Process Mining Summer School, Aachen, 4-8 July 2022

#pmschool22

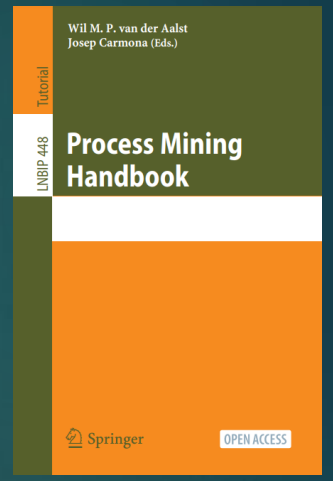
Introduction to Process Mining

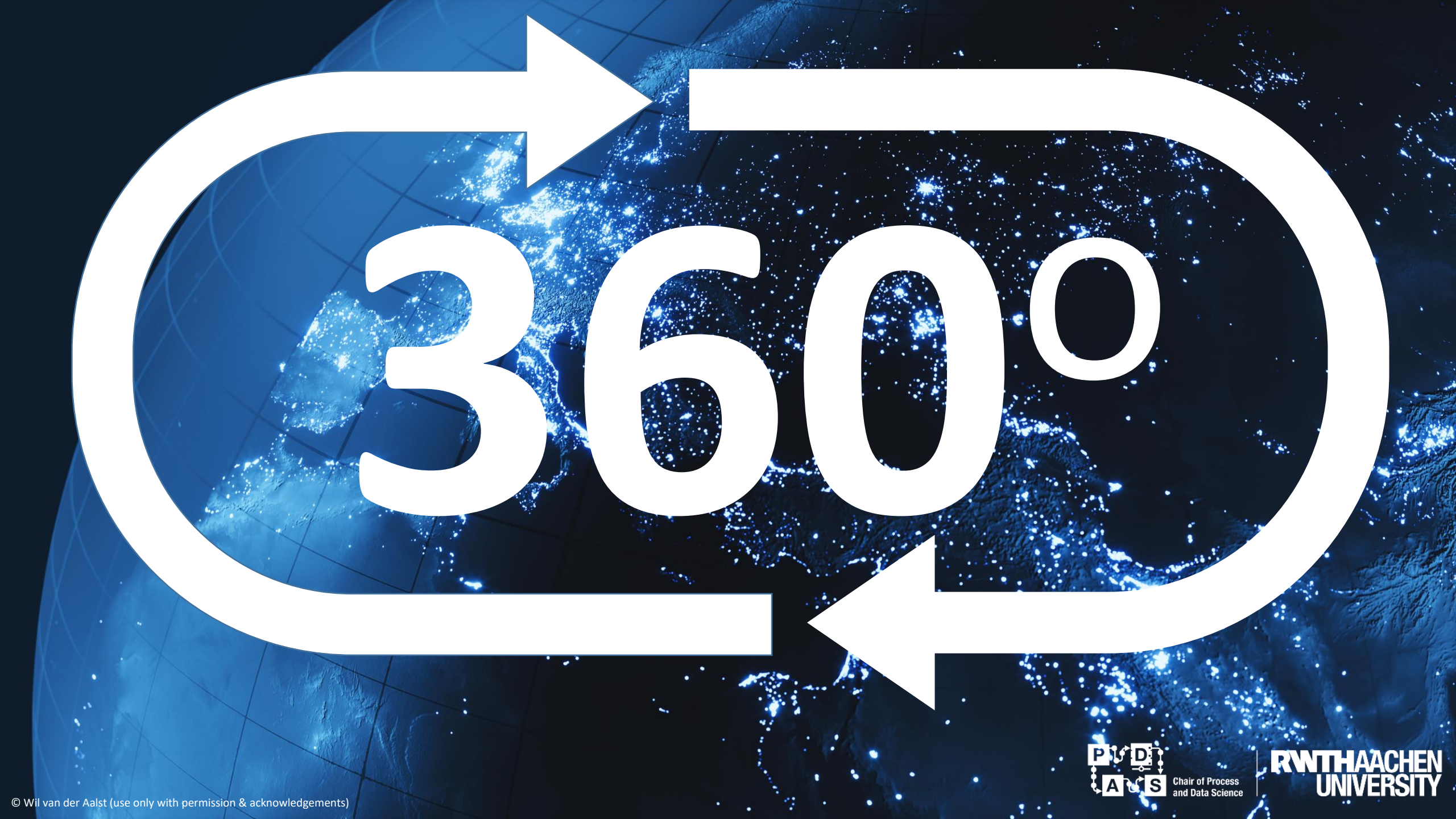
A 360 Degree Overview

WIL VAN DER AALST

PROCESS AND DATA SCIENCE @ RWTH AACHEN UNIVERSITY & CELONIS

www.vdaalst.com, @wvdaalst





Chair of Process and Data Science

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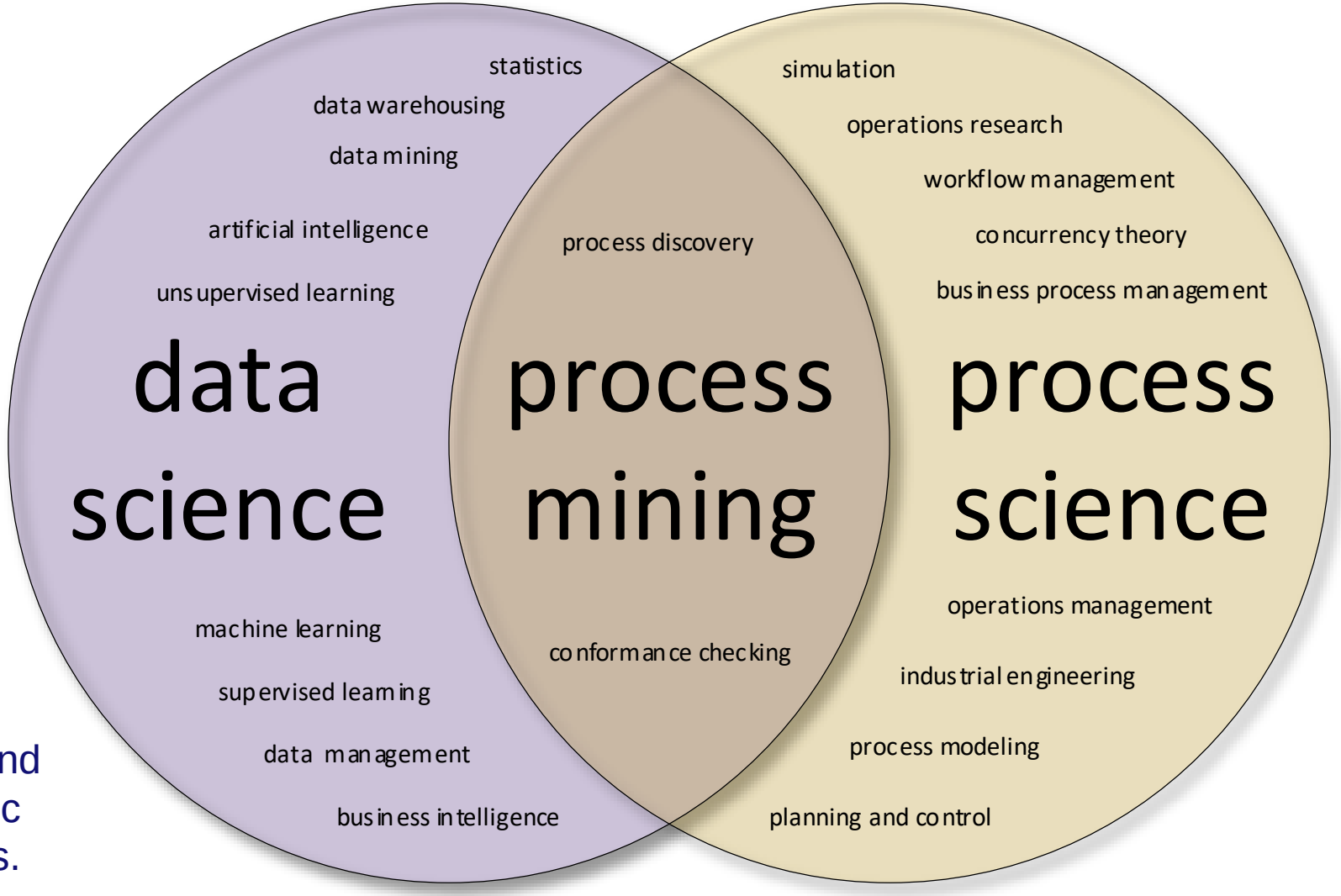
Connecting data and process science



Traditionally, not data-driven and a focus on modeling (languages) and automation.

Traditionally, not process-centric and a focus on specific tasks or decisions.

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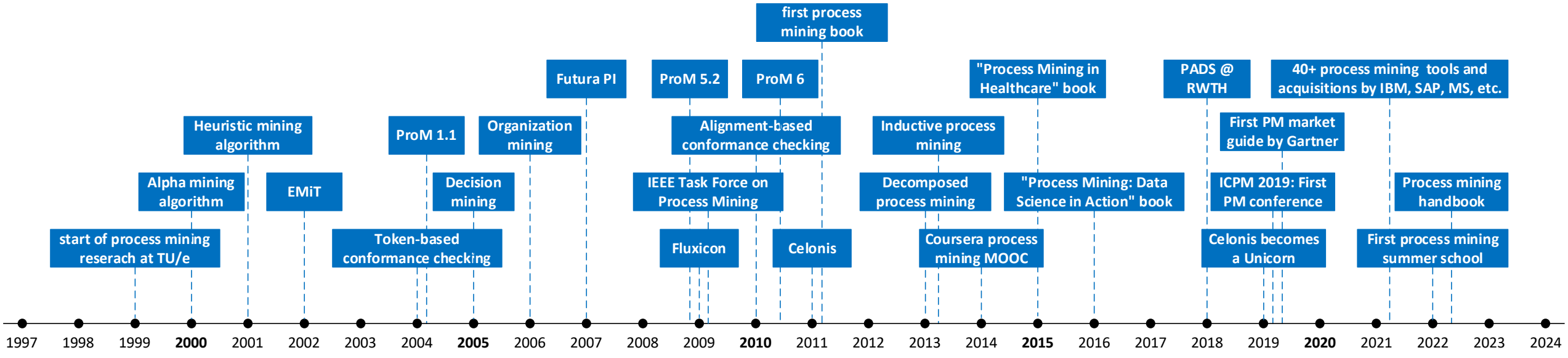
Timeline of Process Mining



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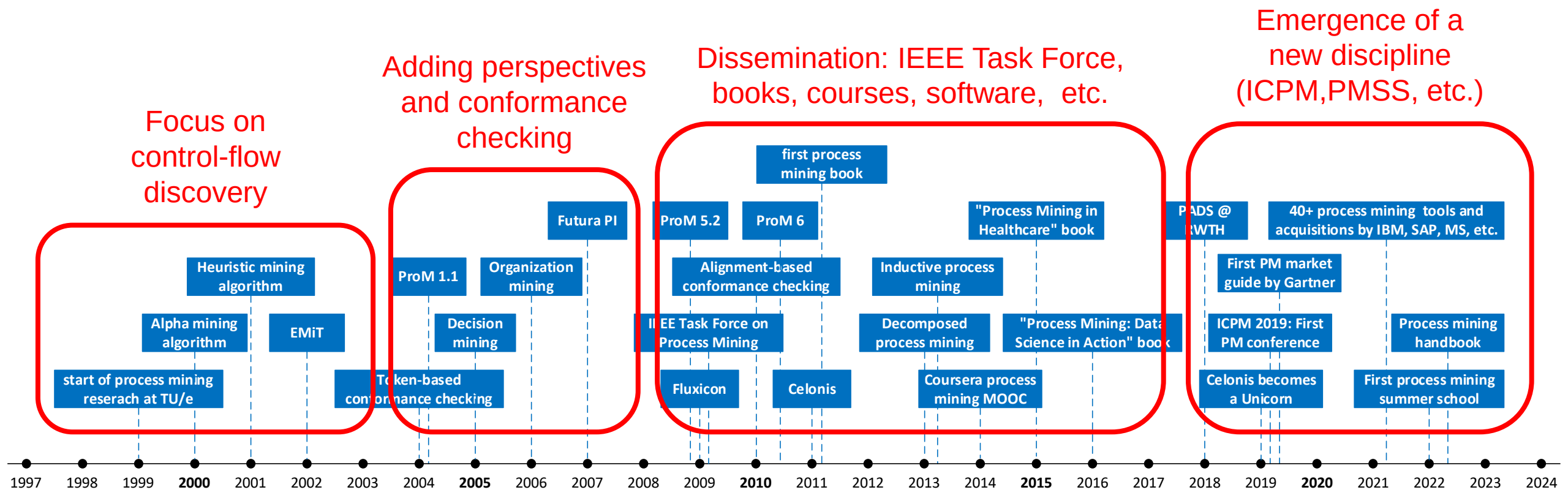
Timeline of Process Mining



