Towards a catalog of design patterns for knowledge discovery with relational concept analysis

Marianne Huchard

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Séminaire
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Introduction

Formal Concept Analysis

Relational Concept Analysis

Design patterns for RCA

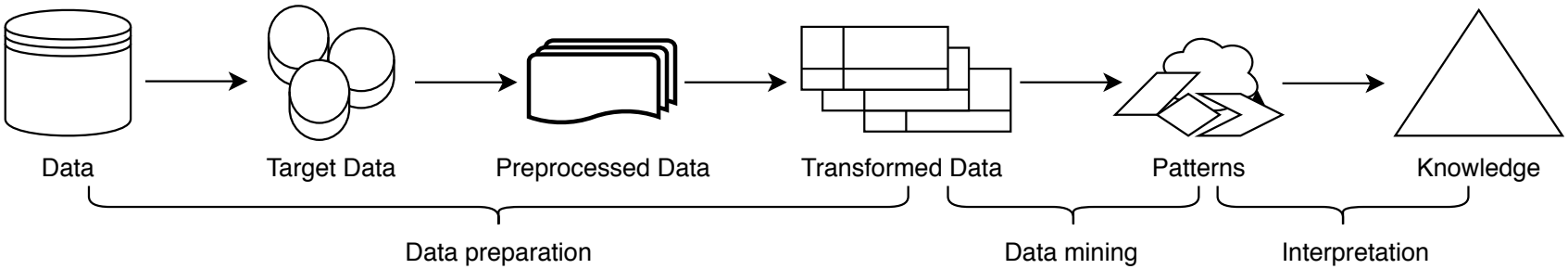
Conclusion

Agenda

Knowledge Discovery (KD)

Fayyad, U., Piatetsky-Shapiro, G., Smyth, P. AI Magazine 1996

From Data Mining to Knowledge Discovery in Databases



Directions

- Symbolic vs. subsymbolic
- White box vs. black box
- Supervised vs. unsupervised
- Structured vs. unstructured data

Knowledge Discovery (KD)

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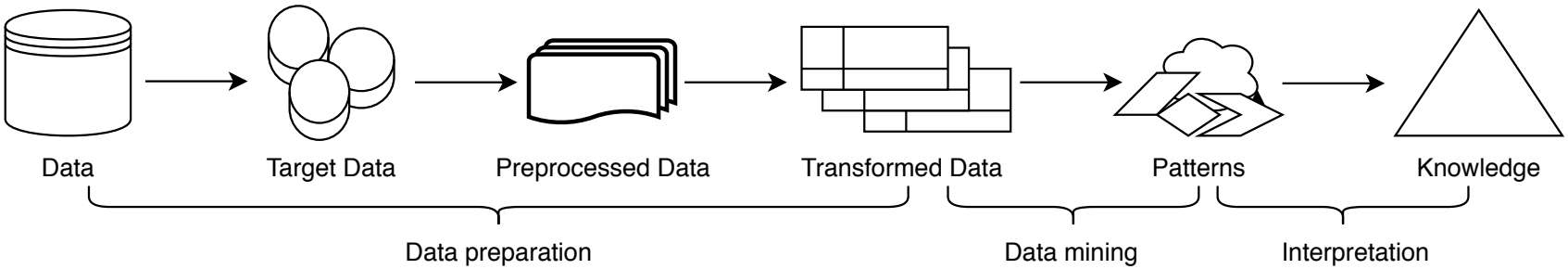

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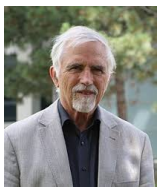
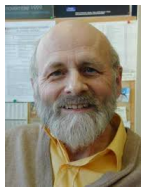
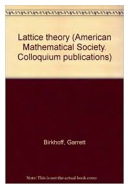
Roots








- Concept lattices
  Rudolf Wille, 1982, Bernhard Ganter & Rudolf Wille, 1999
- Lattice theory, Galois connections, Galois lattices
  Marc Barbut & Bernard Monjardet, 1970; Georges David Birkhoff, 1940; Øystein Ore, 1944
- Galois connection, subgroups/subfields
  Evariste Galois, $\sim$ 1830

Formal Concept Analysis

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

Simple but powerful basics

- Formal Context
- Galois connection
- Concept Lattice
- Implications and associations rules

Formal Context = Triple (O, A, R)

O is a finite set of objects, A is a finite set of attributes

$R \subseteq O \times A$ is a binary relation

$(o, a) \in R$ means that object o owns attribute a.

Ingredient	vege	vegan	spring	summer	autumn
goatcheese	×			×	
burrata	×		×		
scallop			×		
tomato	×	×		×	
shallot	×	×			×
mushroom	×	×			×
eggplant	×	×		×	

Formal Concept = Pair (Extent, Intent)

Extent = Maximal set of owner objects

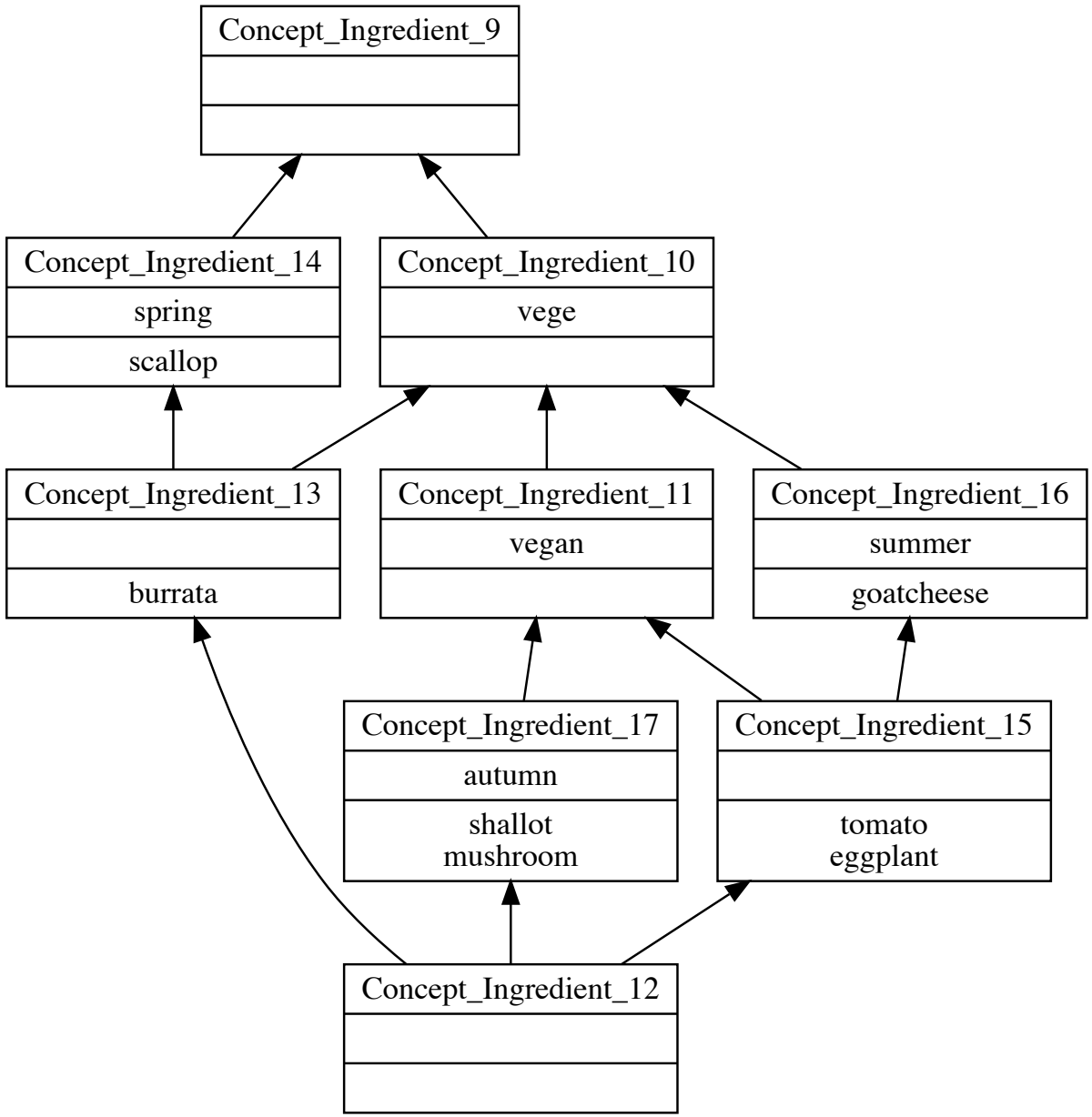
Intent = Maximal set of their shared attributes

Ingredient	vege	vegan	spring	summer	autumn
goatcheese	×			×	
burrata	×		×		
scallop			×		
tomato	×	×		×	
shallot	×	×			×
mushroom	×	×			×
eggplant	×	×		×	

Concept Lattice

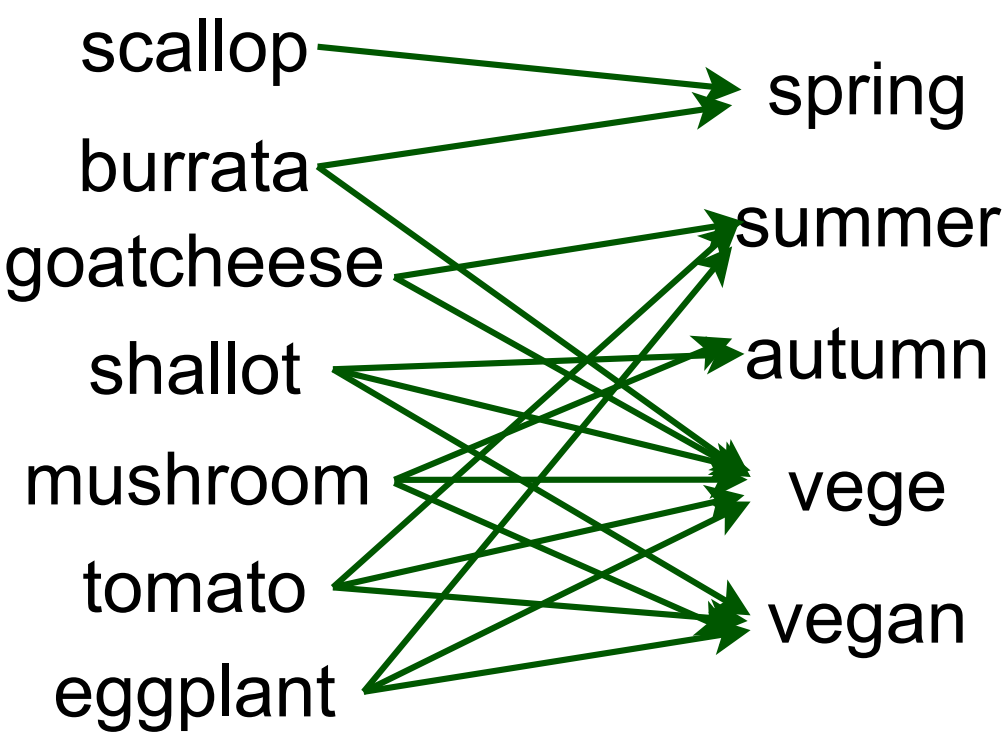
Set of all concepts provided with extent ↑ or intent ↓ inclusion

