

OCPQ: Object-Centric Process Querying & Constraints

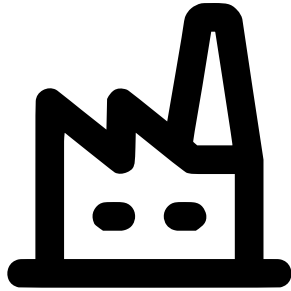
RCIS 2025

2025-05-21

Aaron Küsters & Wil van der Aalst

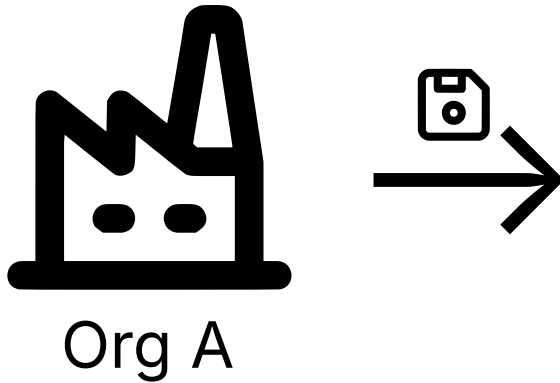
Introduction

Process Querying

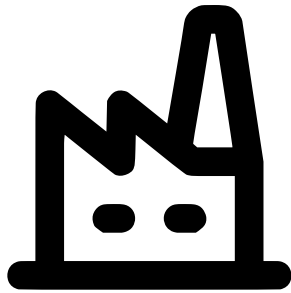


Org A

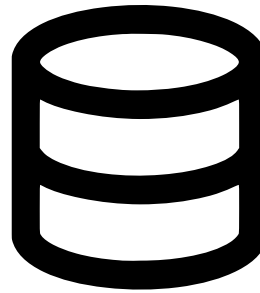
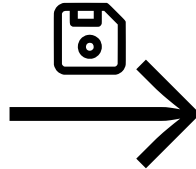
Process Querying



Process Querying

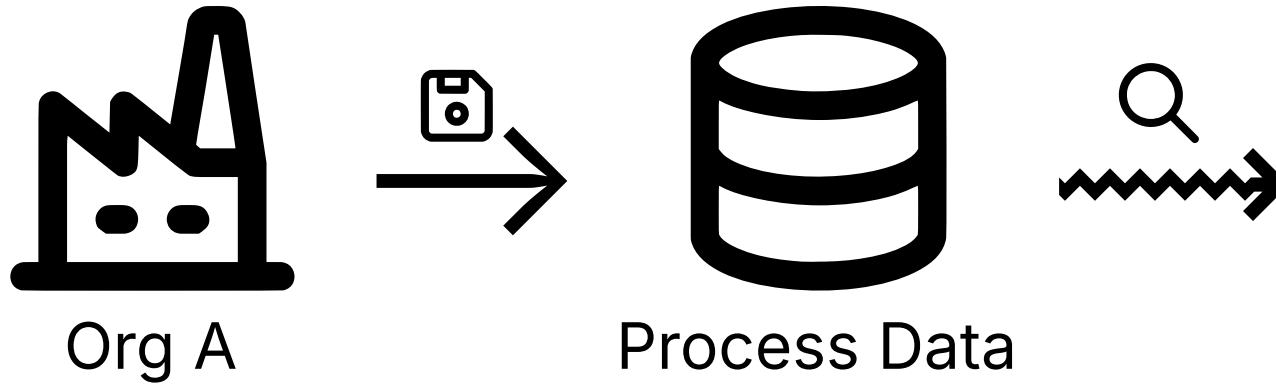


Org A



Process Data

Process Querying



Process Querying



Process Querying



Process Data

Event Data

ID	Activity	Time	Case
	place order	01.05.25 10:30	
	confirm order	02.05.25 08:42	
	place order	10.05.25 07:45	
	pay order	12.05.25 12:54	
	pick item	13.05.25 06:54	 ?
	confirm order	13.05.25 08:31	
	pick item	13.05.25 06:54	 ?
...	...	...	...

Event Data

ID	Activity	Time	Case
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place order

confirm order

pay order

pick item

pick item

place order

confirm order

Object-Centric Event Data: Events

ID	Activity	Time	Objects (E2O)
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...	...	...	...

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place order

confirm order

pay order

place order

confirm order

pick item

Object-Centric Event Data: Objects

ID	Type	Objects (O2O)	Other Attributes
	customers	{  , 	Name: Wil, Age: 59
	orders	{  , 	Total: 112.41
	orders	{ 	Total: 43.95
	items	{ }	Weight: 316
	items	{ }	Weight: 574
	items	{ }	Weight: 413
...	...	...	

