

Services introduced below Concept_ACPF_7 are below query_ACPF, they satisfy the query

```
Concept_ACPF_6
   IRT

Concept_ACPF_3
   vlRT
   C_to_PF_34

Concept_ACPF_2
   AC_to_PF_33

Concept_ACPF_0
   out:PTW

Concept_ACPF_5
   hA

Concept_ACPF_4
   AC_to_PF_31

Concept_ACPF_1
   vhA
   AC_to_PF_32

Concept_ACPF_7
   in:AC
   query_ACPF
```
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
• 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

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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!