C_I_11
vege
vegan
shallot
mushroom
tomato
eggplant



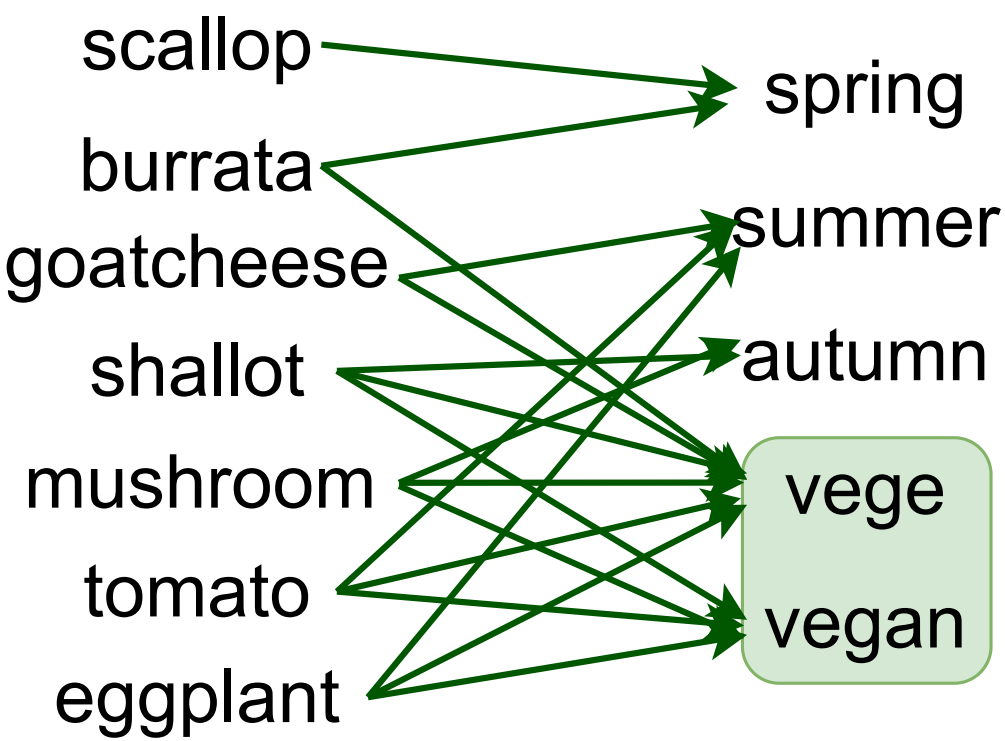
Another view of concept building

Links between objects and attributes



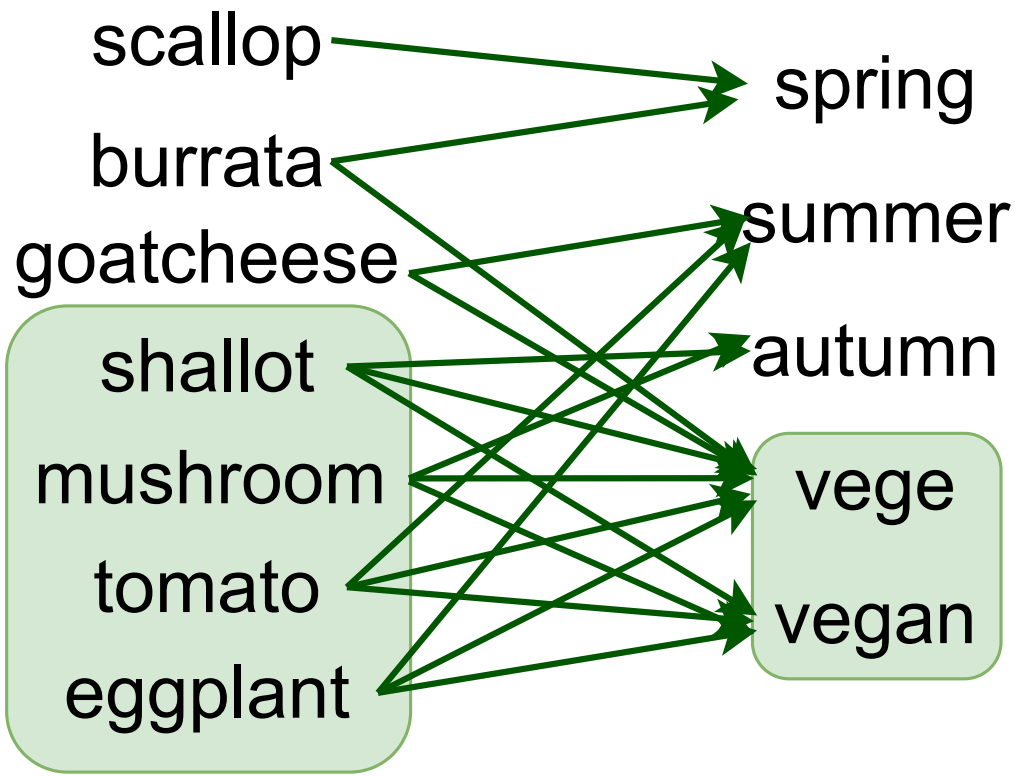
Another view of concept building

Links between objects and attributes vege / vegan



Another view of concept building

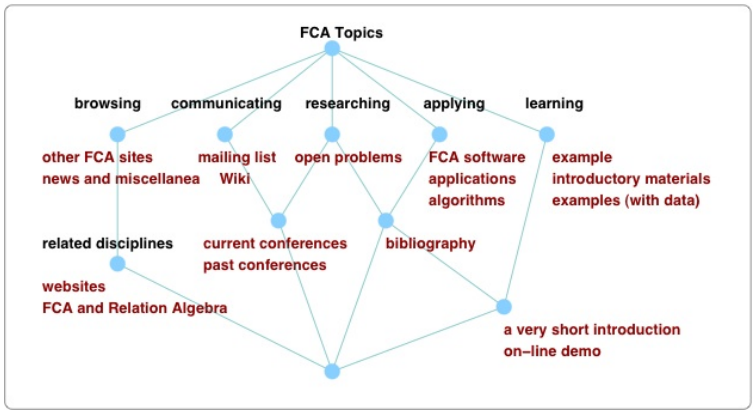
Concept of vegan ingredients



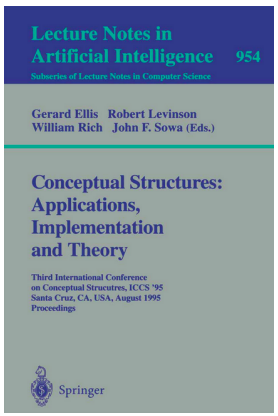
Dissemination 1982-2022

- Conceptualization, philosophical developments
- Data analysis, data mining, clustering
- Knowledge representation (ontology construction)
- Classification, indexation (information retrieval)
- Unsupervised learning
- Supervised learning (adding classes in description)
- Tools
- Applications

Dissemination 1982-2022

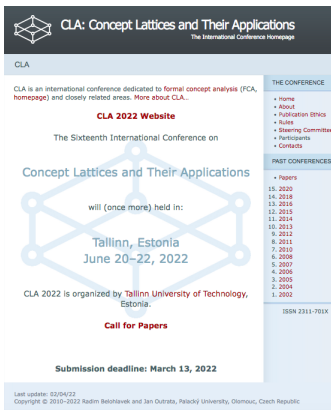


Credits Uta Priss https://upriss.github.io/fca/fca.html

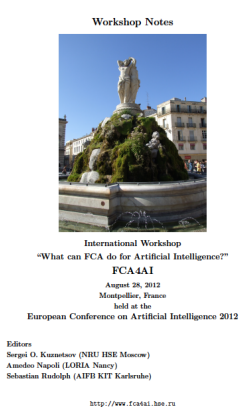


ICCS

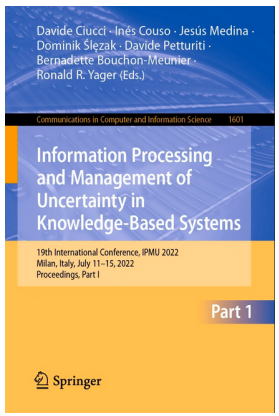
ICFCA



CLA



FCA4AI



IPMU

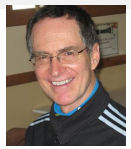
Complex data in FCA

- Multi-valued attributes : integers, double, terms, structures, symbolic objects, etc. (Ganter et Wille, Diday, Polaillon, ...)
- Fuzzy (Belohlavek et al., Cabrera, Cordero, Enciso, Mora, Lòpez-Ròd., Ojeda-Aciego et al., Cornejo, Medina et al., Yahia et al., Dubois Prade ...)
- Value 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., Graph-FCA Ferré et al....)
- Multi-relational, RCA (Priss, Rouane-Hacène et al., ...); RCA+Fuzzy (Boffa et al.)
- Polyadic (Sacarea, Tronca et al.)
- Sequences (Boukhetta, Demko, Bertet et al., Buzmakov et al.)
- Temporal data (Wolff et al., Nica, Braud, Dolques, Le Ber et al., Boukhetta, Demko, Bertet et al.)
- Pattern Structures (Ganter et al., Kuznetsov et al., Napoli et al., Buzmakov et al.)

Agenda

Roots: Class model refactorization [Godin&Mili 1993]

" A formal method that organizes a set of class interfaces into a lattice structure " - Associations in Sect. 3.2.3

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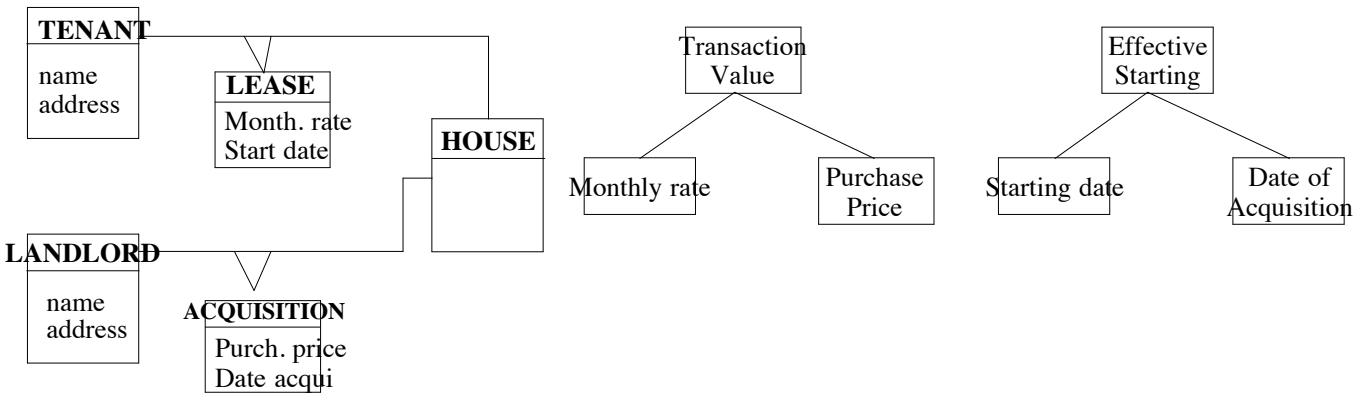
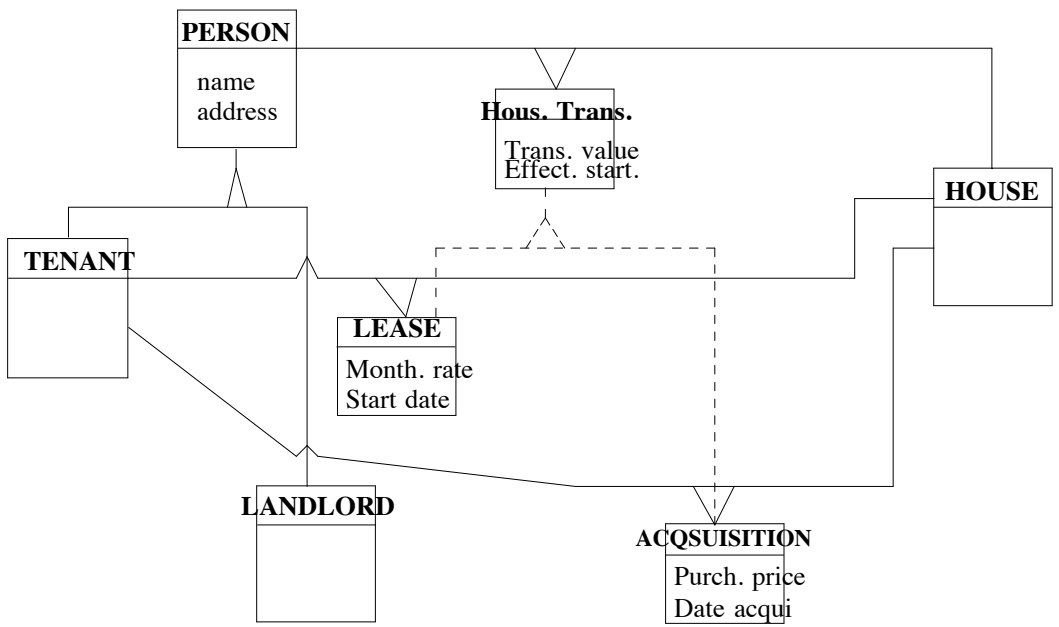
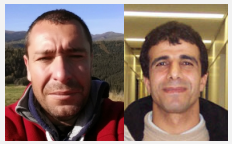
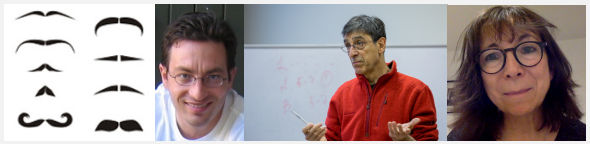