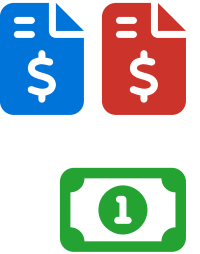
Object-Centric Event Data: Objects

ID	Type	Objects (O2O)	Other Attributes
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	orders	{ 	Total: 43.95
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	items	{ }	Weight: 413
...	...	...	

OCEL 2.0 Specification: <https://www.ocel-standard.org/>

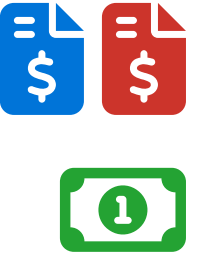
Queries & Constraints

- Identify interesting *scenarios*
 - ♦ *Traditional*: Events, Cases
 - ♦ *Object-centric*: Objects, Events, "Cases"



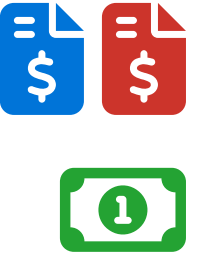
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- **Querying & Constraints closely connected**
 - ♦ *interesting* ↔ *violated*



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Goal: Enable stakeholders to analyze & gain insights *themselves*



Queries & Constraints

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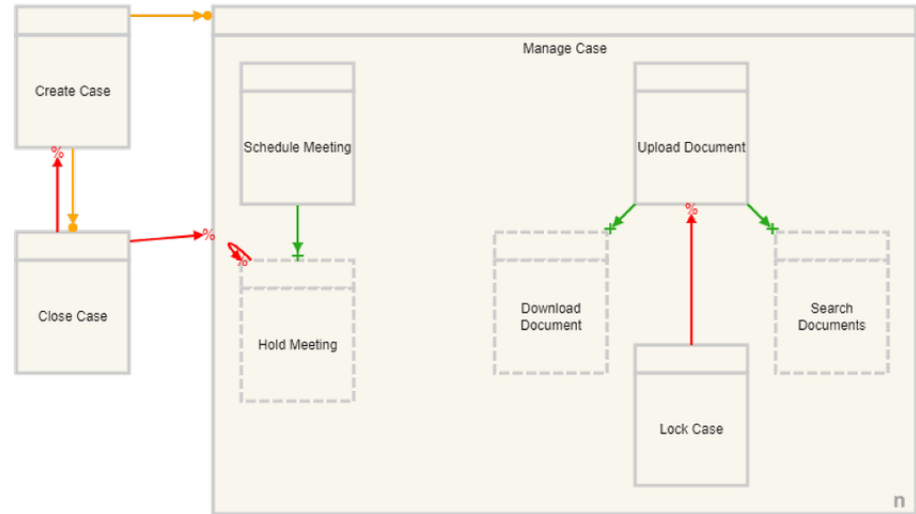


Related Work

Traditional approaches



DECLARE (Pesic et al., 2007)



DCR Graphs (Hildebrandt and Mukkamala, 2010)

Related Work

Object-centric approaches



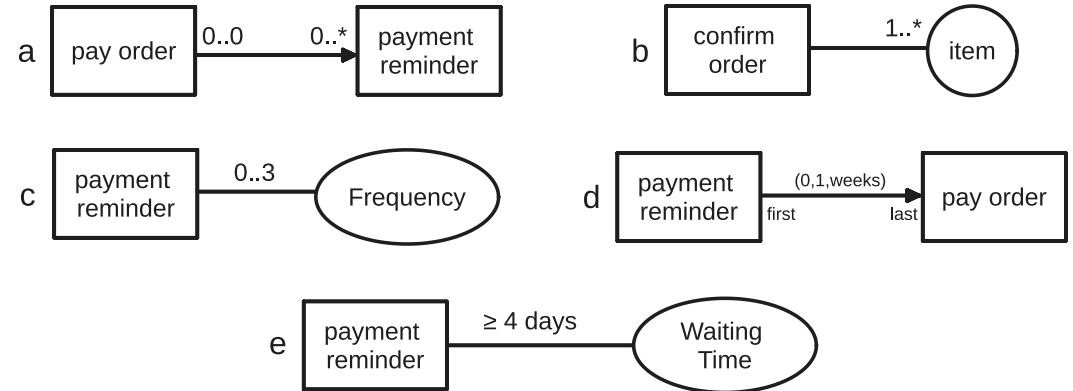
OCCG Constraints (Park and van der Aalst, 2022)

Related Work

Object-centric approaches



OCCG Constraints (Park and van der Aalst, 2022)