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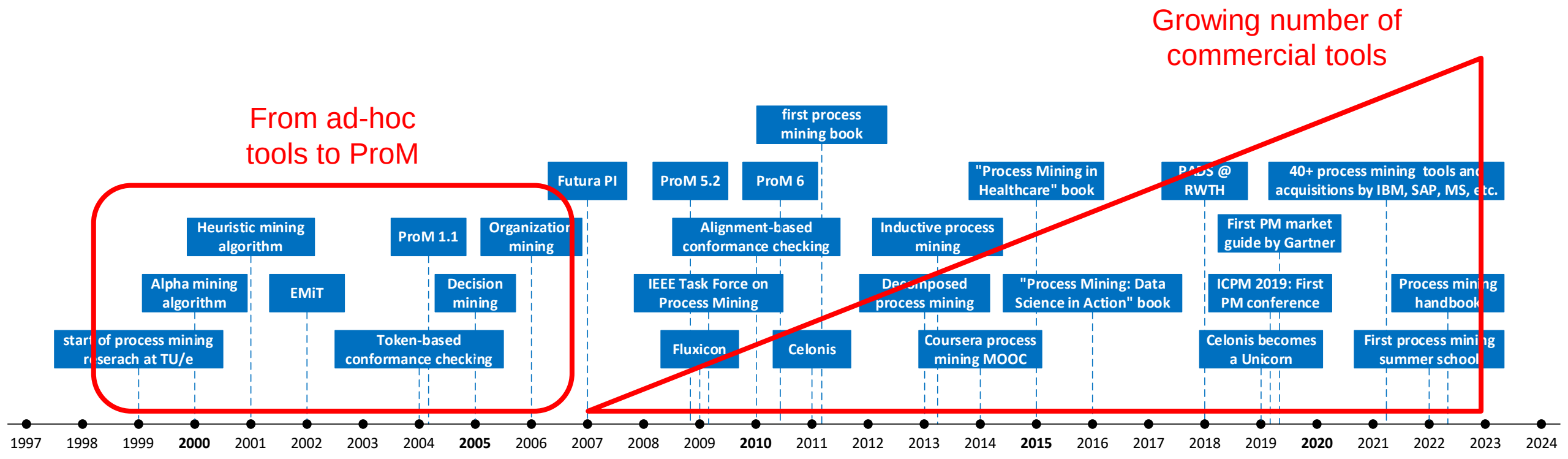
Timeline of Process Mining



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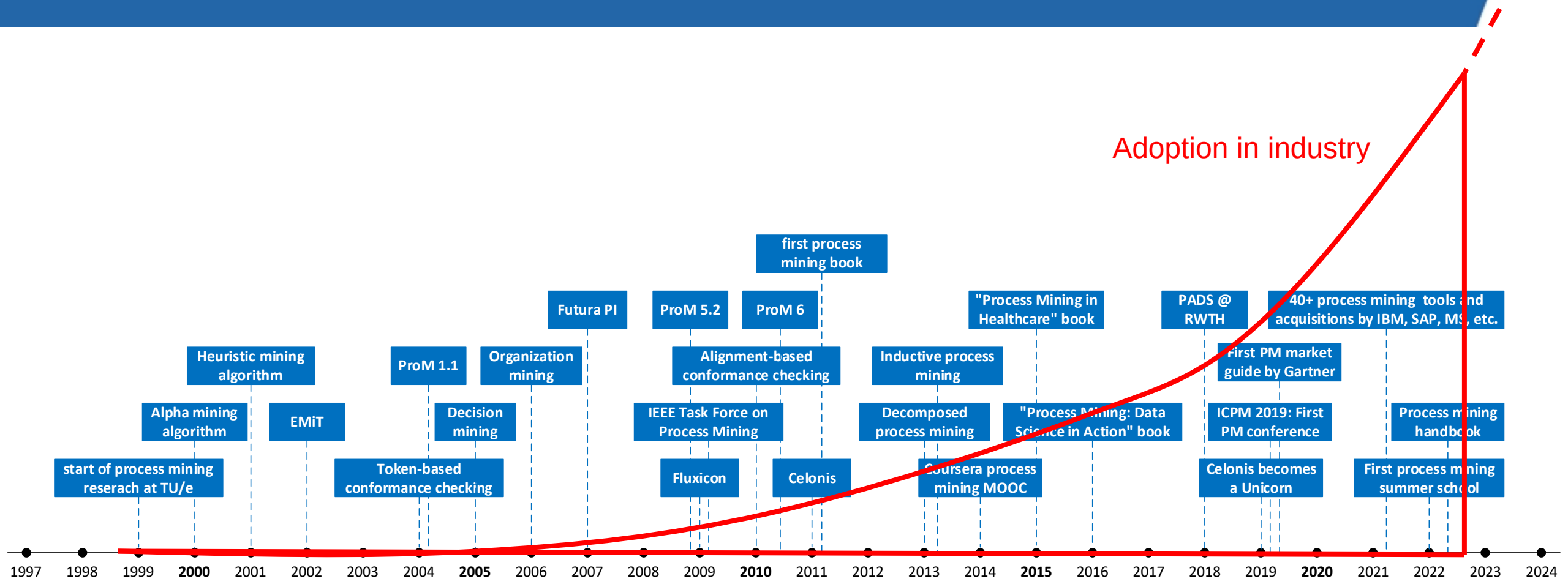
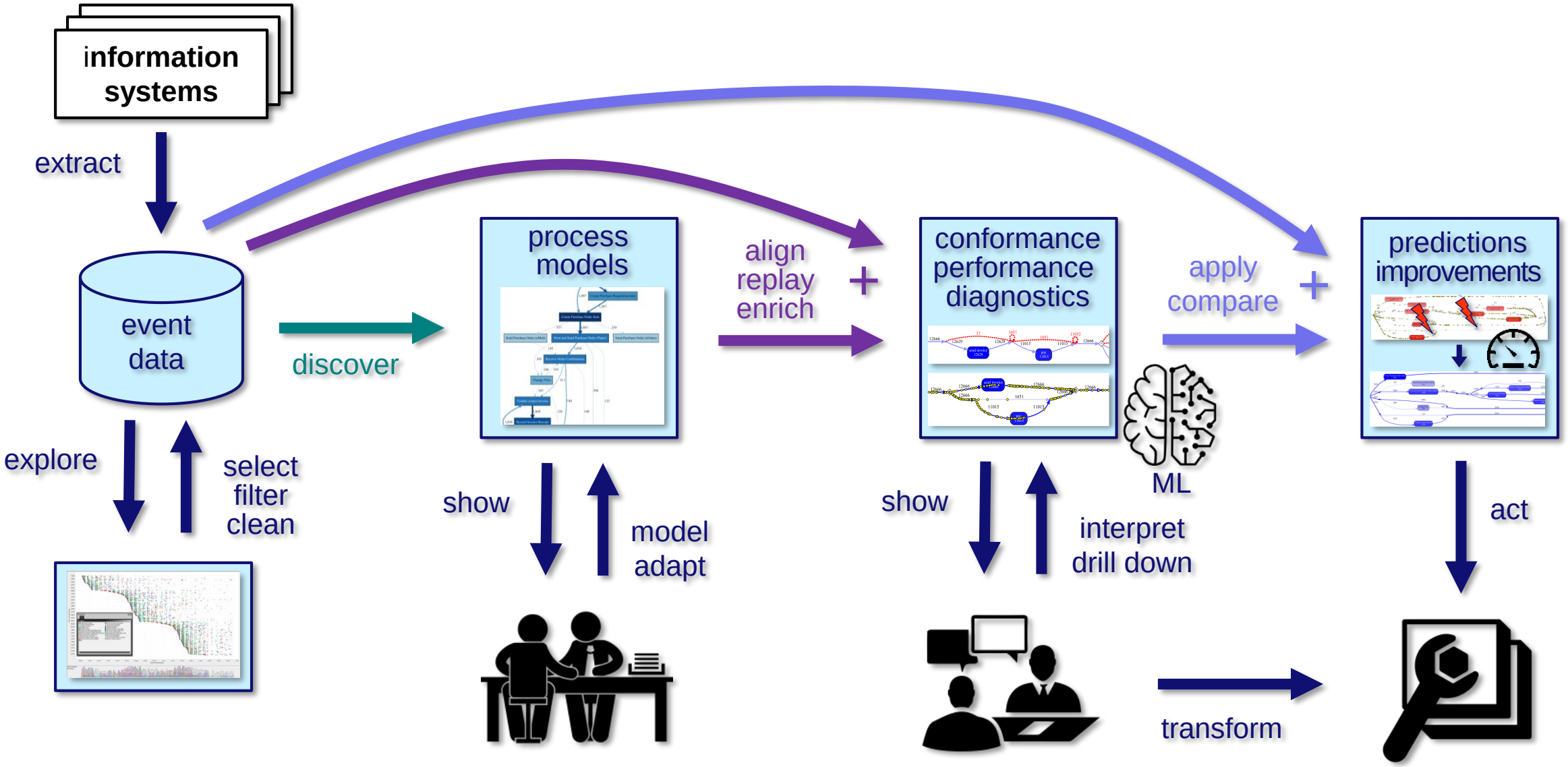
Timeline of Process Mining



Chair of Process and Data Science



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Chair of Process and Data Science

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Starting point: Event data

Case ID	Activity	Resource	Timestamp	product	prod-price	quantity	address
…	…	….	…	….	…	…	…
6350	place order	Aiden	2018/02/13 14:29:45.000	APPLE iPhone 6 16 GB	639,00 €	5	NL-7751DG-21
6283	pay	Lily	2018/02/13 14:39:25.000	SAMSUNG Galaxy S6 32 GB	543.99	3	NL-7828AM-11a
6253	prepare delivery	Sophia	2018/02/13 15:01:33.000	APPLE iPhone 6 16 GB	639,00 €	3	NL-7887AC-13
6257	prepare delivery	Aiden	2018/02/13 15:03:43.000	SAMSUNG Galaxy S6 32 GB	543.99	1	NL-9521KJ-34
6185	confirm payment	Emily	2018/02/13 15:05:36.000	SAMSUNG Galaxy S4	329,00 €	1	NL-9521GC-32
6218	confirm payment	Emily	2018/02/13 15:08:11.000	APPLE iPhone 6s Plus 64 GB	969,00 €	2	NL-7948BX-10
6245	make delivery	Michael	2018/02/13 15:14:04.000	APPLE iPhone 6 16 GB	639,00 €	3	NL-7905AX-38
6272	pay	Emily	2018/02/13 15:20:36.000	APPLE iPhone 6 16 GB	639,00 €	1	NL-7821AC-3
6269	pay	Charlotte	2018/02/13 15:25:21.000	SAMSUNG Galaxy S4	329,00 €	1	NL-7907EJ-42
6212	prepare delivery	Sophia	2018/02/13 15:43:39.000	HUAWEI P8 Lite	234,00 €	1	NL-7905AX-38
6323	send invoice	Alexander	2018/02/13 15:46:08.000	APPLE iPhone 6 16 GB	639,00 €	1	NL-7833HT-15
6246	confirm payment	Jack	2018/02/13 15:56:03.000	SAMSUNG Galaxy S4	329,00 €	3	NL-7833HT-15
6347	send invoice	Jack	2018/02/13 15:57:42.000	SAMSUNG Galaxy S4	329,00 €	3	NL-7905AX-38
6351	place order	Zoe	2018/02/13 16:17:37.000	APPLE iPhone 5s 16 GB	449,00 €	3	NL-9521GC-32
6204	prepare delivery	Sophia	2018/02/13 16:31:28.000	SAMSUNG Core Prime G361	135,00 €	1	NL-7828AM-11a
6204	make delivery	Kaylee	2018/02/13 16:51:54.000	SAMSUNG Core Prime G361	135,00 €	1	NL-7828AM-11a
6265	confirm payment	Lily	2018/02/13 16:55:55.000	SAMSUNG Galaxy S4	329,00 €	4	NL-9521GC-32
6250	confirm payment	Jack	2018/02/13 17:03:26.000	MOTOROLA Moto G	199,00 €	4	NL-7942GT-2
6328	send invoice	Lily	2018/02/13 17:30:16.000	APPLE iPhone 6s 64 GB	858,00 €	4	NL-9514BV-16
6352	place order	Aiden	2018/02/13 17:53:22.000	APPLE iPhone 6 16 GB	639,00 €	2	NL-9514BV-16
6317	send invoice	Jack	2018/02/13 18:45:30.000	APPLE iPhone 6s 64 GB	858,00 €	5	NL-7907EJ-42
6353	place order	Sophia	2018/02/13 20:16:20.000	APPLE iPhone 5s 16 GB	449,00 €	4	NL-7751AR-19
…	…	….	…	…	…	…	…

event

71,043 events
12,666 cases
7 activities

Chair of Process and Data Science

Starting point: Event data

Case ID	Activity	Resource	Timestamp	product	prod-price	quantity	address
…	…	….	…	….	…	…	…
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6204	make delivery	Kaylee	2018/02/13 16:51:54.000	SAMSUNG Core Prime G361	85,00 €	1	NL-7828AM-11a
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6328	send invoice	Lily	2018/02/13 17:30:16.000	APPLE iPhone 6s 64 GB	858,00 €	4	NL-9514BV-16
6352	place order	Aiden	2018/02/13 17:53:22.000	APPLE iPhone 6 16 GB	639,00 €	2	NL-9514BV-16
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6353	place order	Sophia	2018/02/13 20:16:20.000	APPLE iPhone 5s 16 GB	449,00 €	4	NL-7751AR-19
…	…	….	…	…	…	…	…

event = case + activity + timestamp + …

Let’s look at orders 6350, 6351, and 6352

Case ID	Activity	Timestamp
6350	place order	2018/02/13 14:29:45.000
6351	place order	2018/02/13 16:17:37.000
6352	place order	2018/02/13 17:53:22.000
6352	send invoice	2018/02/19 09:20:28.000
6351	send invoice	2018/02/19 16:08:07.000
6350	send invoice	2018/02/21 09:38:16.000
6350	pay	2018/03/02 12:39:37.000
6352	pay	2018/03/05 15:46:47.000
6351	cancel order	2018/03/06 10:17:01.000
6350	prepare delivery	2018/03/07 13:50:35.000
6350	make delivery	2018/03/07 16:41:01.000
6350	confirm payment	2018/03/07 16:53:00.000
6352	prepare delivery	2018/03/07 17:05:59.000
6352	confirm payment	2018/03/07 17:59:55.000
6352	make delivery	2018/03/08 09:54:36.000