To:





Roots and follow up



- Systematization of the idea of Godin&Mili OOPSLA'93
- Projects
  - MACAO (LIRMM, Orange Labs) 2001-2003/2006-2009
  - PICS CNRS "CAdOE" (LORIA, LIRMM, UQAM) 2011-2013
- Premières thèses de doctorat
  - Cyril Roume, Univ. Montpellier (2004)
  - Mohamed Amine Rouane-Hacène, UQAM (2007)
- Foundational papers
  - M. Huchard, C. Roume, P. Valtchev. When concepts point at other concepts: the case of UML diagram reconstruction. FCAKDD 2002@ECAI
  - M. Dao, M. Huchard, M. Rouane-Hacène, C. Roume, P. Valtchev. Improving generalization level in UML models iterative cross generalization in practice. In Conceptual Structures at Work. ICCS 2004.
  - M. Huchard, M. A. Rouane-Hacène, C. Roume, P. Valtchev: Relational concept discovery in structured datasets. AMAI 2007
  - M. A. Rouane-Hacene, M. Huchard, A. Napoli, P. Valtchev: Relational concept analysis: mining concept lattices from multi-relational data. AMAI 2013

Principles

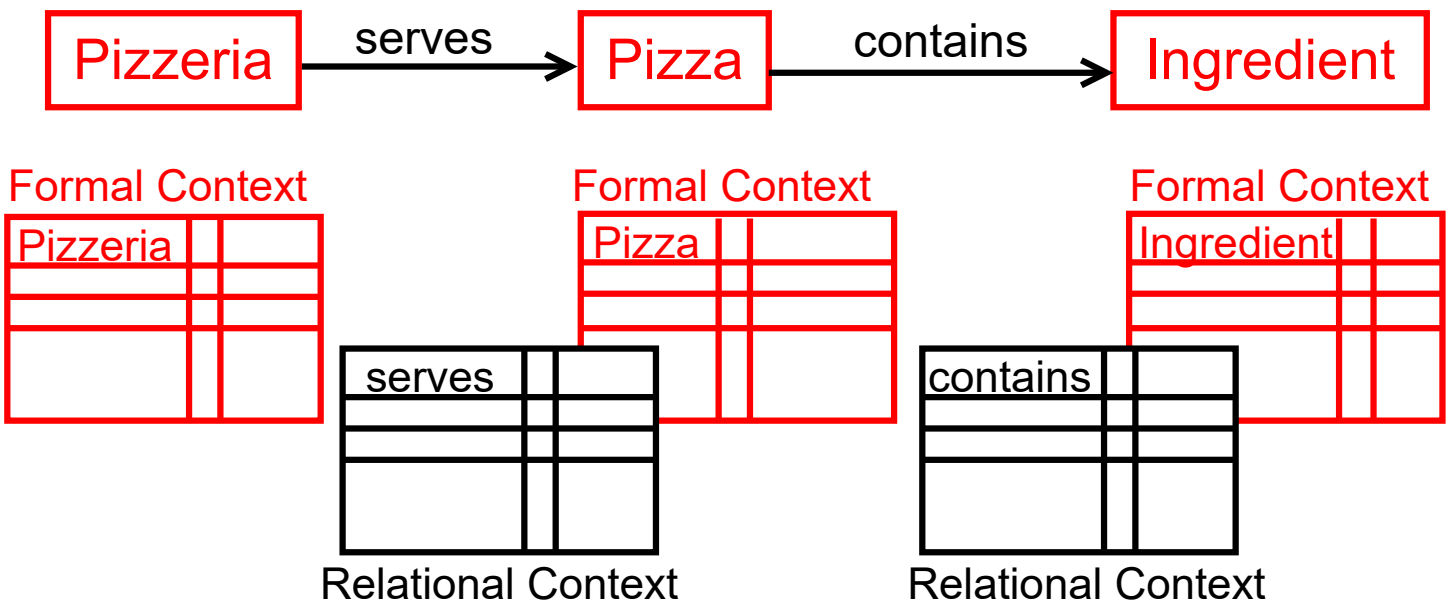
Relational Concept Analysis

- Extends the purpose of FCA for taking into account object categories and links between objects
- Main principles:
  - a relational model based on the entity-relationship model (restricted to unidirectional binary relationships)
  - *relational attributes* integrate relations in formal contexts between objects
  - various operators (*quantifiers*) inspired by description logics
  - iterative and tunable process
- RCA provides a *set of interconnected lattices*
- Produced structures can be written in DLs

Principles: Input data

Relational Context Family (RCF)

- Set of Formal contexts (object-attribute)
  - Represent classes/instances
- Set of Relational contexts (object-object)
  - Represent Unidirectional binary associations/links



Relational Context Family Pizzerias

Pizzeria	*IdHappizzy*	*IdEataly*	*IdLafelicita*	*IdSmallitaly*
happizzy	×			
eataly		×		
lafelicita			×	
smallitaly			×	

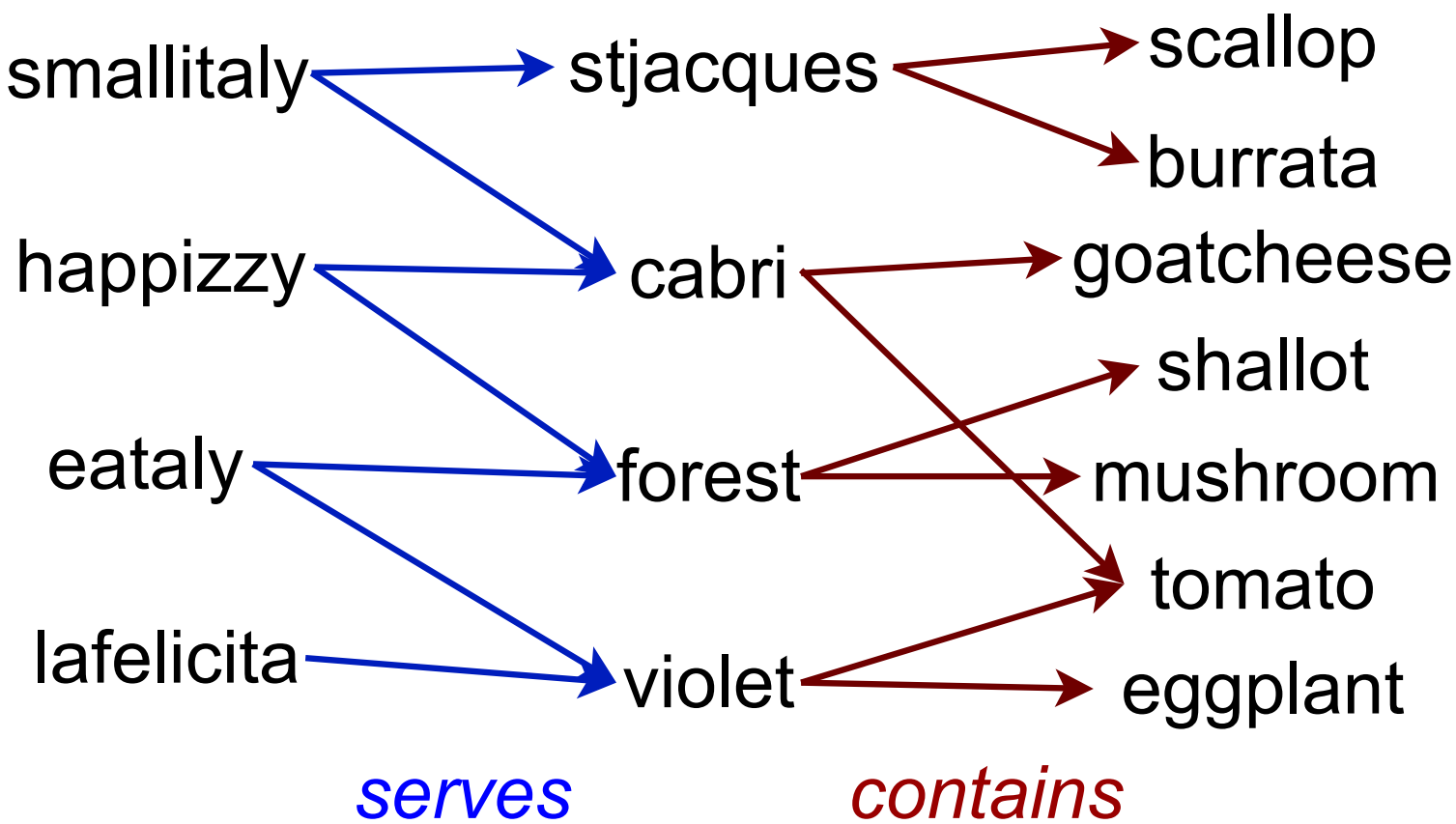
Pizza	*IdCabri*	*IdForest*	*IdViolet*	*IdStjacques*
cabri	×			
forest		×		
violet			×	
stjacques			×	

Ingredient	*vege*	*vegan*	*spring*	*summer*	*autumn*
goatcheese	×			×	
burrata	×		×		
scallop			×		
tomato	×	×		×	
shallot	×	×			×
mushroom	×	×			×
eggplant	×	×		×	