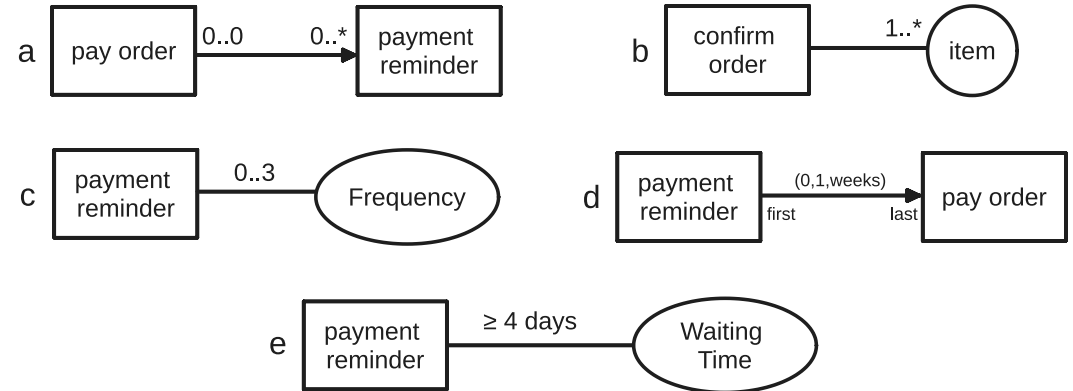
OCCM Constraints (Li et al., 2023)

Related Work

Object-centric approaches



OCCG Constraints (Park and van der Aalst, 2022)



↪ **Multi-Object**

OCCM Constraints (Li et al., 2023)

Expressiveness

- **"Another Offer** for a (Loan) Application should be only sent after the previous one was returned/rejected/cancelled"
- **"Two orders** by the same customer should be confirmed in the same order they are placed in."
- "Either an order should be paid fast **or** a payment reminder should be sent out for it."

 Not expressible in previous work (Declare, OCCG, OCCM, ...)

Code

```

1  SELECT
2  A0.ocel_id AS o0,
3  A1.ocel_id AS o1,
4  A2.ocel_id AS o2,
5  E1.ocel_id AS e1,
6  E2.ocel_id AS e2
7  FROM
8  object AS A0,
9  object AS A1,
10 object AS A2,
11 event AS E1,
12 event AS E2
13 INNER JOIN object_object AS O20 ON O20.ocel_source_id = A0.ocel_id
14 AND O20.ocel_target_id = A1.ocel_id
15 INNER JOIN object_object AS O202 ON O202.ocel_source_id = A0.ocel_id
16 AND O202.ocel_target_id = A2.ocel_id
17 INNER JOIN event_object AS E20 ON E20.ocel_event_id = E1.ocel_id
18 AND E20.ocel_object_id = A1.ocel_id
19 INNER JOIN event_object AS E202 ON E202.ocel_event_id = E2.ocel_id
20 AND E202.ocel_object_id = A2.ocel_id
21 INNER JOIN event_PlaceOrder AS E_PO ON E_PO.ocel_id = e1
22 INNER JOIN event_PlaceOrder AS E_PO2 ON E_PO2.ocel_id = e2
23 AND E_PO.ocel_time < E_PO2.ocel_time
24 WHERE
25 A0.ocel_type = 'customers'
26 AND A1.ocel_type = 'orders'
27 AND A2.ocel_type = 'orders'
28 AND E1.ocel_type = 'place order'
29 AND E2.ocel_type = 'place order'
30 AND o1 != o2
31 AND E_PO.ocel_time < E_PO2.ocel_time

```



```

1  MATCH (o:Entity {EntityType: 'Offer'}) <-[:CORR]- (e1:Event) -[:DF*
   ↳ {EntityType: 'Offer'}]-> (e2:Event)
2  WHERE e1.Activity = "O_Created" AND e2.Activity = "O_Cancelled"
3  RETURN e1,e2

```

 Cypher (Esser and Fahland, 2021)

What is missing?

-  Lacking expressiveness (OCCG, OCCM)
-  Hard to use (SQL, Cypher)

What is missing?

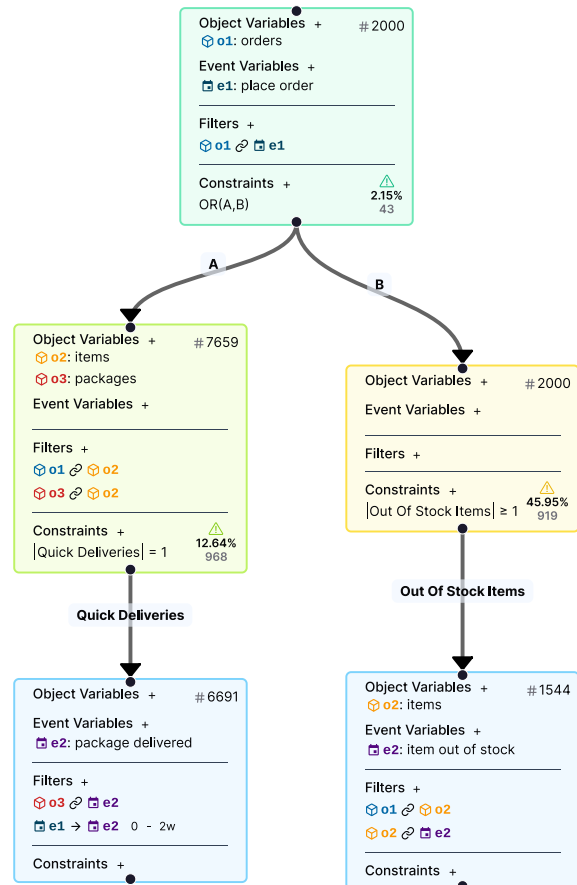
-  Lacking expressiveness (OCCG, OCCM)
-  Hard to use (SQL, Cypher)