Let’s look at orders 6350, 6351, and 6352

Case ID	Activity	Timestamp
6350	**place order**	**2018/02/13 14:29:45.000**
6351	place order	2018/02/13 16:17:37.000
6352	place order	2018/02/13 17:53:22.000
6352	send invoice	2018/02/19 09:20:28.000
6351	send invoice	2018/02/19 16:08:07.000
6350	**send invoice**	**2018/02/21 09:38:16.000**
6350	**pay**	**2018/03/02 12:39:37.000**
6352	pay	2018/03/05 15:46:47.000
6351	cancel order	2018/03/06 10:17:01.000
6350	**prepare delivery**	**2018/03/07 13:50:35.000**
6350	**make delivery**	**2018/03/07 16:41:01.000**
6350	**confirm payment**	**2018/03/07 16:53:00.000**
6352	prepare delivery	2018/03/07 17:05:59.000
6352	confirm payment	2018/03/07 17:59:55.000
6352	make delivery	2018/03/08 09:54:36.000

Order 6350

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Let's look at orders 6350, 6351, and 6352

Case ID	Activity	Timestamp
6350	place order	2018/02/13 14:29:45.000
6351	**place order**	**2018/02/13 16:17:37.000**
6352	place order	2018/02/13 17:53:22.000
6352	send invoice	2018/02/19 09:20:28.000
6351	**send invoice**	**2018/02/19 16:08:07.000**
6350	send invoice	2018/02/21 09:38:16.000
6350	pay	2018/03/02 12:39:37.000
6352	pay	2018/03/05 15:46:47.000
6351	**cancel order**	**2018/03/06 10:17:01.000**
6350	prepare delivery	2018/03/07 13:50:35.000
6350	make delivery	2018/03/07 16:41:01.000
6350	confirm payment	2018/03/07 16:53:00.000
6352	prepare delivery	2018/03/07 17:05:59.000
6352	confirm payment	2018/03/07 17:59:55.000
6352	make delivery	2018/03/08 09:54:36.000

Order 6350

Order 6351

Chair of Process and Data Science

Let's look at orders 6350, 6351, and 6352

Case ID	Activity	Timestamp
6350	place order	2018/02/13 14:29:45.000
6351	place order	2018/02/13 16:17:37.000
6352	**place order**	**2018/02/13 17:53:22.000**
6352	**send invoice**	**2018/02/19 09:20:28.000**
6351	send invoice	2018/02/19 16:08:07.000
6350	send invoice	2018/02/21 09:38:16.000
6350	pay	2018/03/02 12:39:37.000
6352	**pay**	**2018/03/05 15:46:47.000**
6351	cancel order	2018/03/06 10:17:01.000
6350	prepare delivery	2018/03/07 13:50:35.000
6350	make delivery	2018/03/07 16:41:01.000
6350	confirm payment	2018/03/07 16:53:00.000
6352	**prepare delivery**	**2018/03/07 17:05:59.000**
6352	**confirm payment**	**2018/03/07 17:59:55.000**
6352	**make delivery**	**2018/03/08 09:54:36.000**

Order 6350

Order 6351

Order 6352

Chair of Process and Data Science

Let's look at orders 6350, 6351, and 6352

Case ID	Activity	Timestamp
6350	place order	2018/02/13 14:29:45.000
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6352	pay	2018/03/05 15:46:47.000
6351	cancel order	2018/03/06 10:17:01.000
6350	prepare delivery	2018/03/07 13:50:35.000
6350	make delivery	2018/03/07 16:41:01.000
6350	confirm payment	2018/03/07 16:53:00.000
6352	prepare delivery	2018/03/07 17:05:59.000
6352	confirm payment	2018/03/07 17:59:55.000
6352	make delivery	2018/03/08 09:54:36.000

Order 6350

Order 6351

Order 6352

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Let’s look at the whole event log again

71,043 events
12,666 cases
7 activities

Case ID	Activity	Resource	Timestamp	product	prod-price	quantity	address
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6218	confirm payment	Emily	2018/02/13 15:08:11.000	APPLE iPhone 6s Plus 64 GB	969,00 €	2	NL-7948BX-30
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6269	pay	Charlotte	2018/02/13 15:25:23.000	SAMSUNG Galaxy S4	329,00 €	1	NL-7907IZ-42
6212	prepare delivery	Sophia	2018/02/13 15:43:39.000	HUAWEI P8 Lite	234,00 €	1	NL-7905AX-38
6323	send invoice	Alexander	2018/02/13 15:46:08.000	APPLE iPhone 6 16 GB	639,00 €	1	NL-7833HT-35
6246	confirm payment	Jack	2018/02/13 15:56:03.000	SAMSUNG Galaxy S4	329,00 €	3	NL-7833HT-35
6347	send invoice	Jack	2018/02/13 15:57:42.000	SAMSUNG Galaxy S4	329,00 €	3	NL-7905AX-38
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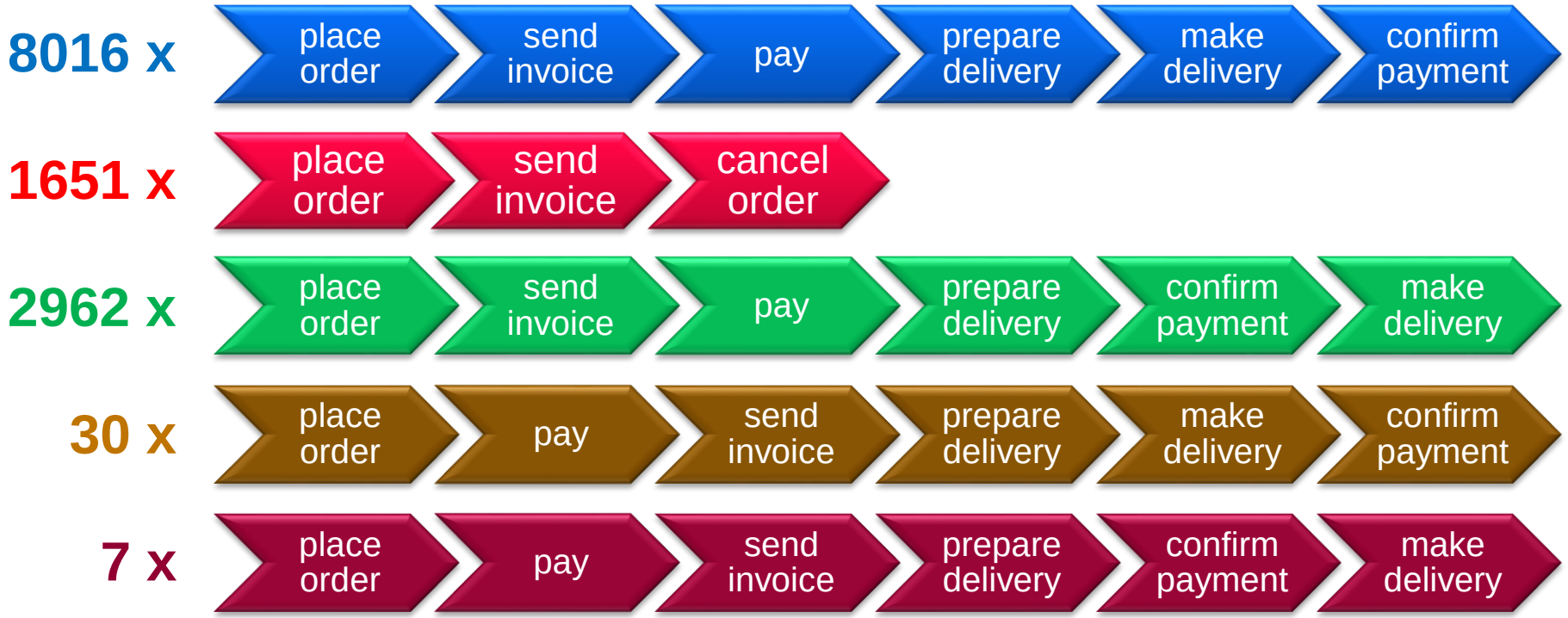

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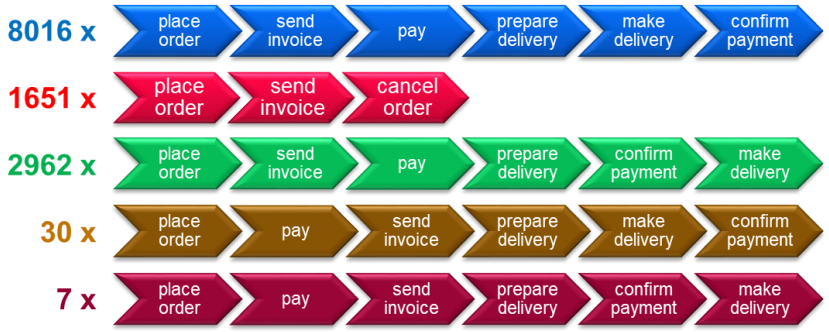
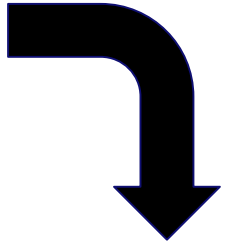
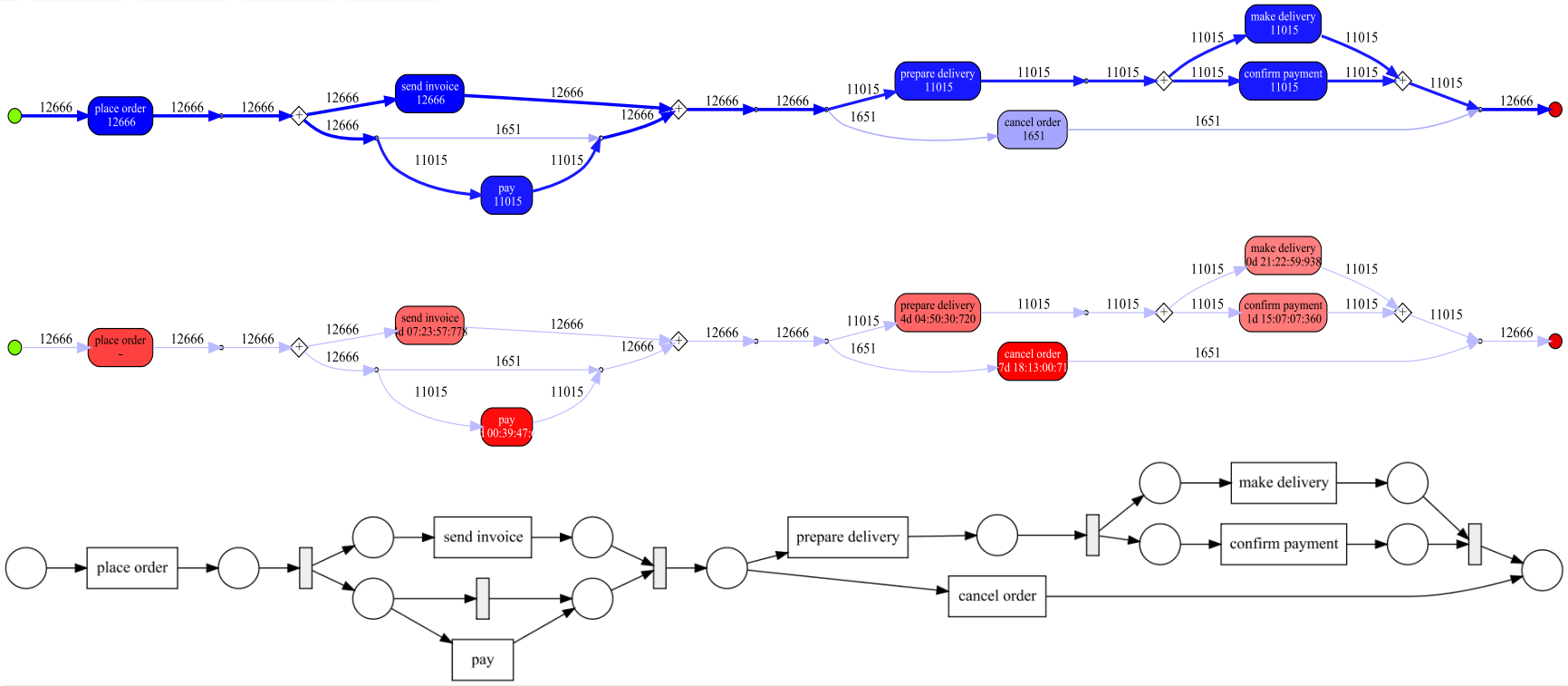
Using the whole event log