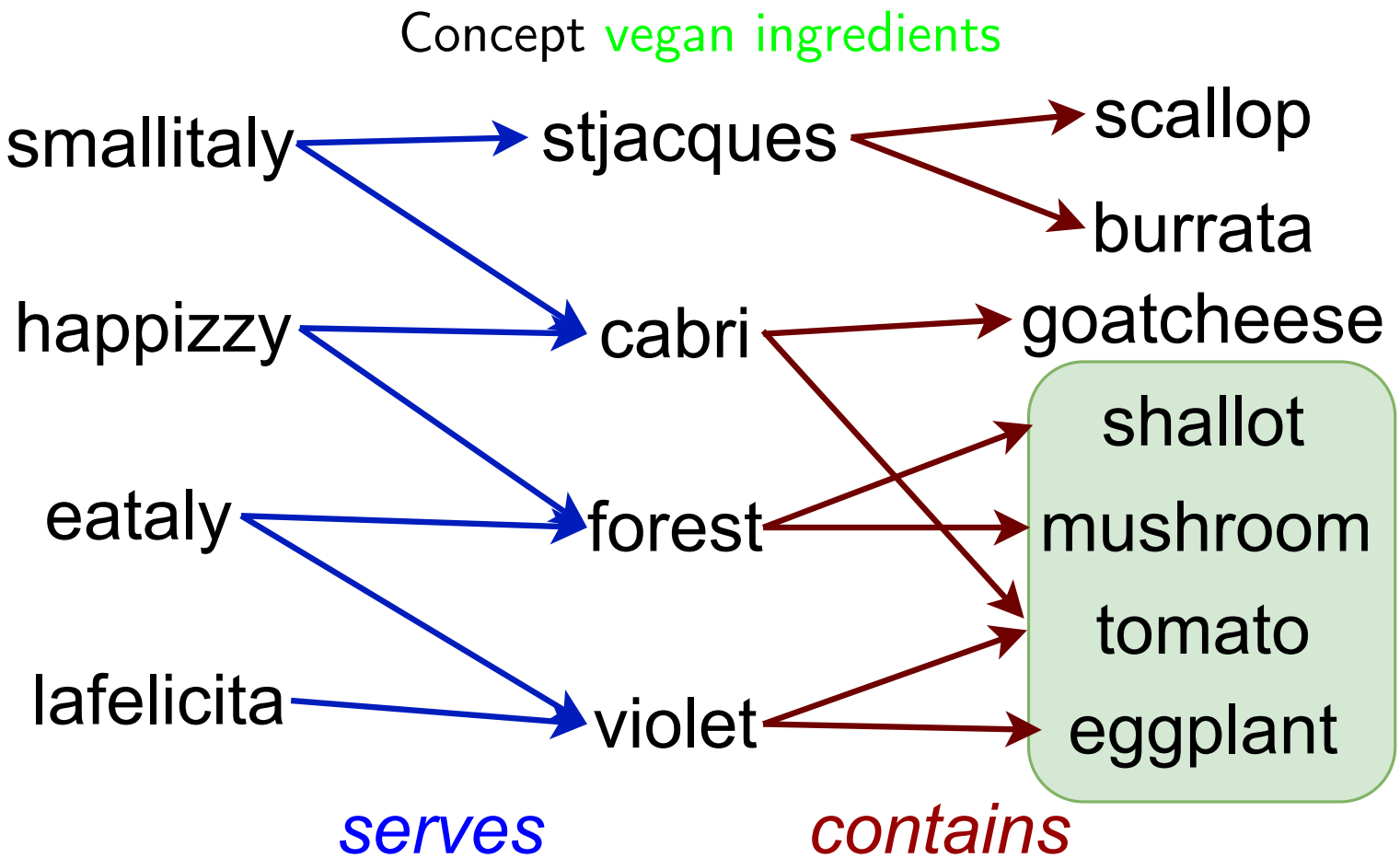
contains	*goatcheese*	*burrata*	*scallop*	*tomato*	*shallot*	*mushroom*	*eggplant*
cabri	x			x			
forest					x	x	
violet				x			x
stjacques		x	x				

serves	*cabri*	*forest*	*violet*	*stjacques*
happizzy	x	x		
eataly		x	x	
lafelicita			x	
smallitaly	x			x