Our approach (OCPQ)

-  Flexible and extremely expressive
-  Easy-to-use & visual representation
-  Very fast runtime

OCPQ

Query Tree Constraint



Output Bindings

2000 Bindings

43 Violations

o1 Search...	e1 Search...	Violation any
o-990501	place_o-990501	☐
o-990502	place_o-990502	☐
o-990503	place_o-990503	☐
o-990504	place_o-990504	☐
o-990505	place_o-990505	☐
o-990506	place_o-990506	☒ OR(A,B)
o-990507	place_o-990507	☐
o-990508	place_o-990508	☐
o-990509	place_o-990509	☐
o-990510	place_o-990510	☐

Rows per page

10

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Idea: Explicit Quantifiers

"Every order should be paid exactly once."

Idea: Explicit Quantifiers

"Every order should be paid exactly once."

- For OCED L with objects O and events E + helper functions `type` and `obj`

$$\underbrace{\forall_{o \in O \wedge \text{type}(o) = \text{order}}}_{\text{Quantifier for } o} \underbrace{|\{e \in E \mid \text{type}(e) = \text{pay order} \wedge o \in \text{obj}(e)\}|}_{\text{Nested Quantifier for } e \text{ (based on } o)} = 1$$

Variable Bindings

- Combinations of objects & events
- "Two orders by the same customer should ..."

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- "Two orders by the same customer should ..."
- $b_1 = \{o1 \mapsto \text{person}, o2 \mapsto \text{blue cart}, o3 \mapsto \text{orange cart}\}$
- $b_2 = \{o1 \mapsto \text{person}, o2 \mapsto \text{orange cart}, o3 \mapsto \text{blue cart}\}$

o1	o2	o3
		
		

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o1	o2	o3
		
		

Output Bindings

133555 Bindings

0 Violations

All output bindings are shown. [Undo](#)

 o1	 o2	 o3	 e2	 e3
Search...	Search...	Search...	Search...	Search...
AlpenTech Innovati...	o-990001	o-990002	place_o-990001	place_o-990002
AlpenTech Innovati...	o-990002	o-990005	place_o-990002	place_o-990005
AlpenTech Innovati...	o-990001	o-990005	place_o-990001	place_o-990005
AlpenTech Innovati...	o-990005	o-990008	place_o-990005	place_o-990008
AlpenTech Innovati...	o-990002	o-990008	place_o-990002	place_o-990008
AlpenTech Innovati...	o-990001	o-990008	place_o-990001	place_o-990008
Vesta Fashion Hous...	o-990009	o-990010	place_o-990009	place_o-990010
Celtica Green Farm...	o-990003	o-990014	place_o-990003	place_o-990014
AlpenTech Innovati...	o-990005	o-990018	place_o-990005	place_o-990018
AlpenTech Innovati...	o-990008	o-990018	place_o-990008	place_o-990018

Rows per page 10

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Binding Box: Query Bindings

- $\mathfrak{b} = (\text{Var}, \text{Pred})$
 - $\text{Var} = \{o1 \mapsto \{\text{orders}\}, e1 \mapsto \{\text{place order}\}\}$
 - $\text{Pred} = \{\text{E2O}(e1, o1)\}$

Object Variables + # 2000

 **o1**: orders

Event Variables +

 **e1**: place order

Filters +

 **o1**   **e1**

Constraints +

Binding Box: Query Bindings

- $b = (\text{Var}, \text{Pred})$
 - $\text{Var} = \{o1 \mapsto \{\text{orders}\}, e1 \mapsto \{\text{place order}\}\}$
 - $\text{Pred} = \{\text{E2O}(e1, o1)\}$
- Output:
 - $\{o1 \mapsto \text{shopping cart icon}, e1 \mapsto \text{calendar icon}\}$
 - $\{o1 \mapsto \text{shopping cart icon}, e1 \mapsto \text{calendar icon}\}$
 - ...