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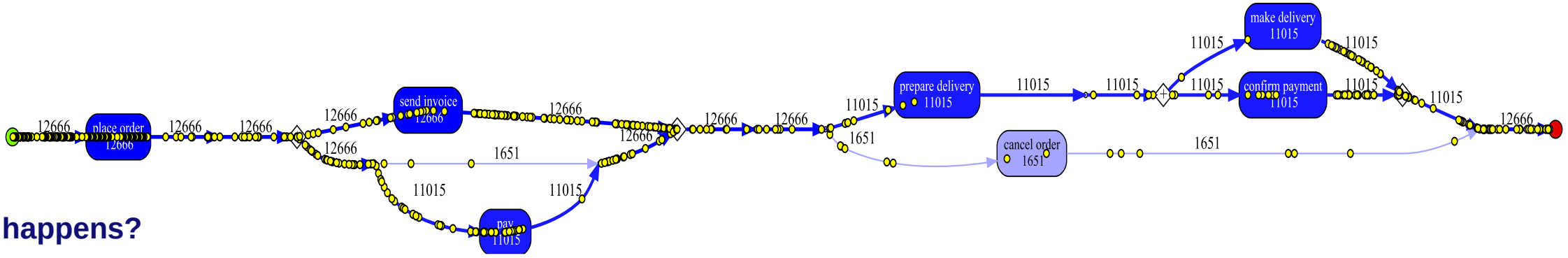
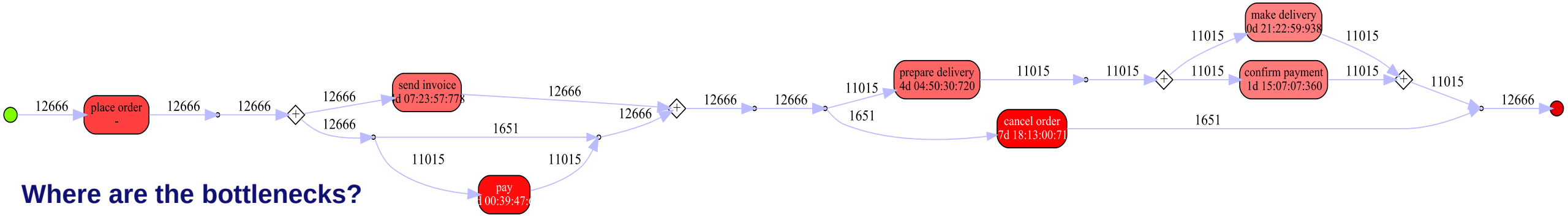
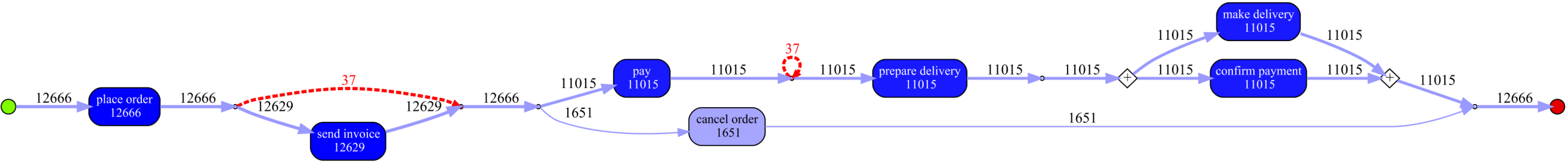
Performance and Compliance



What happens?



Where are the bottlenecks?



Where do we deviate from the happy path?

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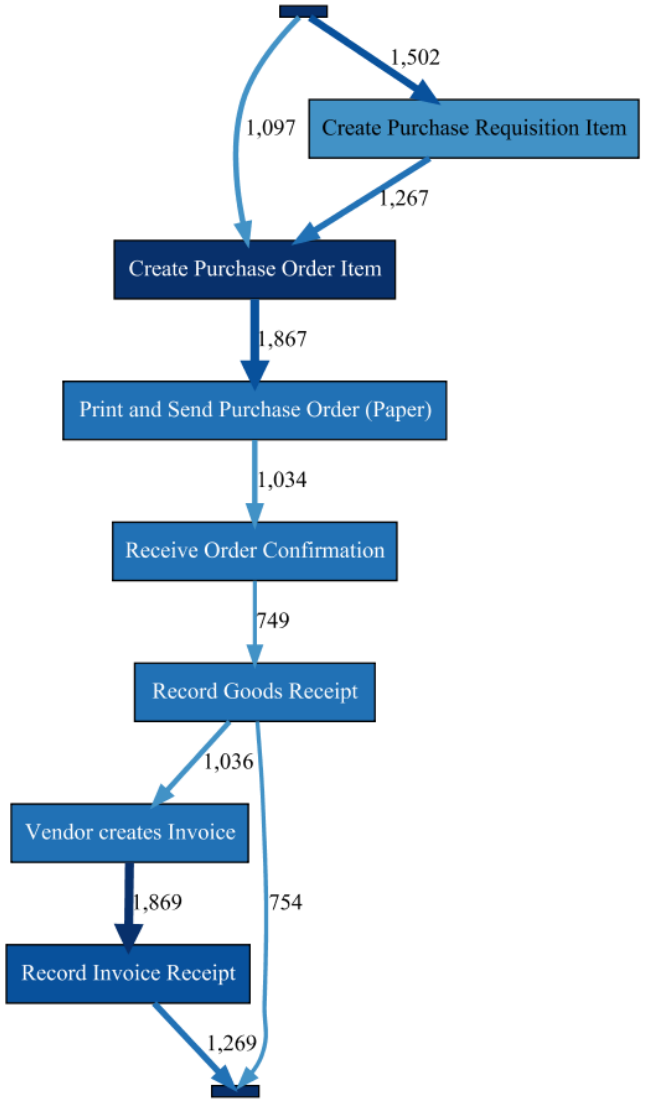
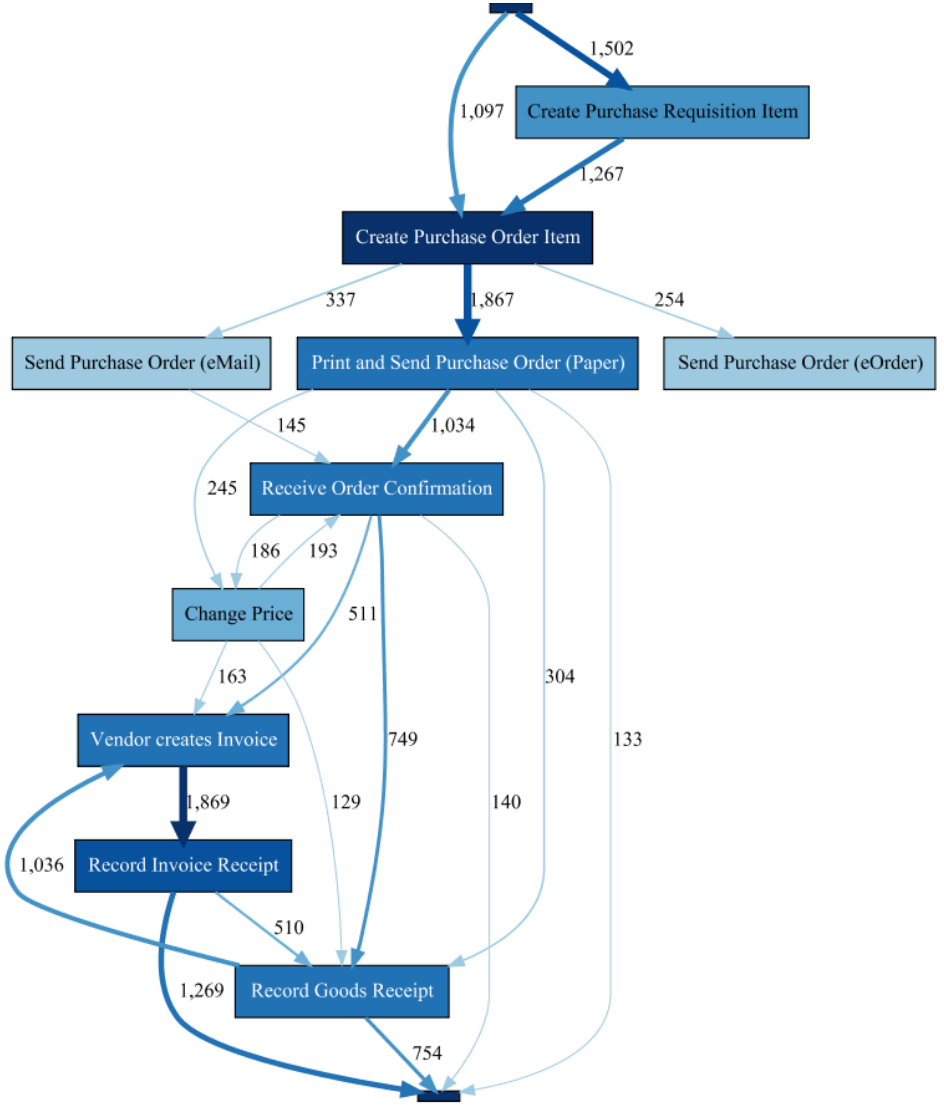
Reality is not so simple





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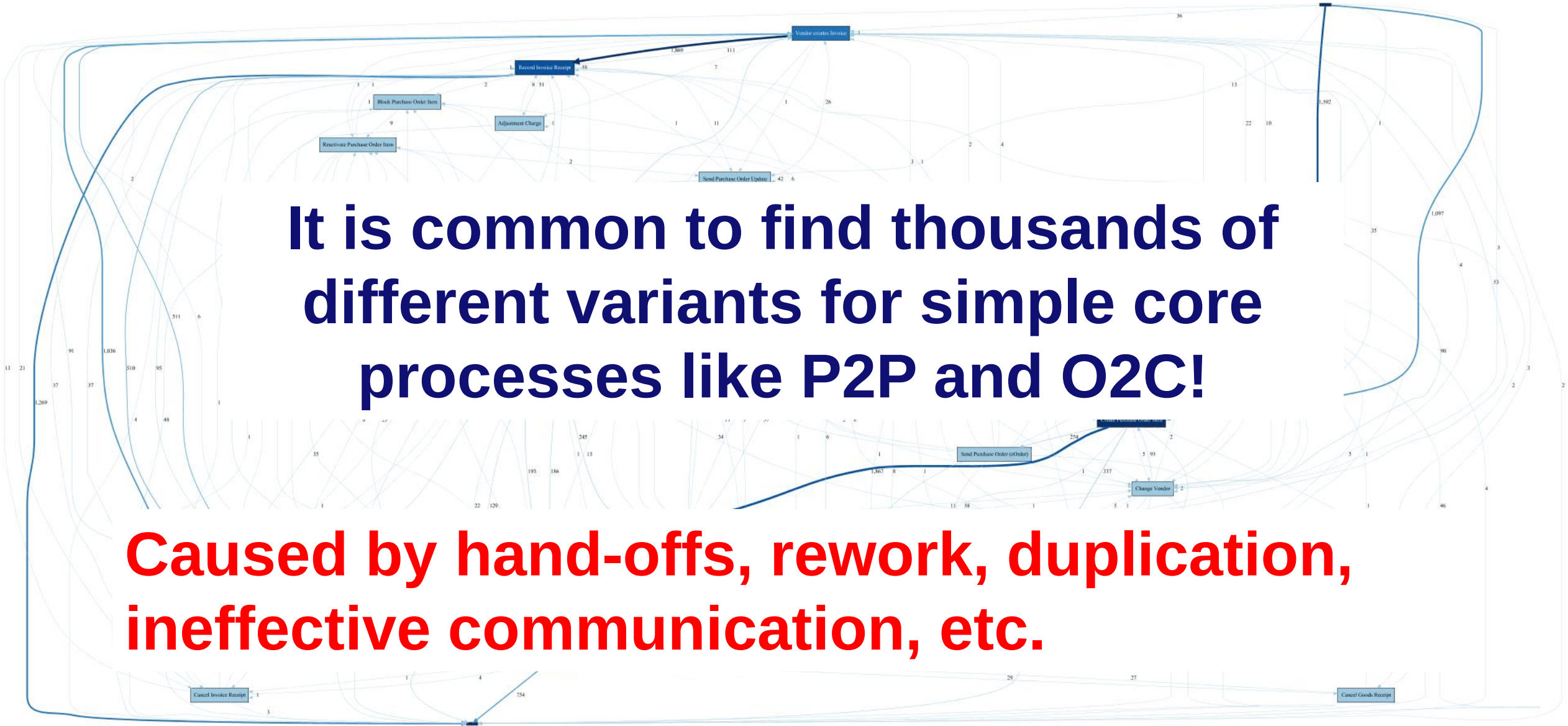
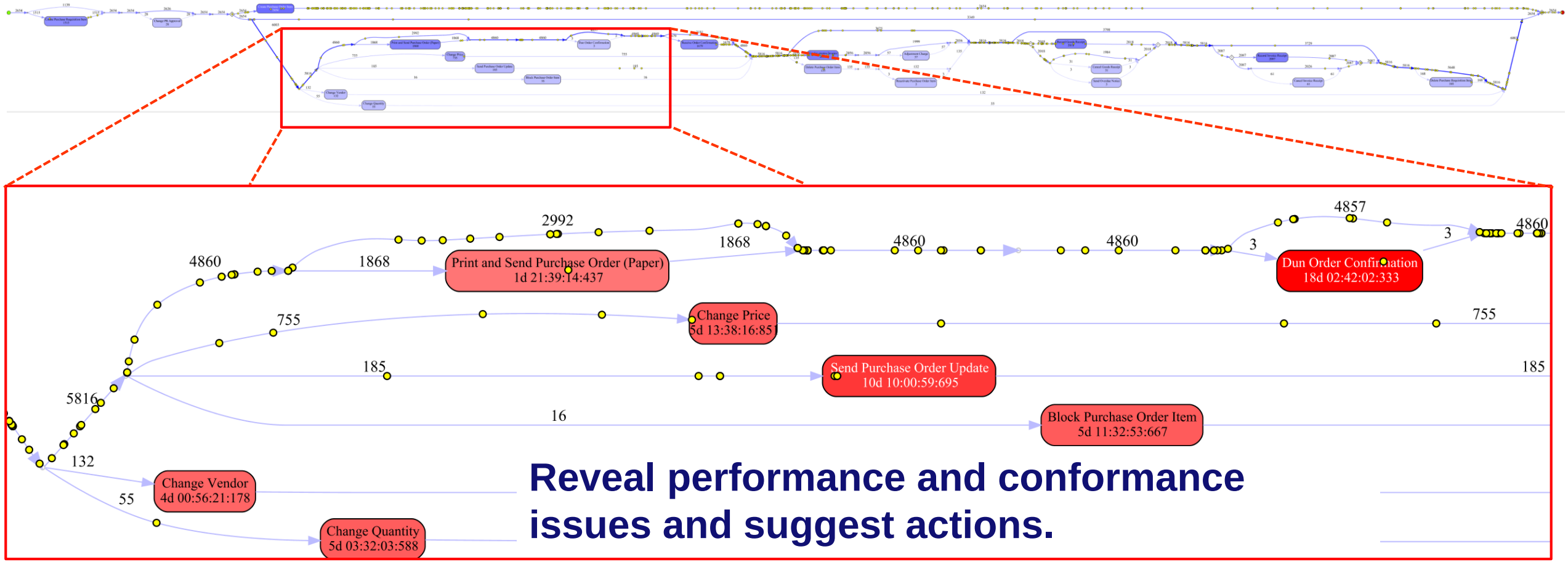
Reality is not so simple