Concept building



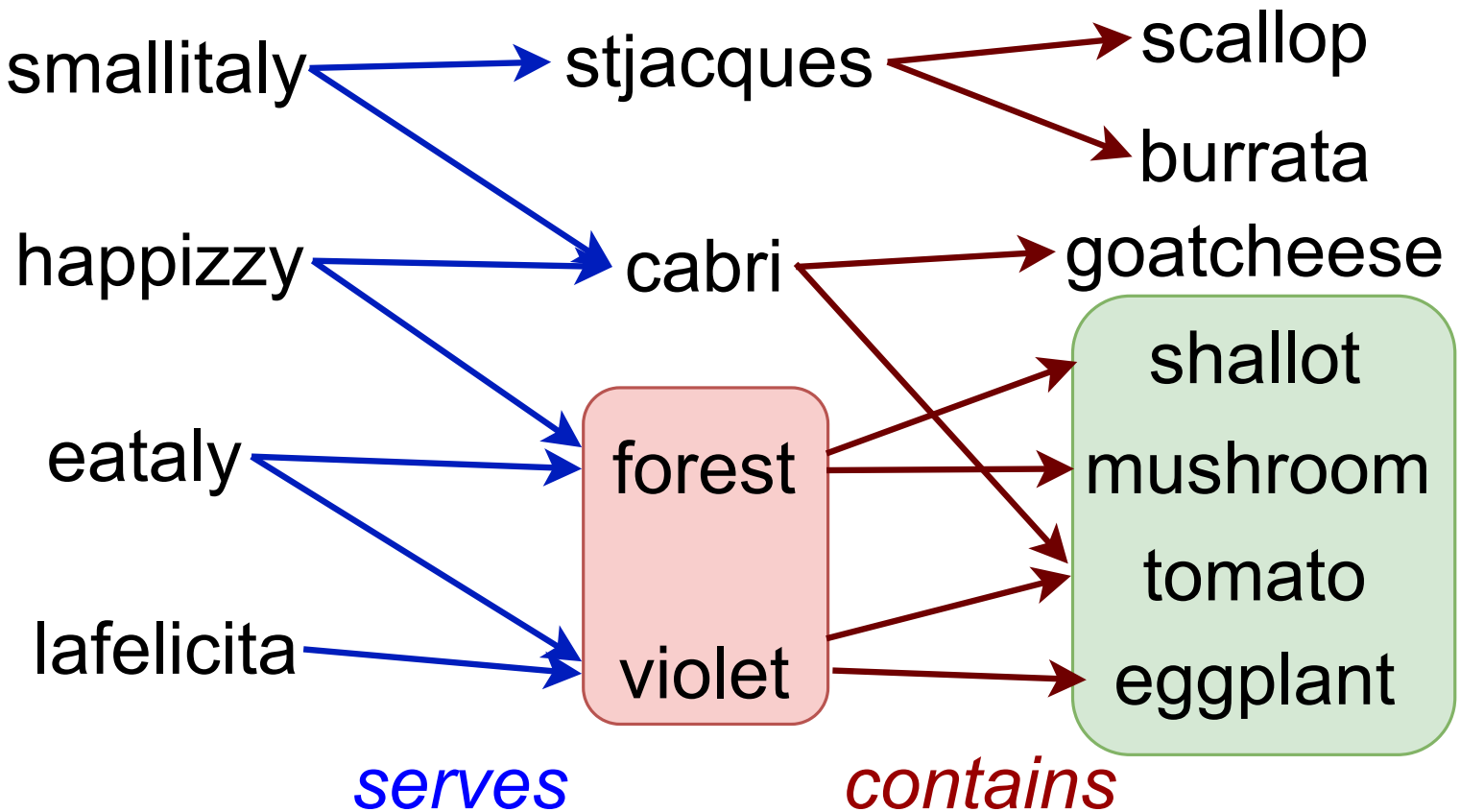
Concept building



Concept building

Concept pizzas that have all their ingredients in concept vegan ingredients

forest and violet share: $\exists\forall contains\ (Vegan)$

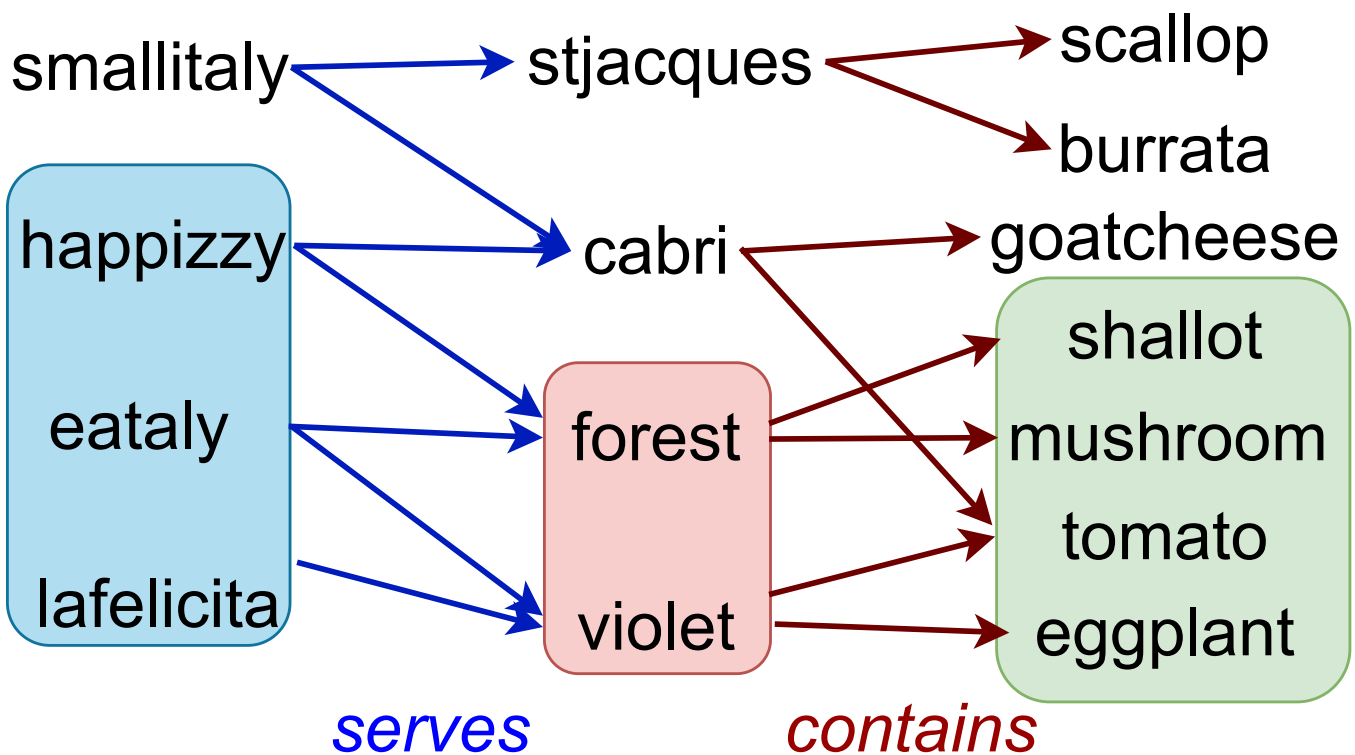


Concept building

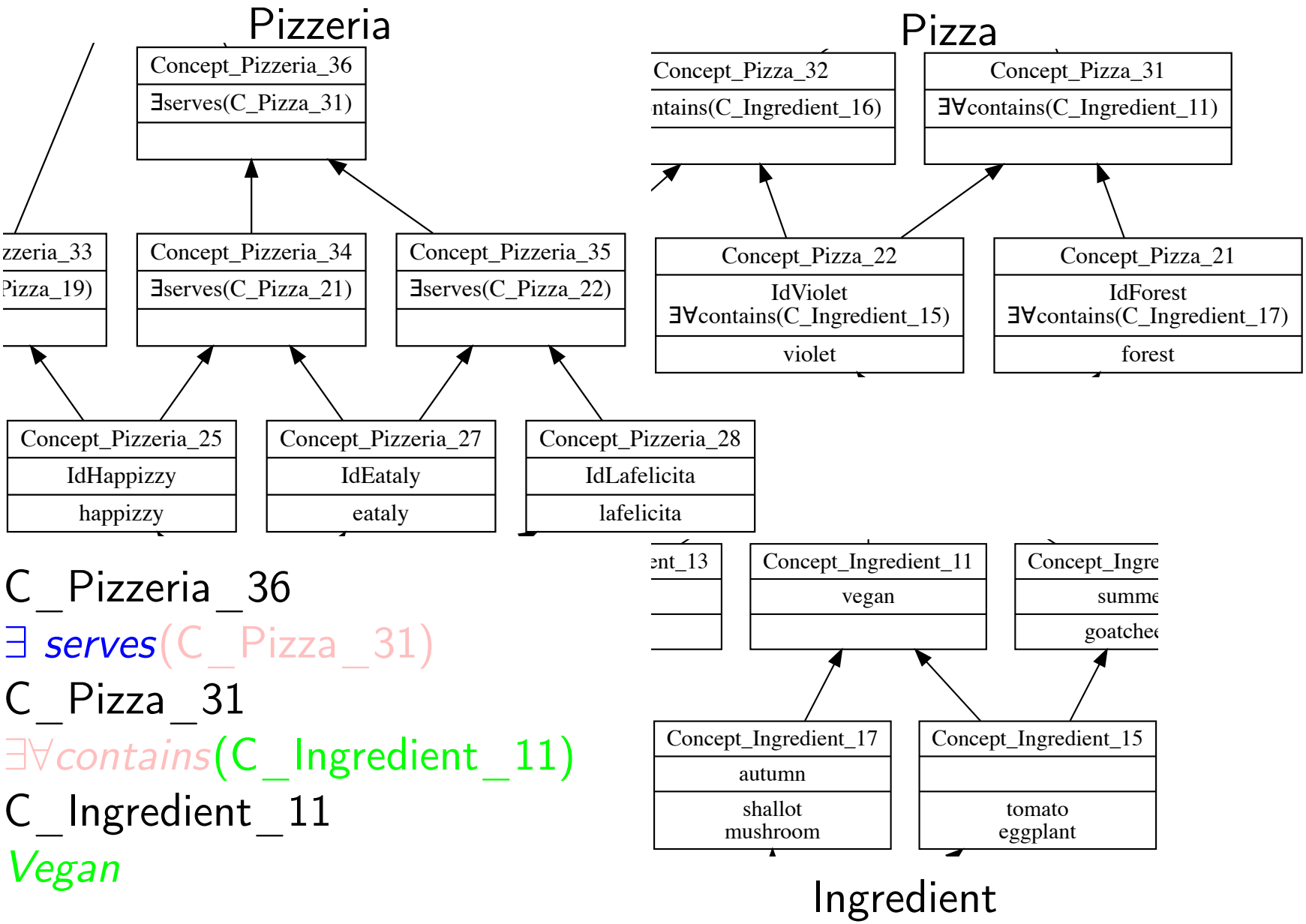
Concept pizzerias that have at least one pizza in concept pizzas that have all their ingredients in concept vegan ingredients

happizzy, eataly and lafelicita share:

$\exists$ *serves* ($\exists\forall$*contains* (*Vegan*))



Interconnected concept lattices



C_Pizzeria_36

∃ *serves*(C_Pizza_31)

C_Pizza_31

∃∀*contains*(C_Ingredient_11)

C_Ingredient_11

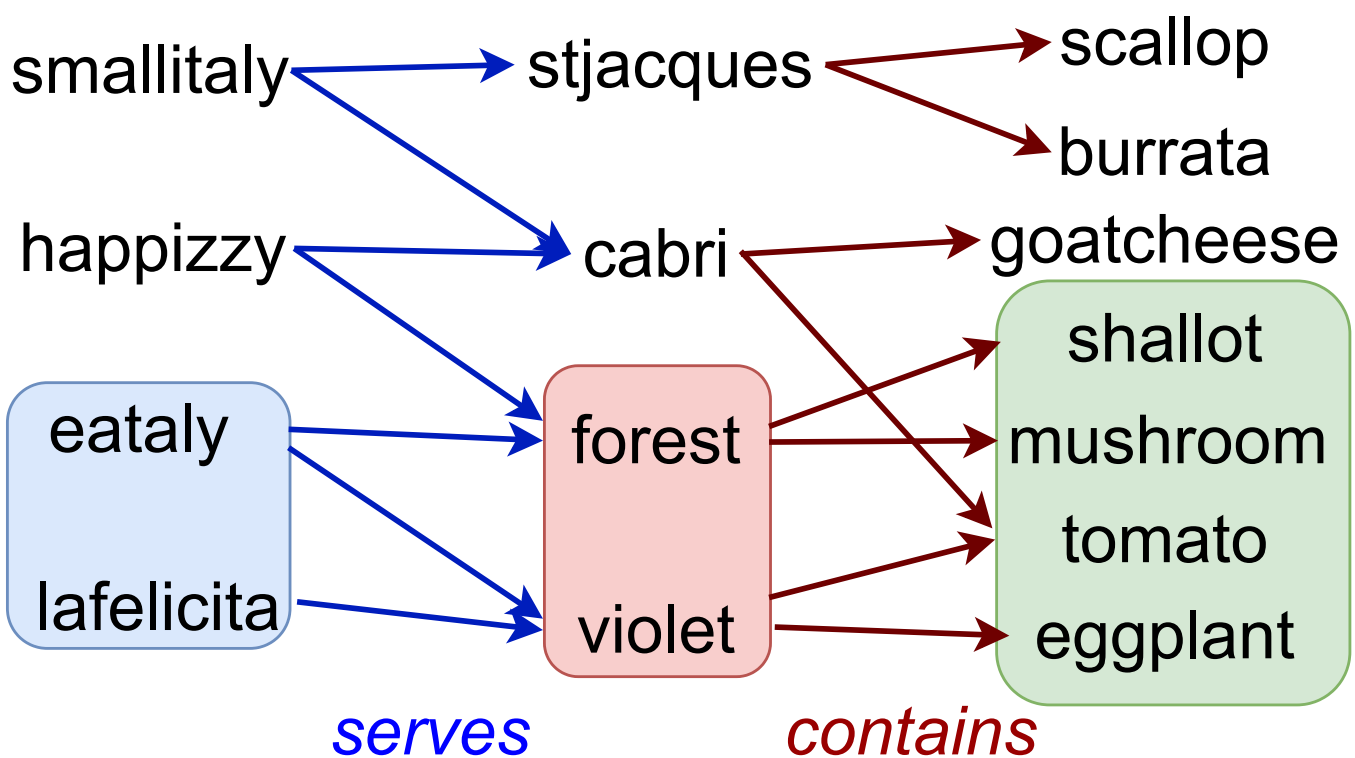
Vegan

Concept building

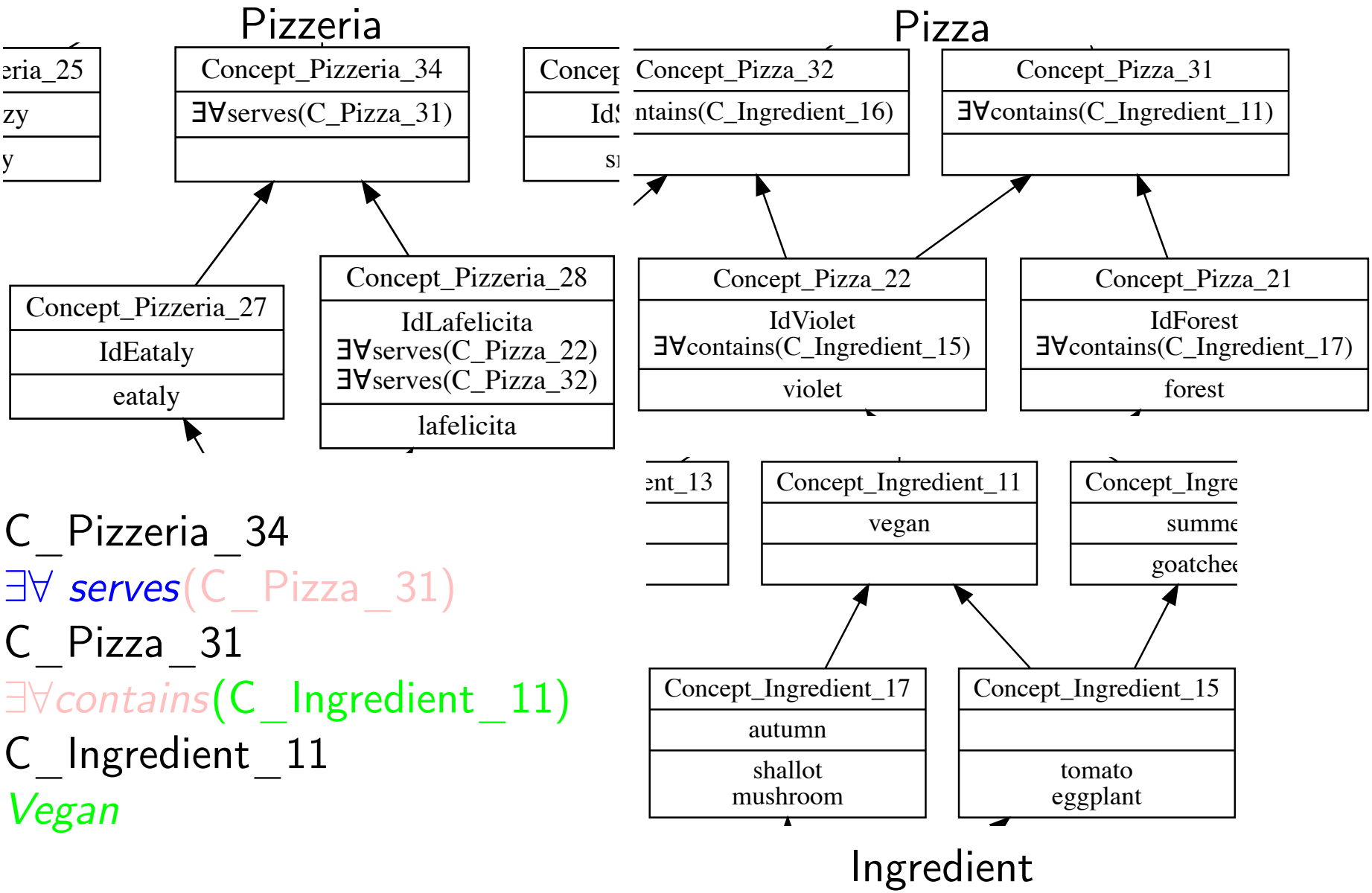
Concept pizzerias that have all their pizzas in concept pizzas that have all their ingredients in concept vegan ingredients

eataly and lafelicita share:

$\exists\forall$ *serves* ($\exists\forall$*contains* (*Vegan*))



Interconnected concept lattices



C_Pizzeria_34

∃∀ *serves*(C_Pizza_31)

C_Pizza_31

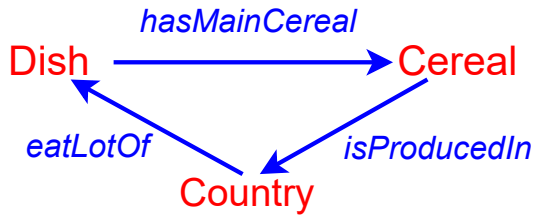
∃∀*contains*(C_Ingredient_11)