Object Variables + # 2000

 **o1**: orders

Event Variables +

 **e1**: place order

Filters +

 **o1**   **e1**

Constraints +

o1	e1
	
	

Binding Box: Query Bindings

Object Variables + # 2000

 **o1**: orders

Event Variables +

 **e1**: place order

Filters +

 **o1**   **e1**

Constraints +

Output Bindings

2000 Bindings
0 Violations

o1	e1
Search...	Search...
o-990001	place_o-990001
o-990002	place_o-990002
o-990003	place_o-990003
o-990004	place_o-990004
o-990005	place_o-990005
o-990006	place_o-990006
o-990007	place_o-990007
o-990008	place_o-990008
o-990009	place_o-990009
o-990010	place_o-990010

Rows per page

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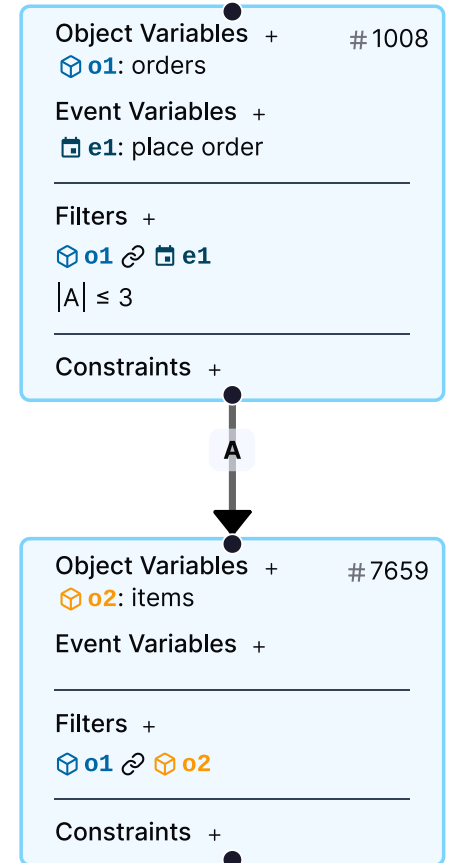


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Query Tree: *Nested* Querying of Bindings

- Query Tree
 - Rooted tree of binding boxes
 - Variables & Predicates are 'propagated down'
- Intuitively: For one binding of parent node
 - Query set of child bindings A



Example of Nested Querying

o1 o-990001	e1 Search...
o-990001	place_o-990001

↓ A

o1 o-990001	o2 Search...	e1 Search...
o-990001	i-880002	place_o-990001
o-990001	i-880003	place_o-990001
o-990001	i-880001	place_o-990001