It is common to find thousands of different variants for simple core processes like P2P and O2C!

Caused by hand-offs, rework, duplication, ineffective communication, etc.

Process mining helps organizations to address compliance and performance problems



Reveal performance and conformance issues and suggest actions.

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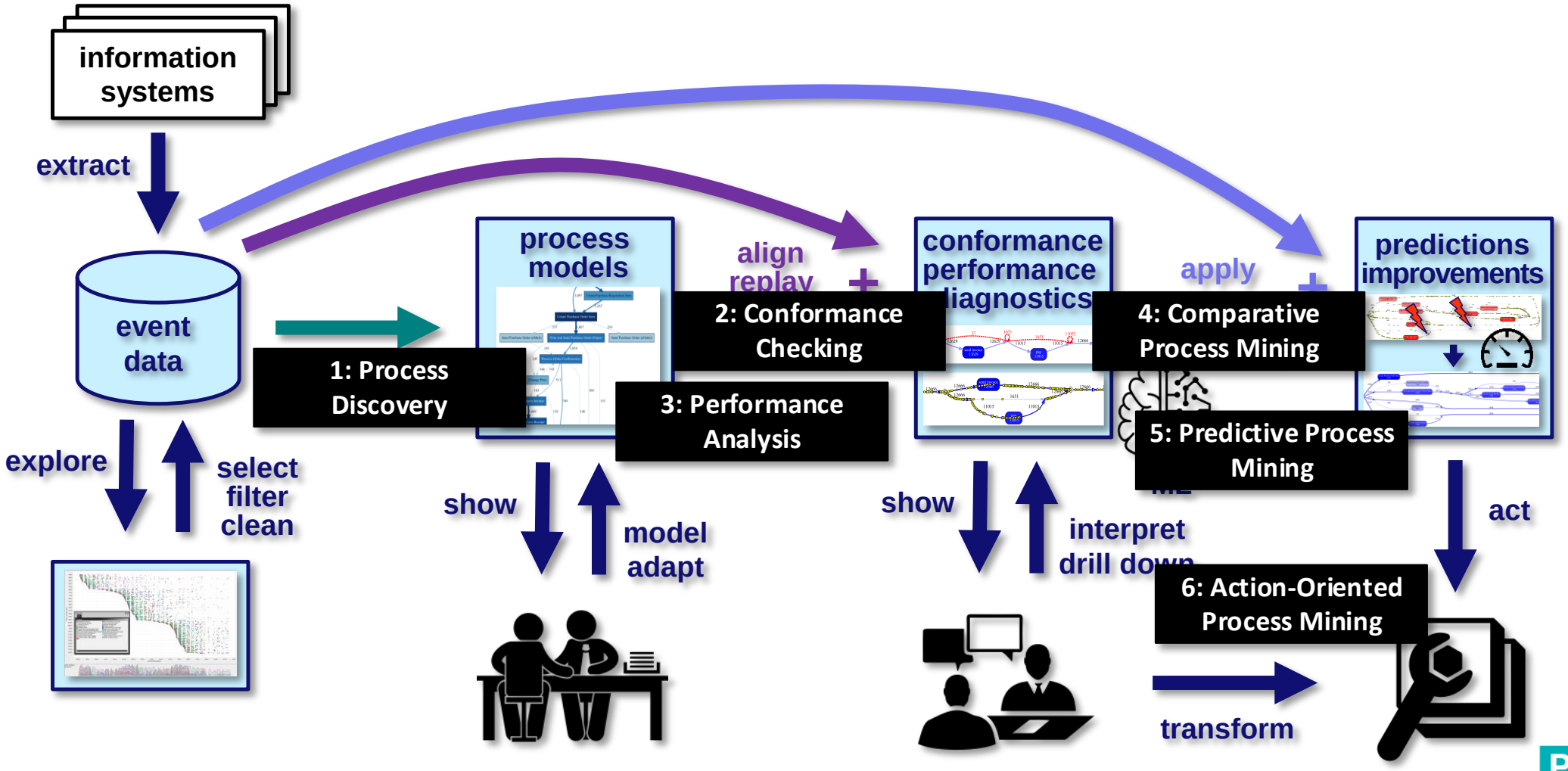
Six types of process mining



Chair of Process and Data Science

To start: Let’s keep it simple!

- For now we focus on control-flow and discovery and (a bit of) conformance checking.
- Later other perspectives and types will follow!
- We start with introducing process models and event logs.

Process Models

(control-flow only)

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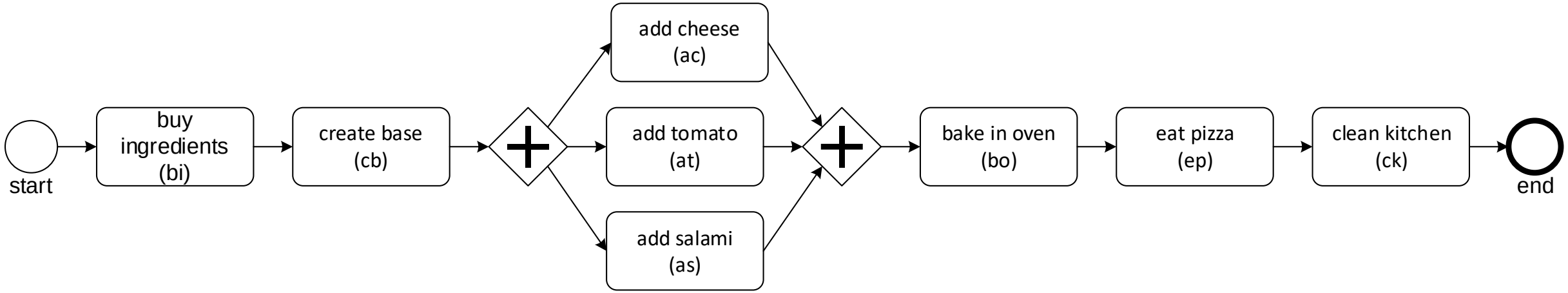
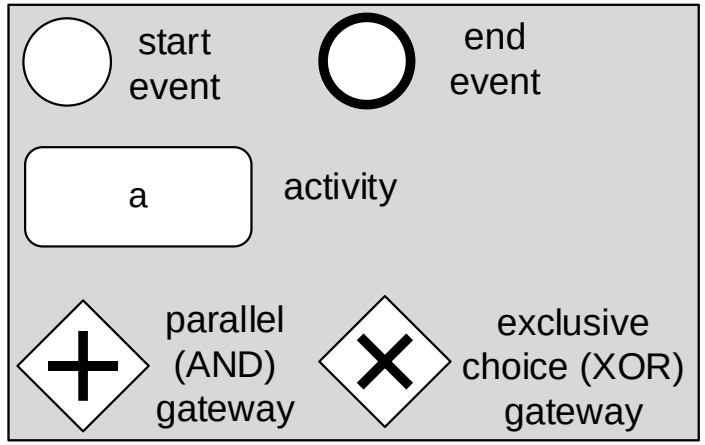
Running example

(yes, process mining is related to Italian food)

A BPMN model

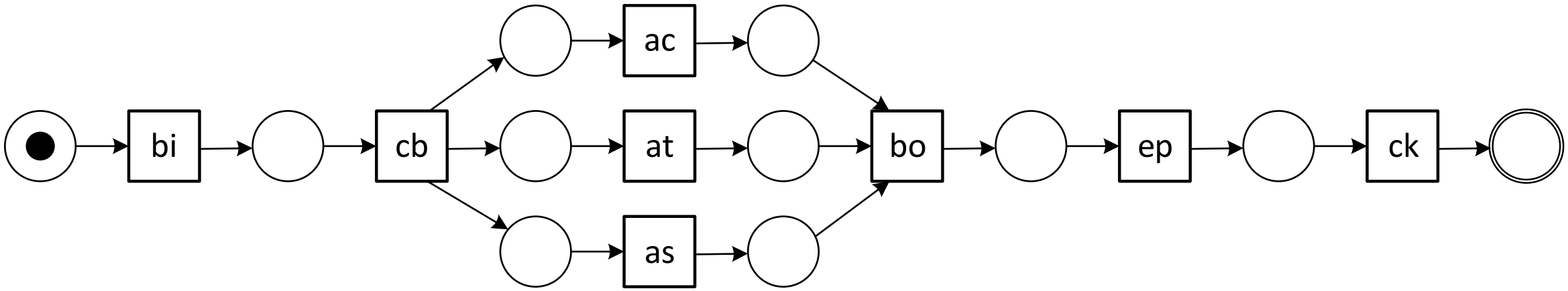


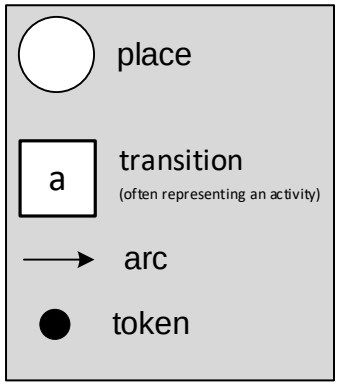


How many possible executions?

Same process now as a Petri net

Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).