C_Ingredient_11

Vegan

Aspects of RCA

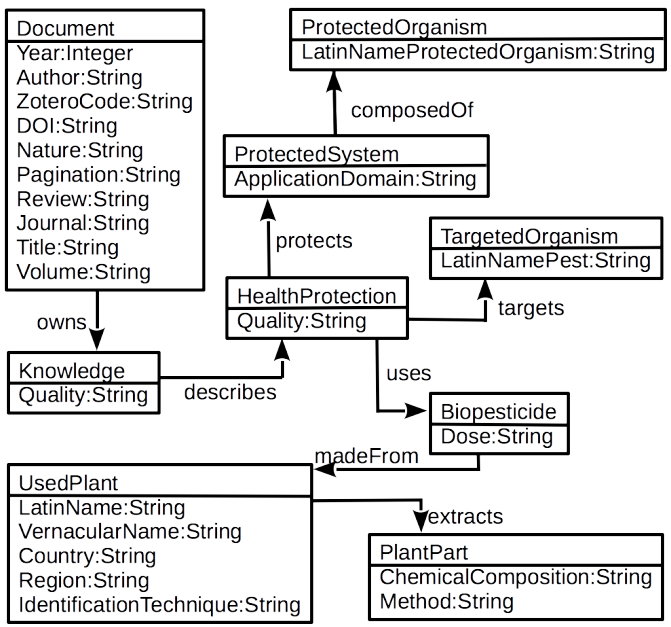
Cyclic-models



A variety of quantifiers

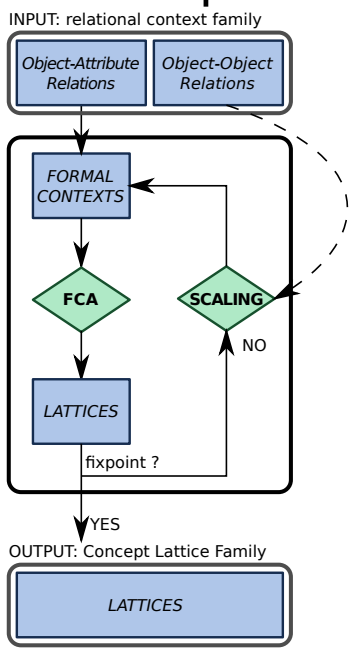
Operator	Attribute form	Condition
Universal (narrow)	$\forall\ r.c$	$r(o) \subseteq Ext(c)$
Universal strict	$\forall\exists\ r.c$	$r(o) \subseteq Ext(c)$ and $r(o) \neq \emptyset$
Universal-percent	$\forall\exists\_\geq n\%\ r.c$	$\lvert r(o) \cap Extent(C)\rvert \geq n\lvert r(o)\rvert/100)$
Covers	$\supseteq\ r.c$	$r(o) \supseteq Ext(c)$
Covers-percent	$\supseteq\ \_\geq n\%\ r.c$	$\lvert r(o) \cap Extent(C)\rvert \geq n\lvert Extent(C)\rvert/100)$
Existential (wide)	$\exists\ r.c$	$r(o) \cap Ext(c) \neq \emptyset$
Universal strict	$\forall\exists\ r.c$	$r(o) \subseteq Ext(c)$ *and* $r(o) \neq \emptyset$
Qualif. card. restriction	$\geq\ n\ r.c$	$r(o) \subseteq Ext(c)$ *and* $\lvert r(o)\rvert \geq\ n$
Card. restriction	$\geq\ n\ r.\top_{\mathcal{L}}$	$\lvert r(o)\rvert \geq\ n$

Complex-models



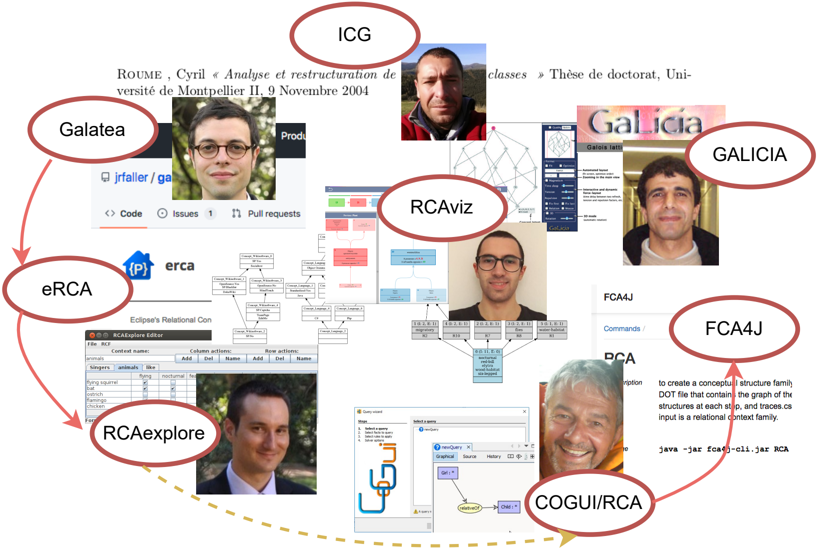
Credits P. Martin

Iterative-process



Credits X. Dolques

RCA tools


ICG
Roume , Cyril « Analyse et restructuration de … classes » Thèse de doctorat, Université de Montpellier II, 9 Novembre 2004
Galatea
jrfaller / ga
Code
Issues 1
Pull requests
eRCA
erca
Eclipse's Relational Con
RCAExplore Editor
File RCF
Context name:
Column actions:
Row actions:
animals
Add
Del
Name
Singers
like
flying
nocturnal
flying squirrel
bat
ostrich
flamingo
chicken
RCAexplore
RCAviz
migratory
flies
water-habitat
nocturnal
red-bill
elytra
wood-habitat
six-legged
Galicia
Galois latti
GALICIA
FCA4J
Commands
RCA
to create a conceptu l structure famil
DOT file that contain the graph of the
structures at each st p, and traces.cs
input is a relational context family.
java -jar fca4 j-cli.jar RCA
Query wizard
Steps
Select a query
newQuery
Graphical
Source
History
Girl : *
relativeOf
Child : *
COGUI/RCA

Application domains

- Environment (Le Ber+, Martin+, Miralles+)
- Health (Wajnberg+)
- Ontologies (Rouane-Hacène+), Link key extraction (Atencia+)
- Software engineering
  - UML class model, use case model normalization (Huchard+, Dolques+)
  - Design defects refactoring (Moha+)
  - Model transformation pattern extraction (Dolques+)
  - Web service, component classification (Azmeh+, Urtado/Vauttier+)
  - Multiple variability modelling (Galasso+, Waffo Kouhoué+), Feature mining or location (Al-Msie'deen, Eyal-Salman, Seriai+, Hlad+),
- Industry (Wajnberg+)
- Legal documents (Mimouni+)

Agenda

Modeling for RCA

- Naive view: A model is provided with data which can be used
- Practice is more complex, e.g.
  - Associations: bidirectional or N-ary
  - Particular relations: E.g. *is-a*, *instance-of*, *contains*
  - The analyst may want to focus on specific parts of the data
  - Data may be provided without a model (e.g. textual data)

$\Rightarrow$ The RCF has to be built by considering a transformation of the initial model, or even created from scratch

The spirit is similar to *scaling* of FCA that transforms non-Boolean attributes into Boolean ones.
Here the needed modeling addresses models, instances (objects) and values.

Rationalizing RCF design

- Recurring situations
- Capitalizing them would accelerate future applications
- Design Pattern approach (C. Alexander, GOF: E. Gamma, J. Vlissides, R. Johnson, R. Helm)
  - Problem
  - Recurring solution
  - Typical example
  - Variants and discussion

Design Pattern Separate/Gather Viewpoints

Problem

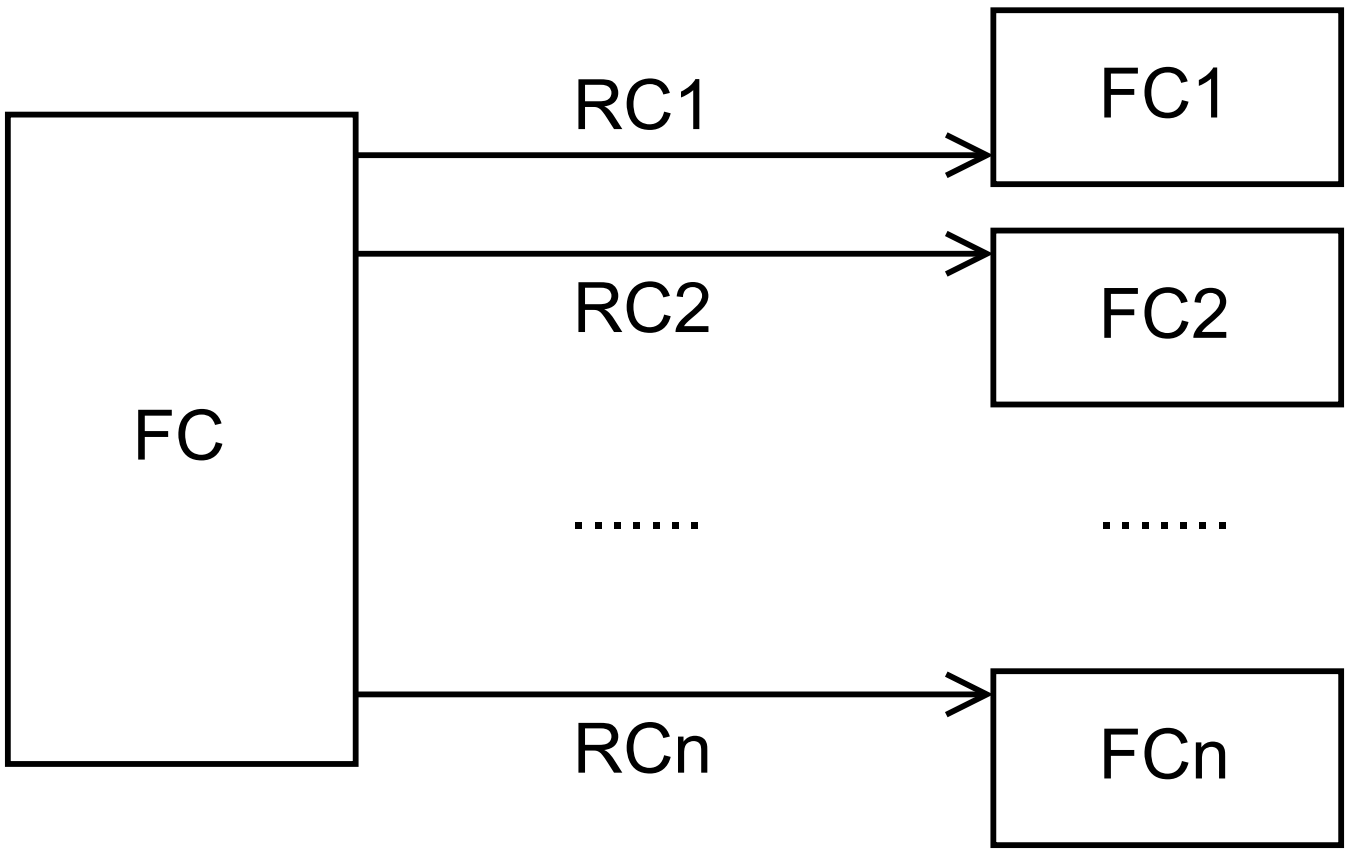
- Objects are described by Boolean attributes that can be put into different categories; or initial multi-valued attributes have been transformed into Boolean attributes
- Each attribute category is a view or a concern
- It is relevant to analyze objects through the perpective of:
  - a single view
  - several views (including all)

Focus on Separate/Gather Viewpoints

Solution

- Formal contexts (FC)
  - One FC for the initial objects
    - FC objects are the initial objects, FC attributes are initial object identifiers, or other description, or none
  - One FC_i for each view $i, 1 \leq i \leq n$, one per attribute category
    - FC_i objects are views on the initial objects, FC_i attributes are initial Boolean attributes of one view
- Relational contexts (RC)
  - For each $i, 1 \leq i \leq n$, one RC_i connecting an object of FC to its corresponding view object in an FC_i