Object Variables + # 1008

o1: orders

Event Variables +

e1: place order

Filters +

o1 e1

|A| ≤ 3

Constraints +



Object Variables + # 7659

o2: items

Event Variables +

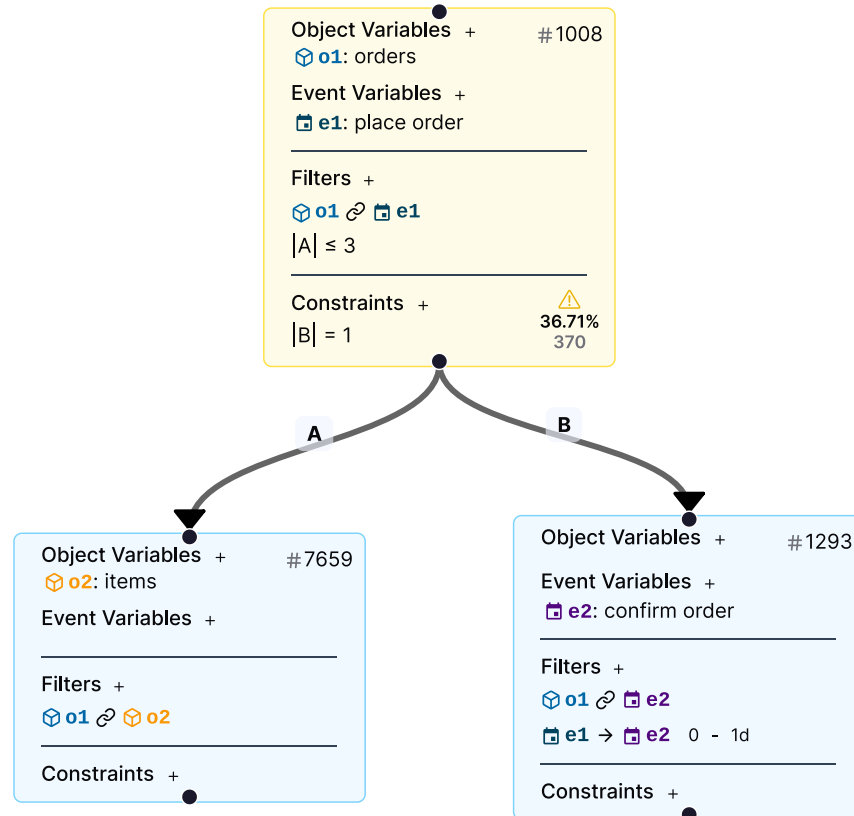
Filters +

o1 o2

Constraints +

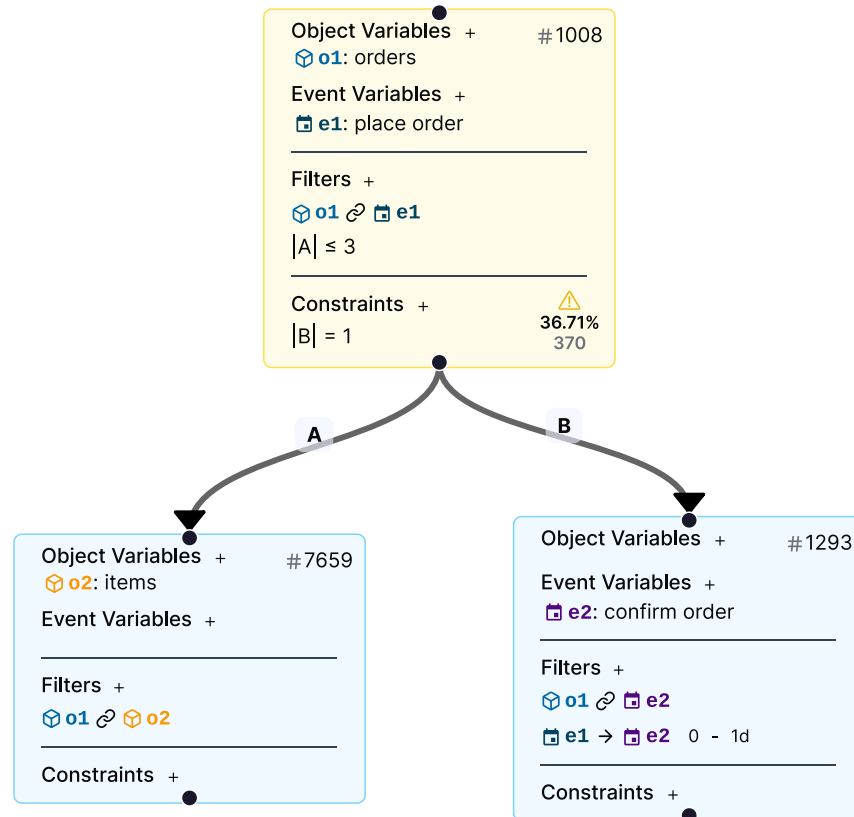
Adding Constraints

"Every placed order with ≤ 3 items should be confirmed within a day"



Adding Constraints

"Every placed order with ≤ 3 items should be confirmed within a day"



Output Bindings

1008 Bindings
370 Violations

o1	e1	Violation
Search...	Search...	☐ any
o-990001	place_o-990001	☒ $ B = 1$
o-990002	place_o-990002	☐
o-990011	place_o-990011	☒ $ B = 1$
o-990014	place_o-990014	☒ $ B = 1$
o-990015	place_o-990015	☒ $ B = 1$
o-990019	place_o-990019	☐
o-990020	place_o-990020	☐
o-990021	place_o-990021	☐
o-990024	place_o-990024	☒ $ B = 1$
o-990025	place_o-990025	☐

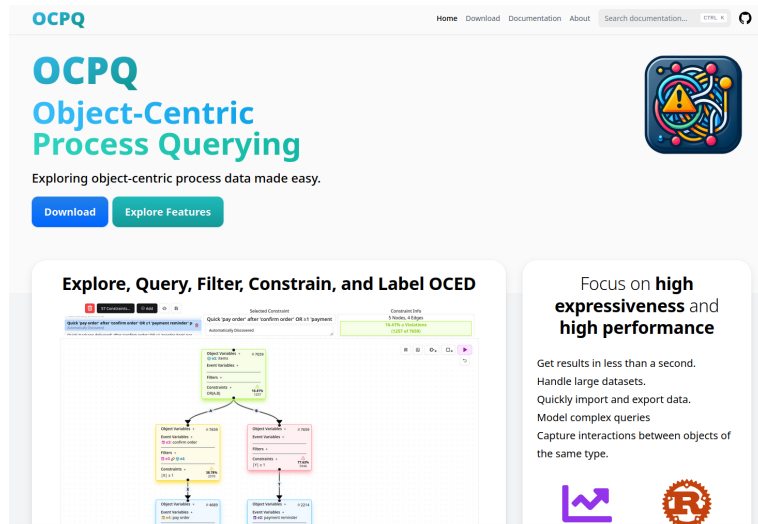
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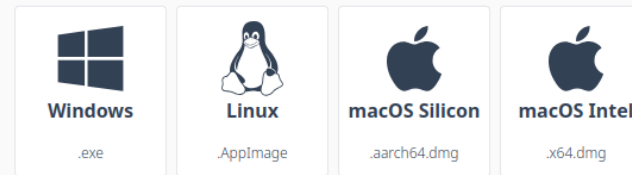
OCPQ Tool