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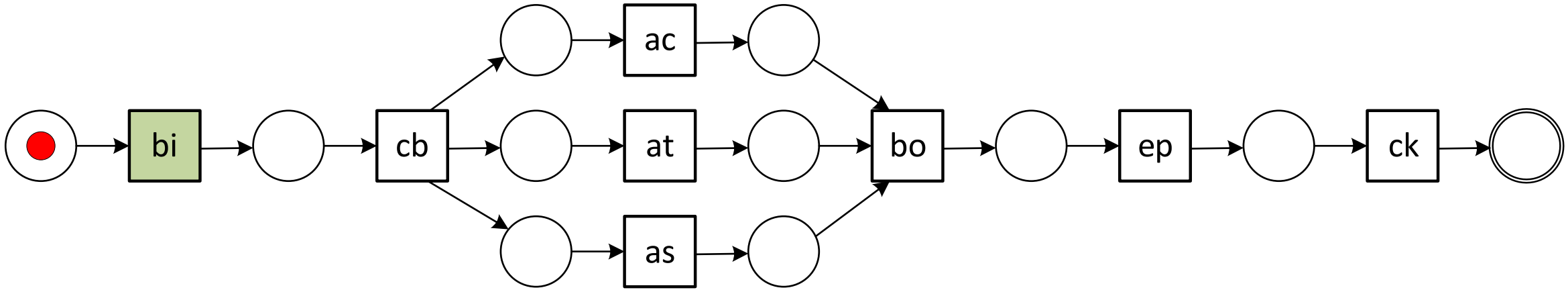
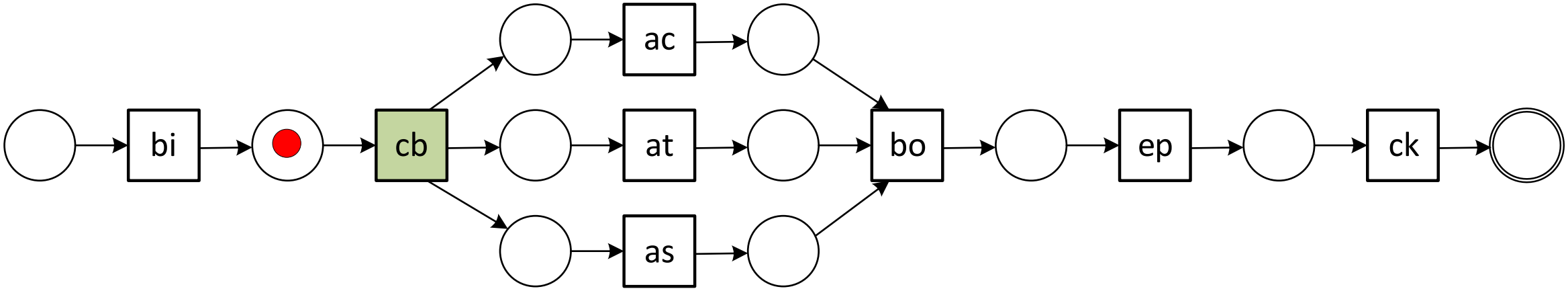
One execution of the Petri net (1/9)



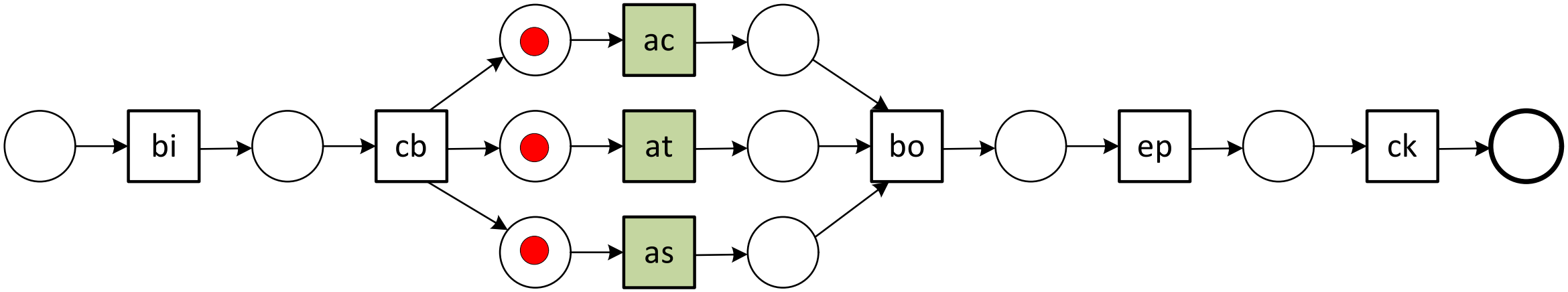
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the Petri net (2/9)



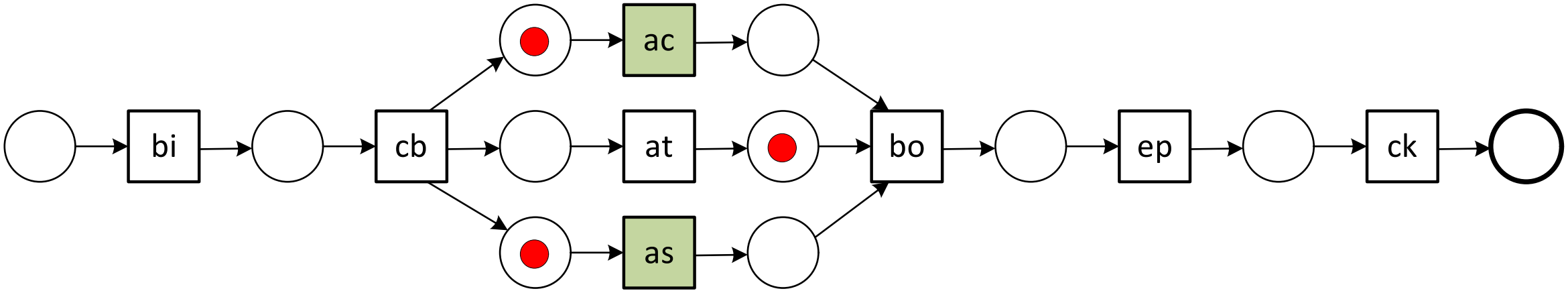
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the Petri net (3/9)



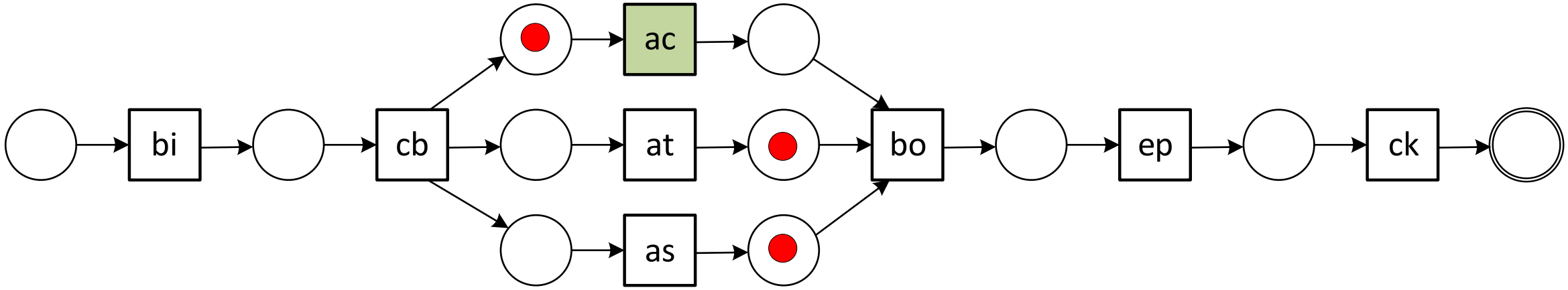
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the Petri net (4/9)



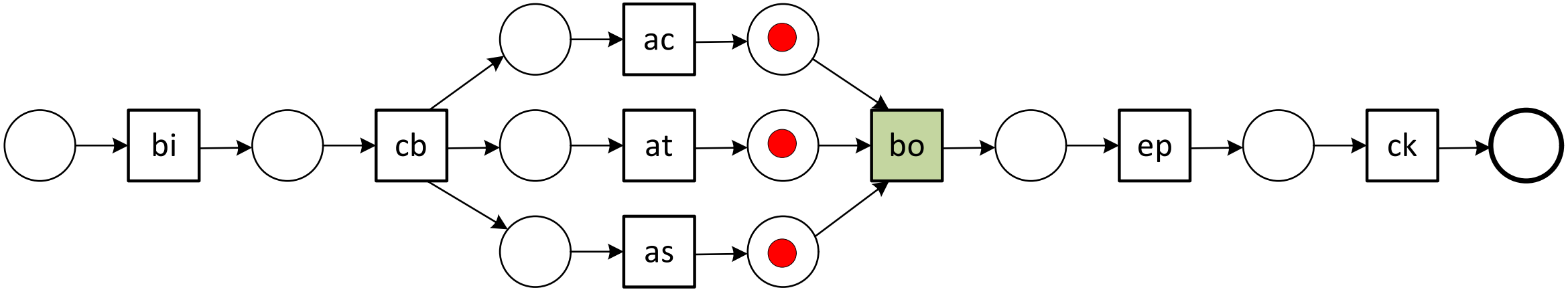
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the Petri net (5/9)



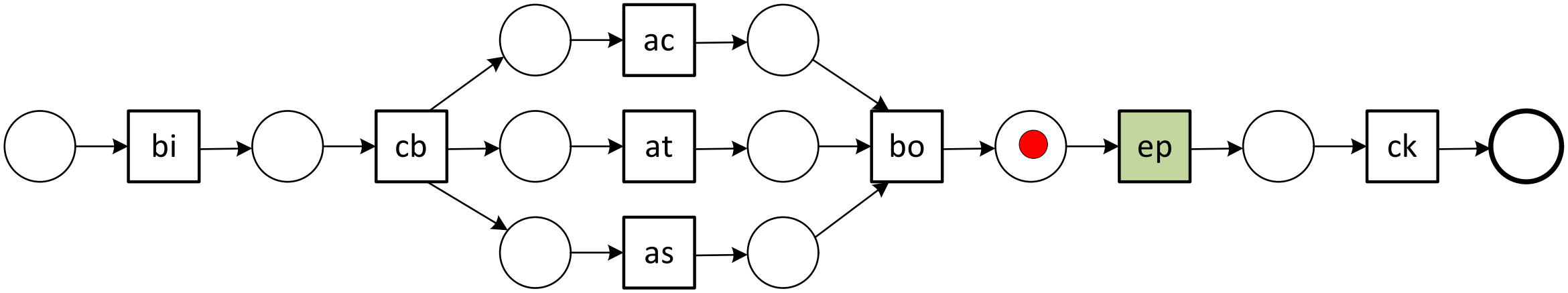
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the Petri net (6/9)



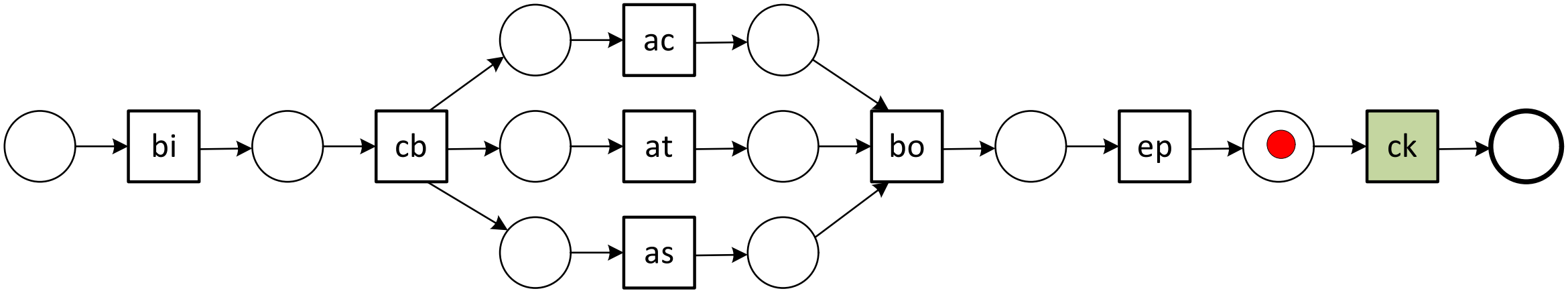
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the Petri net (7/9)



Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the Petri net (8/9)



Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

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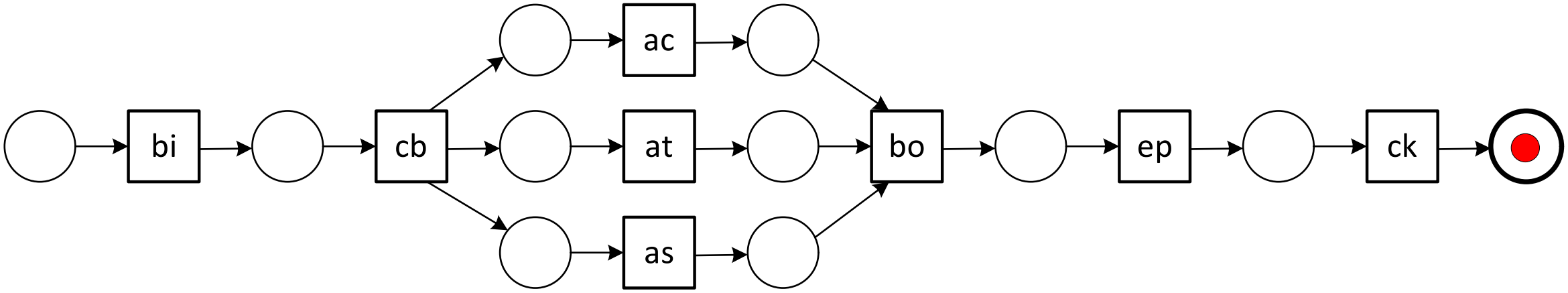
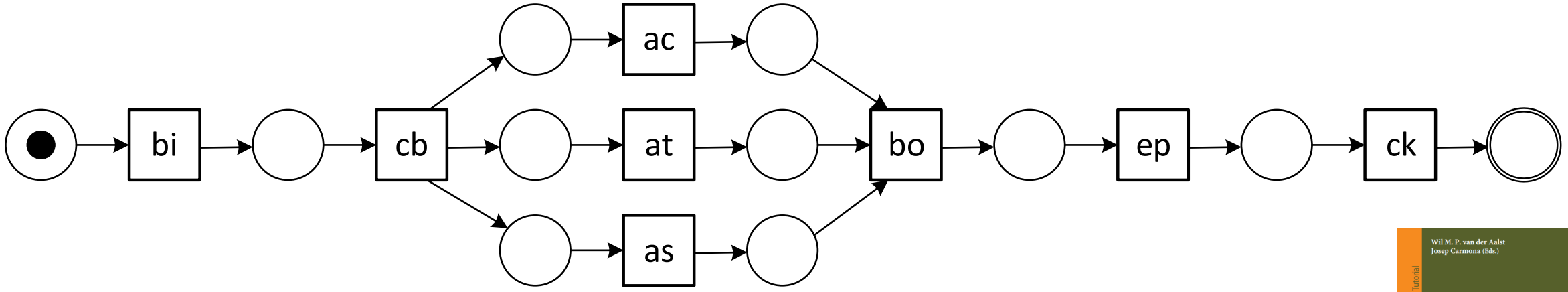
One execution of the Petri net (9/9)