RCF multi-views model



Focus on Separate Viewpoints: an application

Assist Feature location in Software Products Lines
(Hlad, Lemoine, Huchard, Seriai, GPCE 2021)

- Migrate a similar software family into a software product line
- Feature location: find the software artefacts (E.g. code) corresponding to a feature
- Principle: if a group of artefacts and a group of features are shared by products, this suggests that these features may be coded through these artefacts
- Challenges:
  1. have a sufficient product number to discriminate and associate a single feature to a group of artefacts
  2. some pieces of code do not correspond to a feature but suggest an interaction between features, or missing features in the product description

Focus on Separate Viewpoints: Vehicles

Input

Features and code of similar products

```
[MOVE, SECU,PROGCONT,WATER]
public class Vehicle{
 public void move_(){..}
 public void passControl_(){..}
 public void float_(){..}
} //Oceanis30

[MOVE, SECU,PROGCONT,AIR]
public class Vehicle{
 public void move_(){..}
 public void passControl_(){..}
 public void fly_(){..}
} //A380
```

Output

Annotated SPL code

```
public class Vehicle{
 //#if MOVE & SECU & PROGCONT
 public void move_(){...}
 public void passControl_(){...}
 //#endif
 //#if WATER
  public void float_(){...}
 //#endif
 //#if AIR
  public void fly_(){...}
 //#endif
}
```

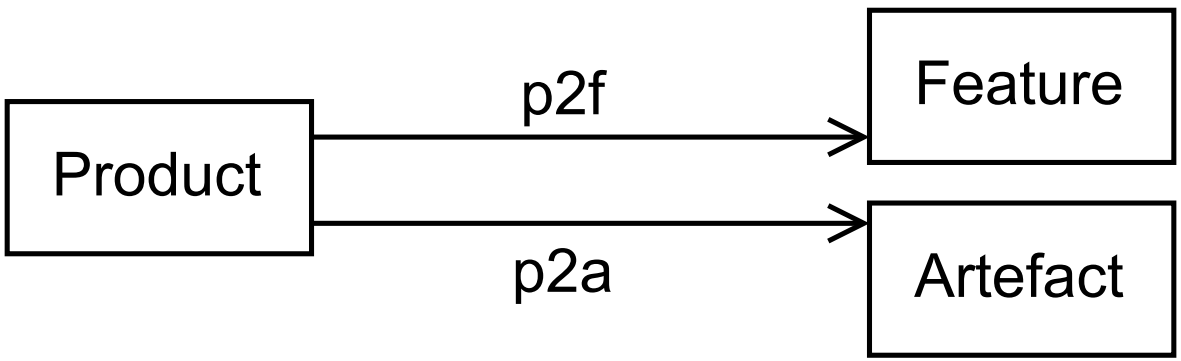
Products derived according selected features

Focus on Separate Viewpoints: an application

Assist Feature location in Software Products Lines
(Hlad, Lemoine, Huchard, Seriai, GPCE 2021)

- Separately group features and artefacts to extract:
  - Feature variability (variability model)
  - Artefact variability (potentially reusable code pieces)
  - Traceability between propositional logic formula on features vs. code artefacts
    - Identification of apparition context of artefacts in terms of positive vs. negative features followed by formula reduction
    - Generation of code annotations `#if FORMULA-ON-FEATURES`
- RCF
  - Objects: similar products
  - View 1: products described by features
  - View 2: products described by software artefacts

RCF product model



Focus on Separate Viewpoints: Vehicles

The two views: by feature and by artefacts

Feature	MOVE	AIR	WATER	GROUND	SECU_	PROG_CONT_	UNAN_INSP_
A380Feat	x	x			x	x	x
Oceanis30Feat	x		x		x	x	
AkoyaFeat	x	x	x		x	x	
SqubaFeat	x		x	x	x	x	
TringaT650Feat	x		x	x	x	x	
TwingoFeat	x			x	x	x	

Artefact	*move*	*ride*	*honk*	*float*	*fly*	*takeoff*	*land*	*ditch*	*dive*	*raisewheel_/*	*reportinsp_/*	*passcontrol*
A380Art	x	x			x	x	x				x	x
Oceanis30Art	x			x								x
AkoyaArt	x			x	x	x	x	x				x
SqubaArt	x	x	x	x					x			x
TringaT650Art	x	x	x	x						x		x
TwingoArt	x	x	x									x

Focus on Separate Viewpoints: Vehicles

Formal Context `Product` ⟶

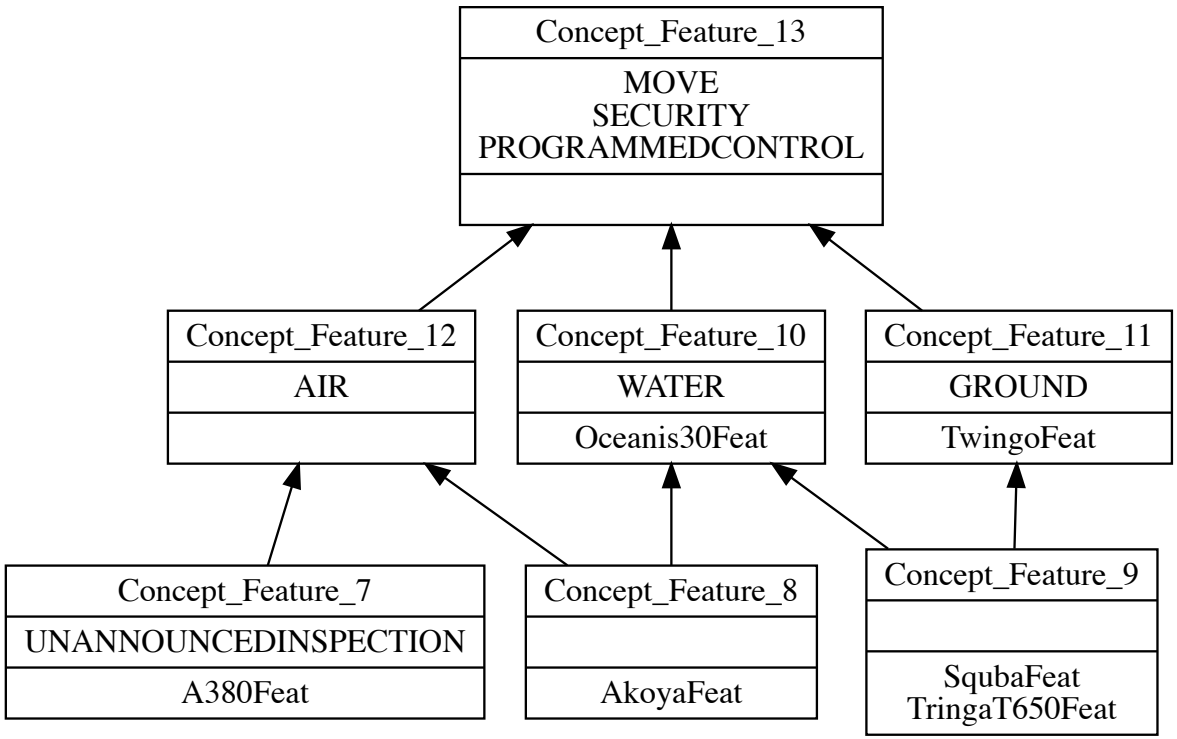
Relational contexts connecting products
to the feature view or to the artefact view ↓

Product
A380
Oceanis30
Akoya
Squba
TringaT650
Twingo

p2f	A380Feat	Oceanis30Feat	AkoyaFeat	SqubaFeat	TringaT650Feat	TwingoFeat
A380	x					
Oceanis30		x				
Akoya			x			
Squba				x		
TringaT650					x	
Twingo						x

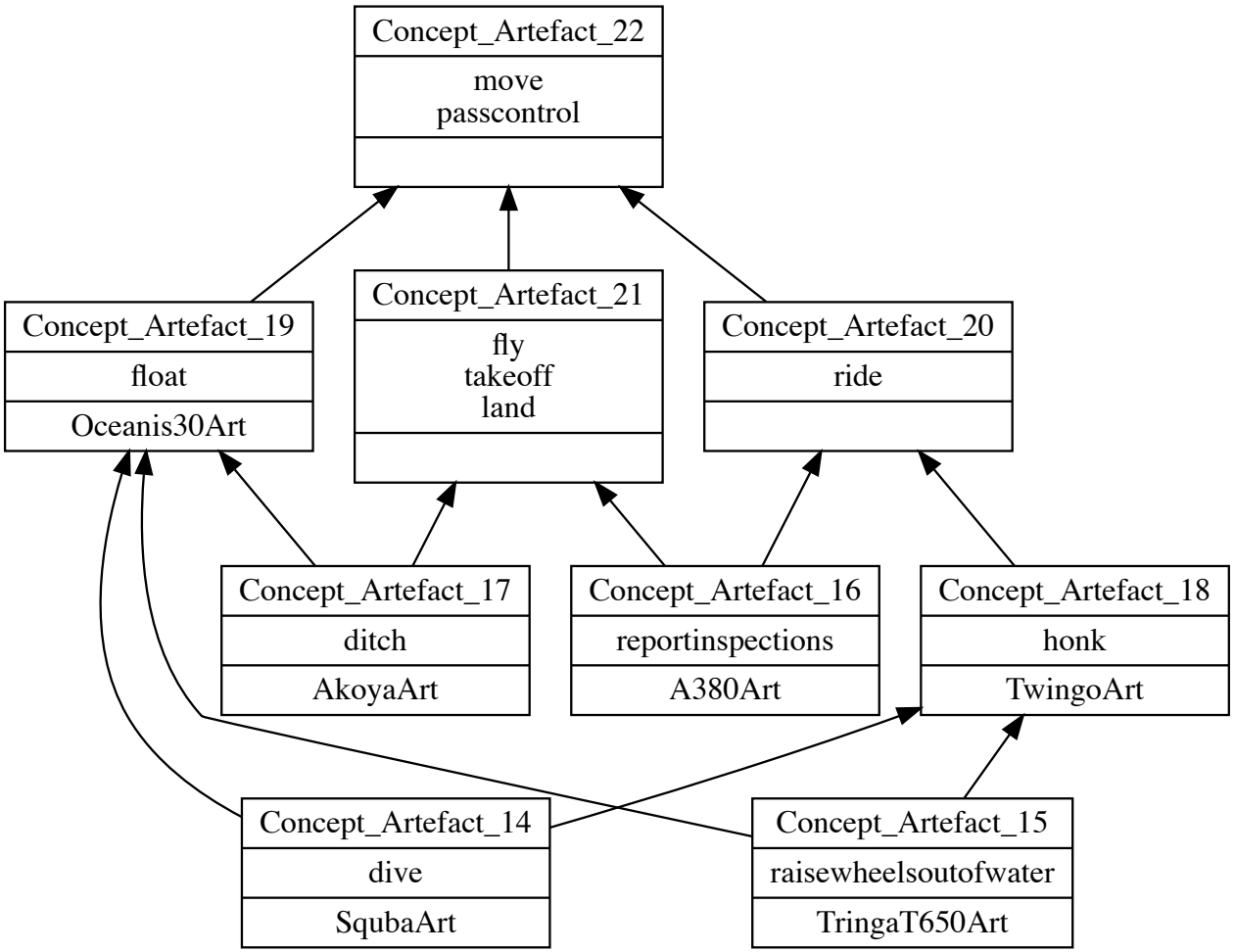
p2a	A380Art	Oceanis30Art	AkoyaArt	SqubaArt	TringaT650Art	TwingoArt
A380	x					
Oceanis30		x				
Akoya			x			
Squba				x		
TringaT650					x	
Twingo						x