- <https://ocpq.aarkue.eu/>
- <https://github.com/aarkue/OCPQ>
- Installer (Desktop App), Docker (Web App)



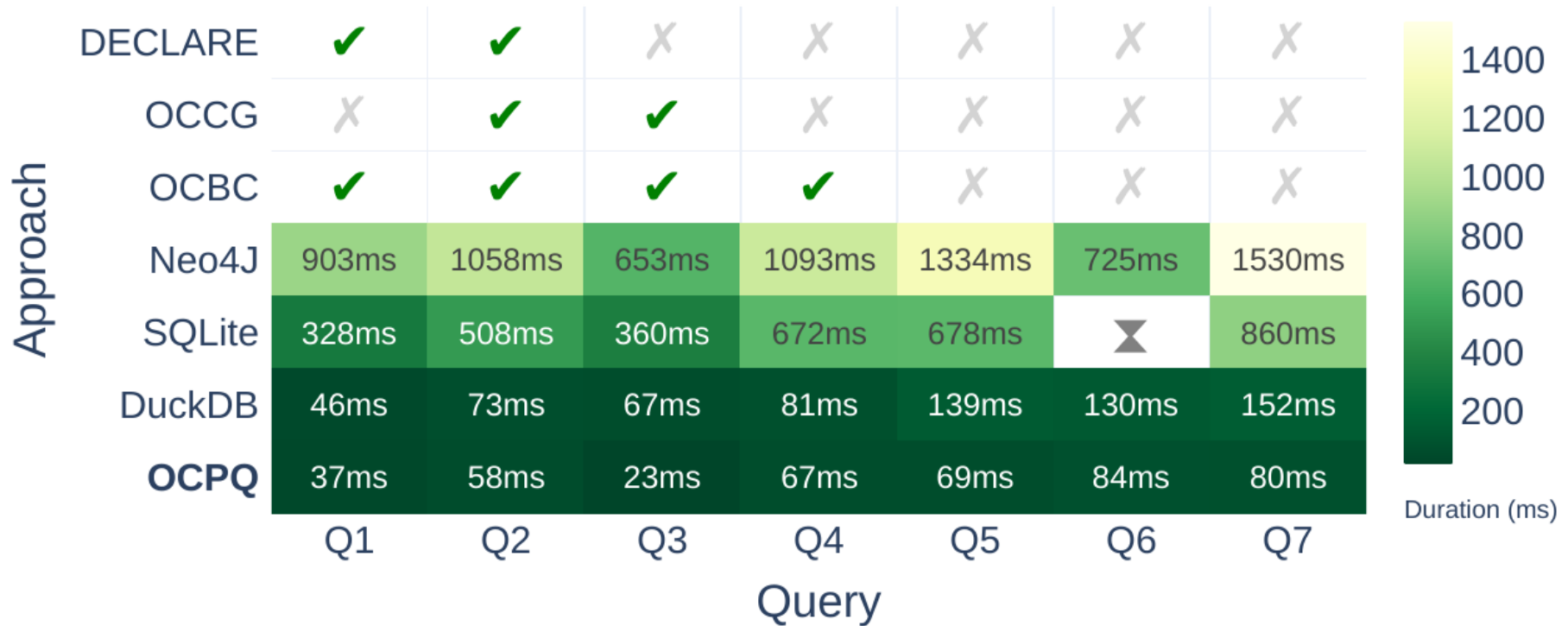
Download

You can download and install the current version **v0.7.5** using the installer links below.



See <https://github.com/aarkue/OCPQ/releases> for more releases and installer versions.

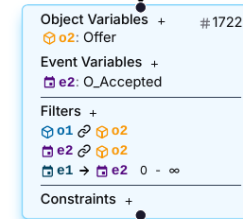
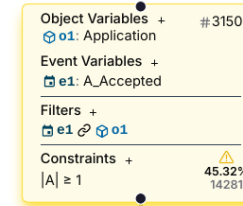
Qualitative & Quantiative Evaluation



OCPQ vs SQL & Cypher

? Query Q4

After an *Application* was accepted, there should be at least one associated *Offer* accepted afterwards.