Feature view



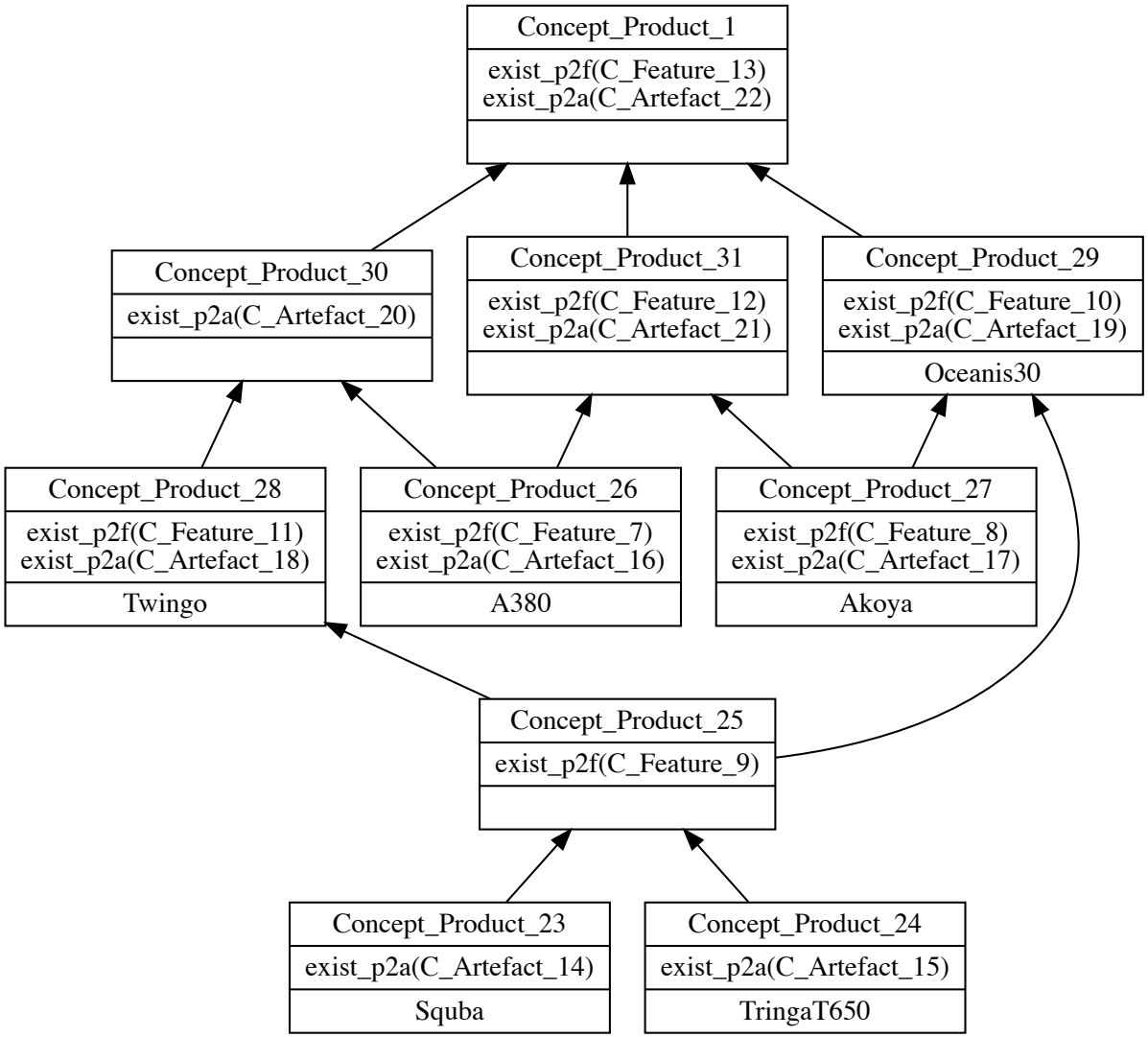
May be used to derive a feature model: *J. Galasso-Carbonnel et al. Modelling equivalence classes of feature models with concept lattices to assist their extraction from product descriptions. J. Syst. Softw. 152: 1-23 (2019)*

Artefact view



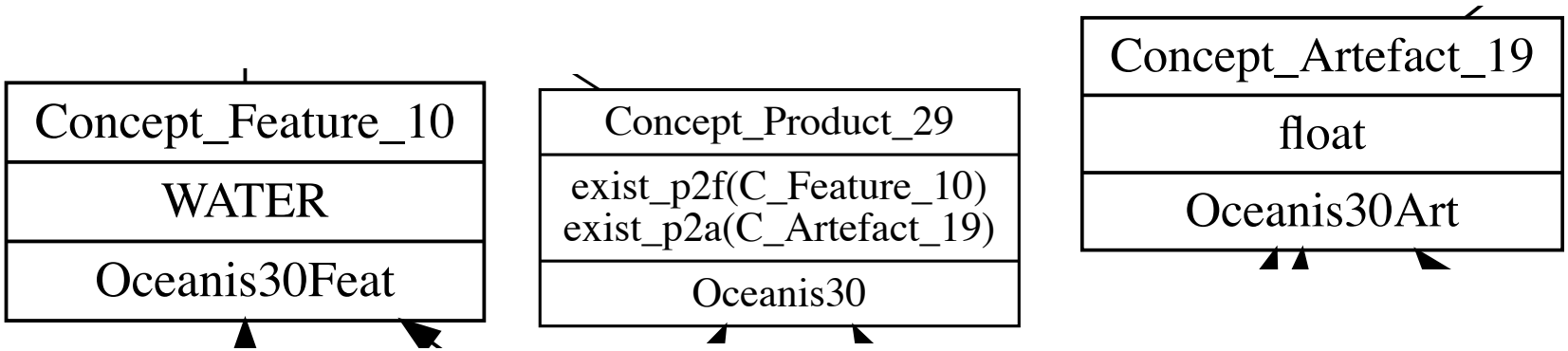
May be used to suggest reusable code pieces: E.g. methods `fly`, `takeoff`, `land` can be grouped in a component `AirVehicle`

Gathered product views



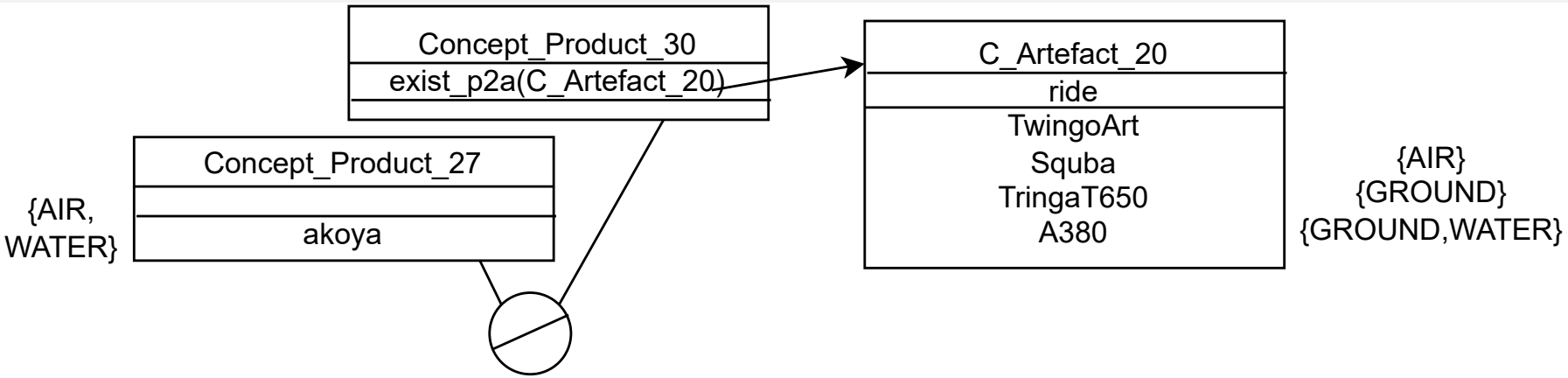
Used to find annotations and create the annotated code of the SPL

Gathered product views: annotation extraction




```
public class Vehicle{
...
 //#if WATER
  public void float_(){...}
 //#endif
...
}
```

Gathered product views: annotation extraction




```
public class Vehicle{
 //#if (AIR || GROUND) && ! ( AIR  &&  WATER )
  public void ride_(){...}
 //#endif
...
}
```

Extent(C_Prod._30)={Twingo, Squba, TringaT650, A380}
Positive part from C_Art._20: (AIR || GROUND)

Extent(C_Prod._30) ∩ Extent(C_Prod._27) = ∅
Extent(C_Prod._27 = {Akoya}
Negative part from C_Prod._27 = ! (AIR && WATER)

Focus on Separate Viewpoints: an application

For more details

- Identification of artefacts at the instruction-level
- Reduction of annotation formulas (e.g. by factorization, using implications from the AOC-poset, etc.)
- Tools: CLEF (J. Galasso), IsiSPL (N. Hlad, B. Lemoine)
- Experimentations
  - FakePrinterSPL, DrawSPL, ArgoUML, NotePad, GameOfLife, Elevator
  - évaluation de la régénération correcte des produits et réduction des formules en nombre ($\sim$-30%) et taille des formules ($\sim$-60% de features)

Focus on Separate Viewpoints: an application

For more details

- Readings
  - N. Hlad, thèse de doctorat, *IsiSPL : un processus automatisé pour faciliter l'ingénierie des lignes de produits logiciels selon une stratégie d'adoption industrielle réactive ou extractive*, Univ. Montpellier 2022, ISIA
  - B. Lemoine, thèse de Master, *Localisation de caractéristiques dans le cadre des lignes de produits logiciels*, Univ. Montpellier 2021, prix IESF-CODIGE
  - N. Hlad et al. *Leveraging relational concept analysis for automated feature location in software product lines.* GPCE 2021: 170-183

Focus on Separate Viewpoints

Another developed application

- Analyzing Visual Accessibility Options in Operating Systems
  - Objects are operating systems (OS); Views are three visual accessibility options categories (contrast, text, zoom)
  - Allows to analyze constraints on these options e.g.: implications, mutual exclusion
  - Objectives: recommendations for a new system version (OS developer), or user assistance in changing versions
  - A. Waffo Kouhoué et al. *Exploring Variability of Visual Accessibility Options in Operating Systems.* Future Internet 13(9): 230 (2021)

Towards a catalog of DPs

Opportunities for other design patterns

- Collapse Specialization — Godin/Mili (classes), Huchard/Miralles+ (Java interfaces, UML), Martin+ (plants)
- N-ary relation reification /split — Martin+ (plants)
- Separate topics — Martin+ (plants), Miralles+ (UML)
- Instances2Model — Dolques+ (Model transformation pattern extraction), B.Seriai+ (RDF)
- Workflow — Azmeh+ (web services workflow classification)
- Query — Azmeh+ (web service replacement in a workflow)
- Temporal — Le Ber+ (hydrological data)
- Correspondence/matching — Dolques+ (Model transformation pattern extraction)

Agenda

Conclusion

- FCA as a symbolic/white-box/structured-data KD method
- RCA, a variant for multi-relational datasets
- Practicing RCA demands a quite complex data preparation
- Recurring situations to be capitalized in Design Patterns

Perspectives

- Pursue the formalization of DPs
- Develop the corresponding interpretation tools
- Analyze effects on extracted knowledge:
  - conceptual structures
  - logical constraints: implication and association rules, mutual exclusion, OR groups, XOR groups
- Develop a methodology integrating DPs usage
- Build bridges with Graph-FCA and Polyadic Concept Analysis

Thank you!

SmartFCA

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This reflexion could not have happened without ...