(a) Q4 in OCPQ

```
WITH
  AcceptedOffers AS (
    SELECT DISTINCT
      O2O.ocel_source_id,
      E2.ocel_id,
      E2.ocel_time
    FROM
      object_object AS O2O
      INNER JOIN object_offer AS A2 ON O2O.ocel_target_id = A2.ocel_id
      INNER JOIN event_object AS E2O2 ON E2O2.ocel_object_id = A2.ocel_id
      INNER JOIN event_O_Accepted AS E2 ON E2O2.ocel_event_id = E2.ocel_id
  )
SELECT
  A1.ocel_id,
  E1.ocel_id,
  (
    SELECT
      COUNT(*)
    FROM
      AcceptedOffers AS AO
    WHERE
      AO.ocel_source_id = A1.ocel_id
      AND AO.ocel_source_id = A1.ocel_id
      AND E1.ocel_time <= AO.ocel_time
  ) >= 1 AS satisfied
FROM
  object_Application AS A1
  INNER JOIN event_object AS E2O ON E2O.ocel_object_id = A1.ocel_id
  INNER JOIN event_A_Accepted AS E1 ON E2O.ocel_event_id = E1.ocel_id;
```

(b) Q4 in SQL

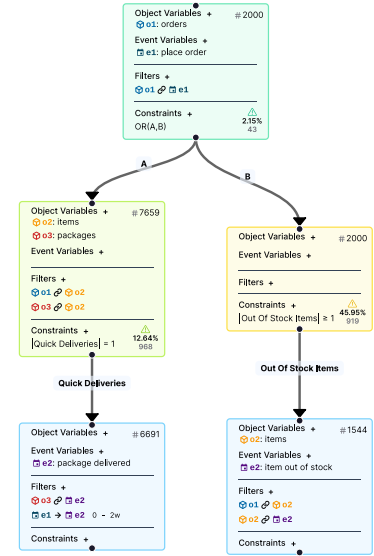
```
MATCH (o1:Entity { EntityType: "Application" }) <-[:CORR]- (e1:Event {Activity:
  <- "A_Accepted"})
OPTIONAL MATCH (e2:Event { Activity: "O_Accepted" }) -[:CORR]-> (o2:Entity {EntityType:
  <- "Offer"}) -[:REL]-> (o1)
WHERE e1.timestamp <= e2.timestamp
WITH o1, COUNT(e2) AS e2_c, COUNT(o2) AS o2_c
WHERE e2_c < 1 OR o2_c < 1
RETURN COUNT(o1) AS violationCount
```

(c) Q4 in Cypher (violation count only)

Fig. 8. Constraint Q4 formulated in OCPQ, SQL, and Cypher.

Conclusion

- **OCPQ Approach & Tool**
- Beyond "*multi-object*", to full object-centricity
- Modeling Nested **Queries & Constraints**
 - High Expressiveness
 - Easy-to-use
 - Fully-featured & efficient tool implementation



Outlook & Future Work



✓ OCPQ for **Filtering** OCED



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✓ **Extensions** of binding-based approach
→ General annotations (e.g., KPI)



⌚ **Interoperatability** with existing databases



⌚ **Usability** Analysis & User Study



⌚ **Case Study** showing real-life business usage

Annotated Output Table of Root Node

o1	orderVolume	customerClass
<i>o</i> ₁	400	silver
<i>o</i> ₂	800	gold
<i>o</i> ₃	600	silver
<i>o</i> ₄	200	bronze

```
A.map(b, b['o2'].attr('price')).sum()
```

CEL program for orderVolume

```
orderVolume < 300 ? 'bronze' :  
(orderVolume < 800 ? 'silver' : 'gold')
```

CEL program for customerClass.

Thanks!

References

- Esser, S., and Fahland, D. (2021). Multi-Dimensional Event Data in Graph Databases. *J. Data Semant.* 10, 109–141. doi: 10.1007/S13740-021-00122-1
- Hildebrandt, T. T., and Mukkamala, R. R. (2010). Declarative Event-Based Workflow as Distributed Dynamic Condition Response Graphs., in *Proceedings Third Workshop on Programming Language Approaches to Concurrency and Communication-cEntric Software, PLACES 2010, Paphos, Cyprus, 21st March 2010*, eds.K. Honda and A. Mycroft, 59–73. doi: 10.4204/EPTCS.69.5
- Li, T., Park, G., and van der Aalst, W. M. P. (2023). Checking Constraints for Object-Centric Process Executions., in *Process Mining Workshops - ICPM 2023 International Workshops, Rome, Italy, October 23-27, 2023, Revised Selected Papers*, eds.J. D. Smedt and P. Soffer (Springer), 392–405. doi: 10.1007/978-3-031-56107-8_30
- Park, G., and van der Aalst, W. M. P. (2022). Monitoring Constraints in Business Processes Using Object-Centric Constraint Graphs., in *Process Mining Workshops - ICPM 2022 International Workshops, Bozen-Bolzano, Italy, October 23-28, 2022, Revised Selected Papers*, eds.M. Montali, A. Senderovich, and M. Weidlich (Springer), 479–492. doi: 10.1007/978-3-031-27815-0_35
- Pesic, M., Schonenberg, H., and van der Aalst, W. M. P. (2007). DECLARE: Full Support for Loosely-Structured Processes., in *11th IEEE International Enterprise Distributed Object Computing Conference (EDOC 2007), 15-19 October 2007, Annapolis, Maryland, USA*, (IEEE Computer Society), 287–300. doi: 10.1109/EDOC.2007.14