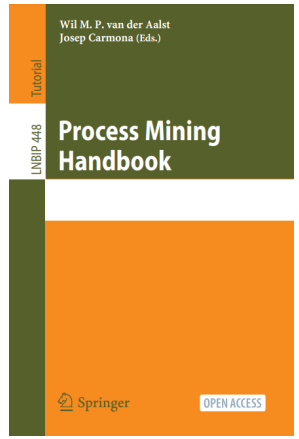


Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

An accepting Petri net has an initial and final marking



Definition 14 (Accepting Petri Net). *An accepting Petri net is a triplet* $AN = (N, M_{init}, M_{final})$ *where* $N = (P, T, F, l)$ *is a labeled Petri net,* $M_{init} \in \mathcal{B}(P)$ *is the initial marking, and* $M_{final} \in \mathcal{B}(P)$ *is the final marking.* $\mathcal{U}_{AN} \subseteq \mathcal{U}_M$ *is the set of accepting Petri nets.*



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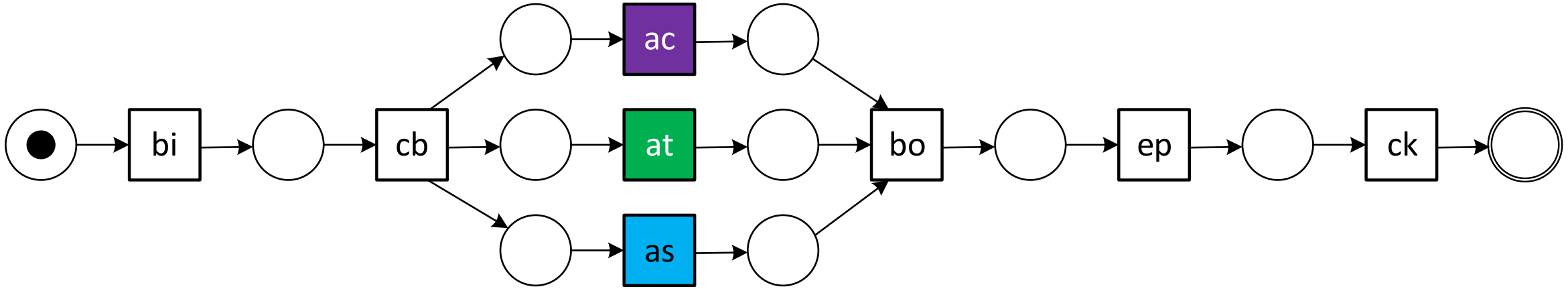
An accepting Petri net defines a set of traces

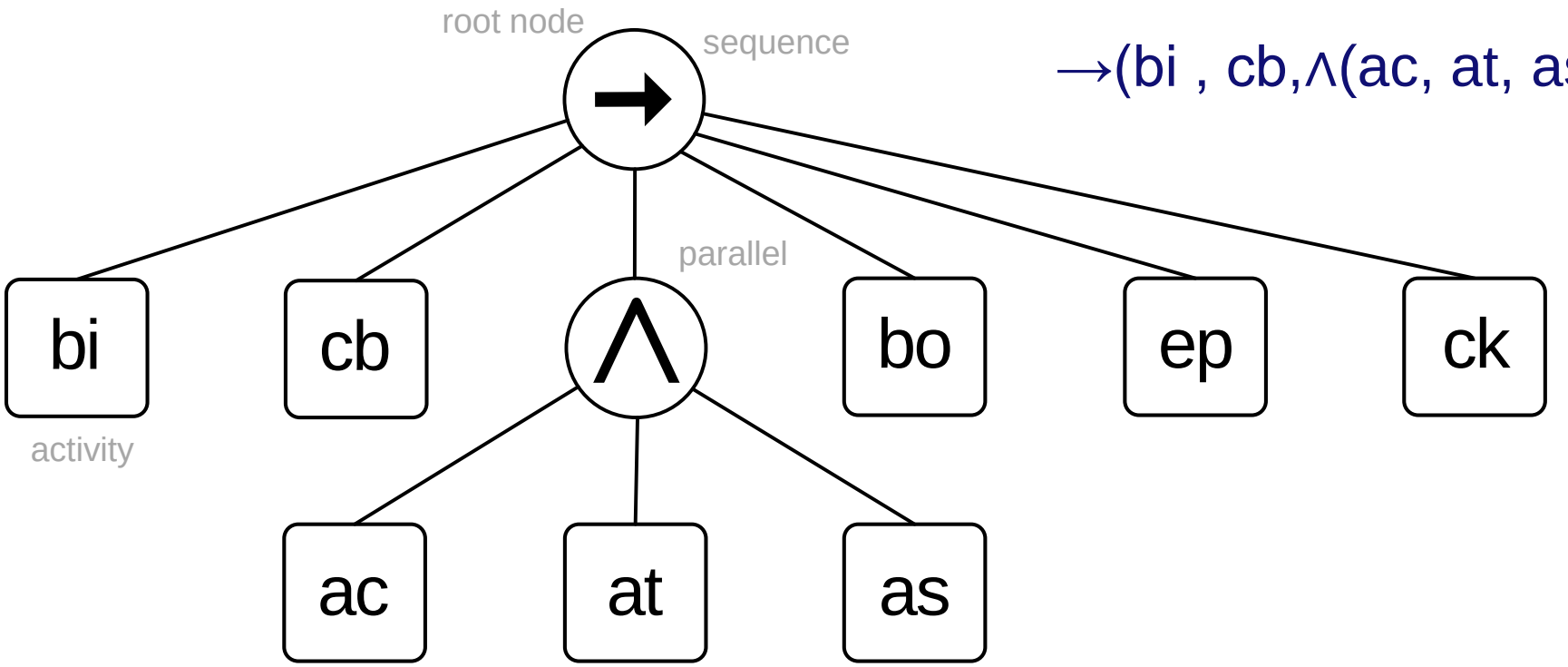


bi cb at as ac bo ep ck

bi cb ac at as bo ep ck

3! = 3x2x1 = 6 possible traces

A process tree

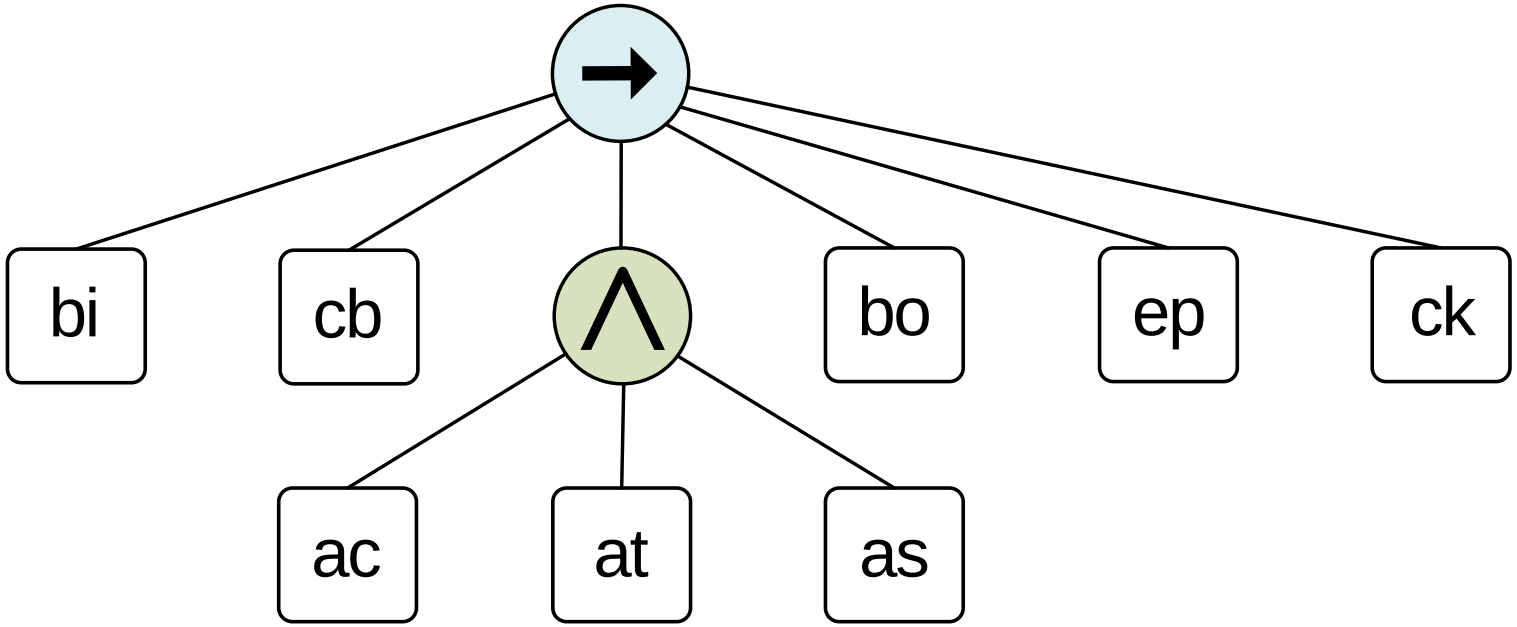


→(bi , cb,∧(ac, at, as), bo, ep, ck)

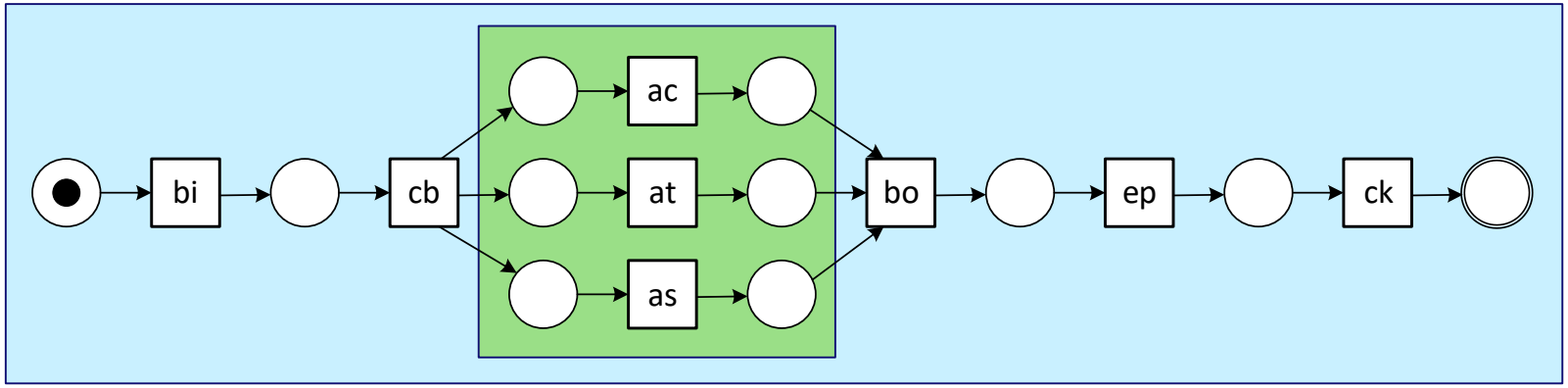
Four types of operators: → (sequential composition), × (exclusive choice), ∧ (parallel composition), and ↺ (redo loop).

Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

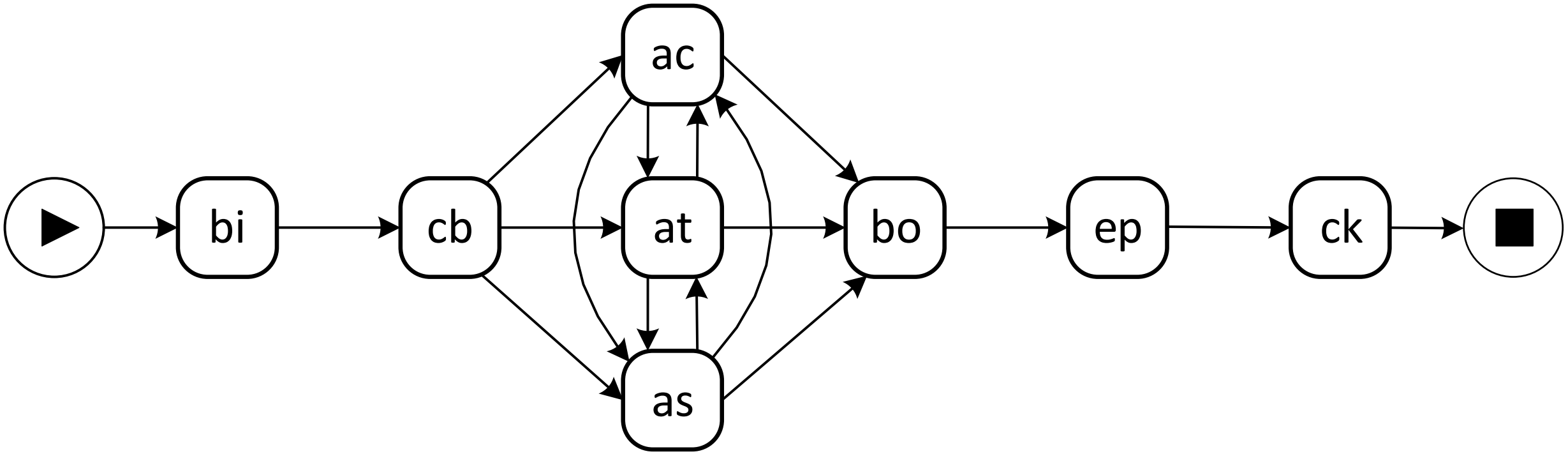
The semantics of a process tree



Direct or in terms of accepting Petri nets.

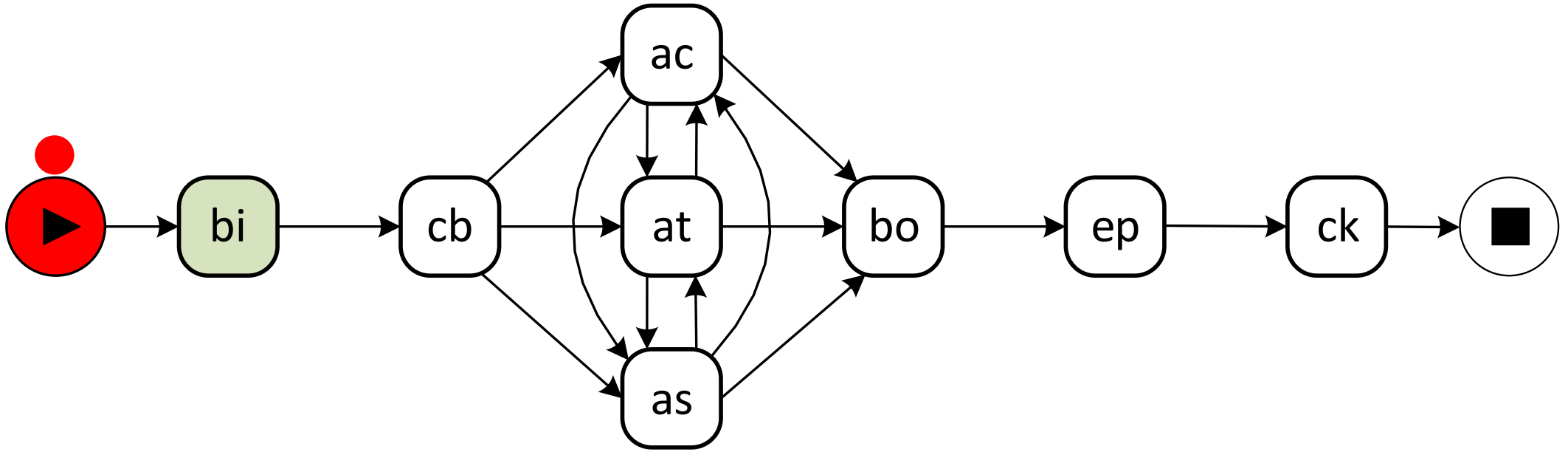


Directly-Follows Graph (DFG)



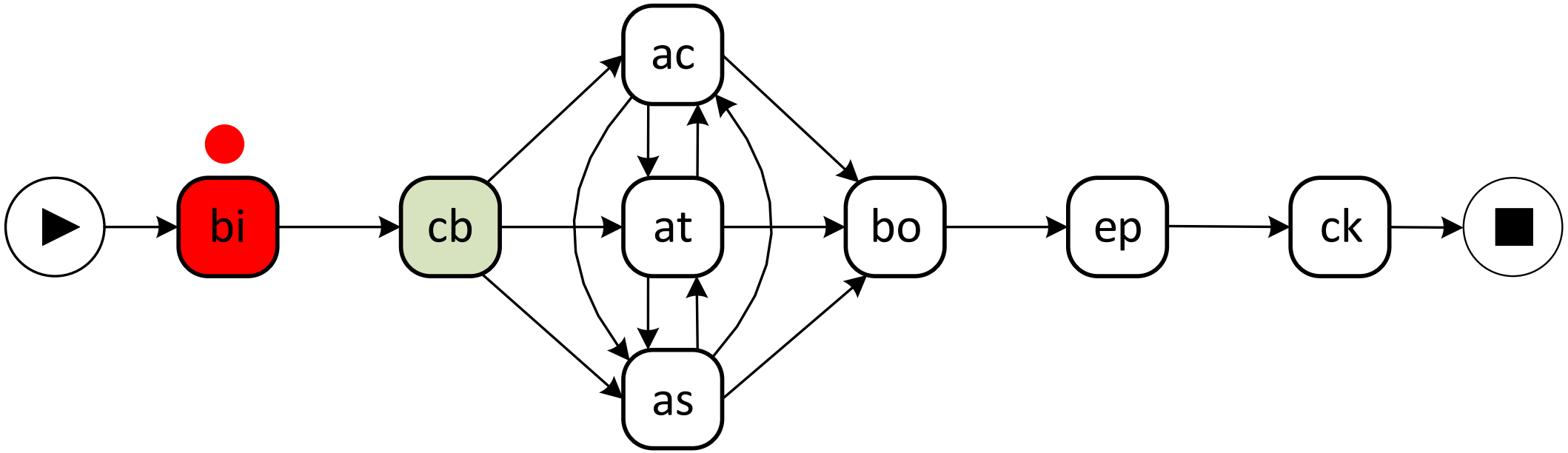
- A one-to-one correspondence between activities and nodes (except for start and end).
- One can think of the “state” as the last activity executed, i.e., just one token.

One execution of the DFG (1/9)



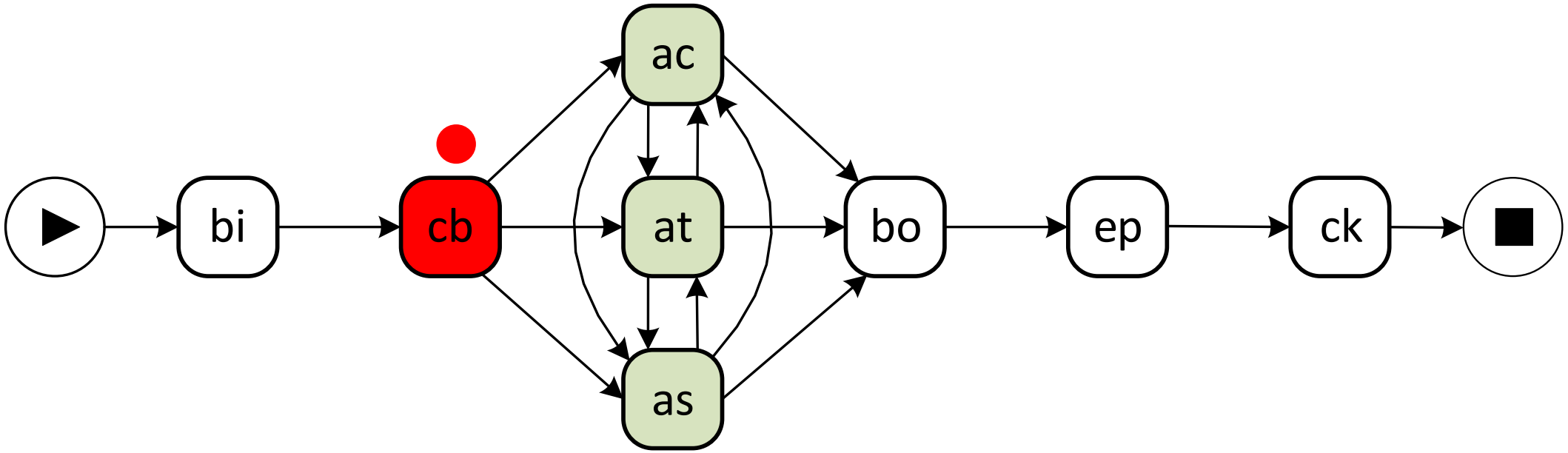
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the DFG (2/9)



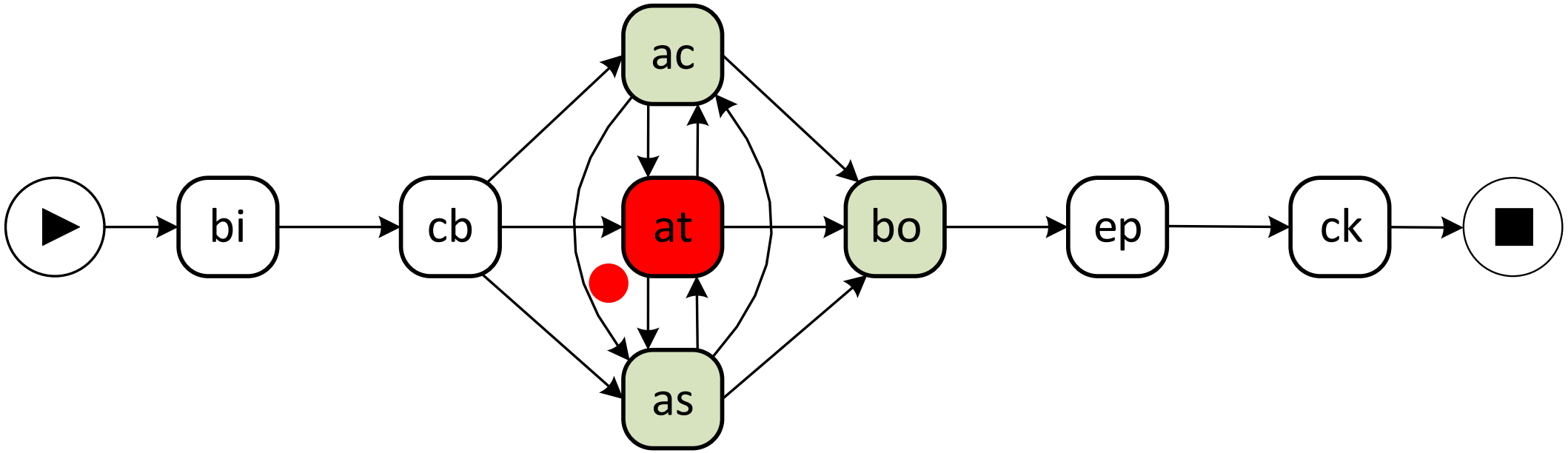
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the DFG (3/9)



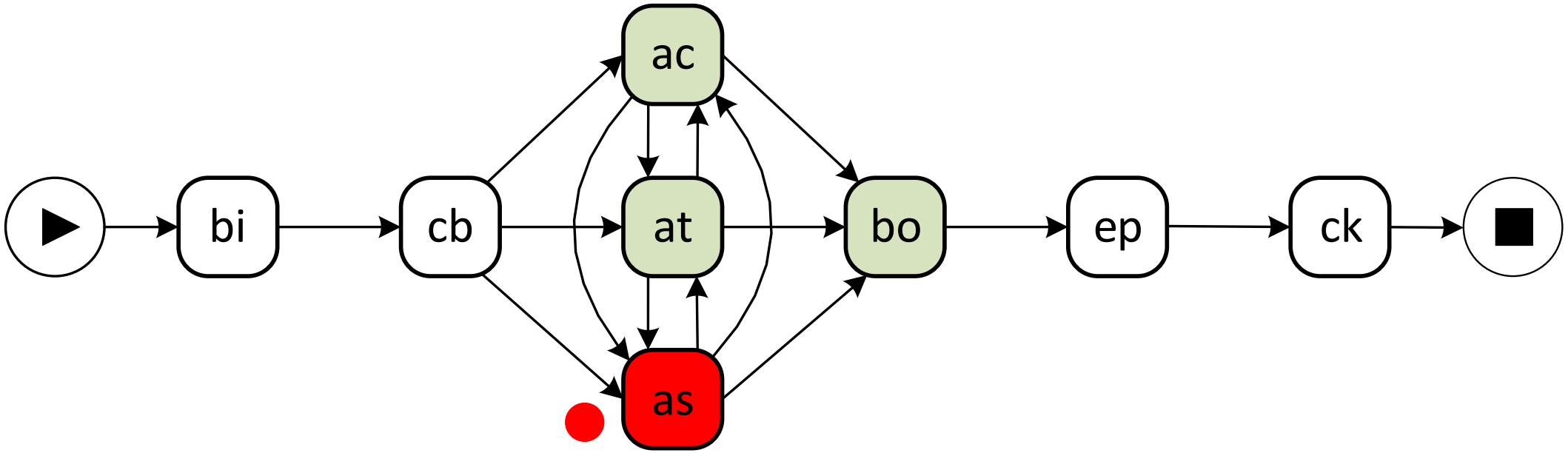
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the DFG (4/9)



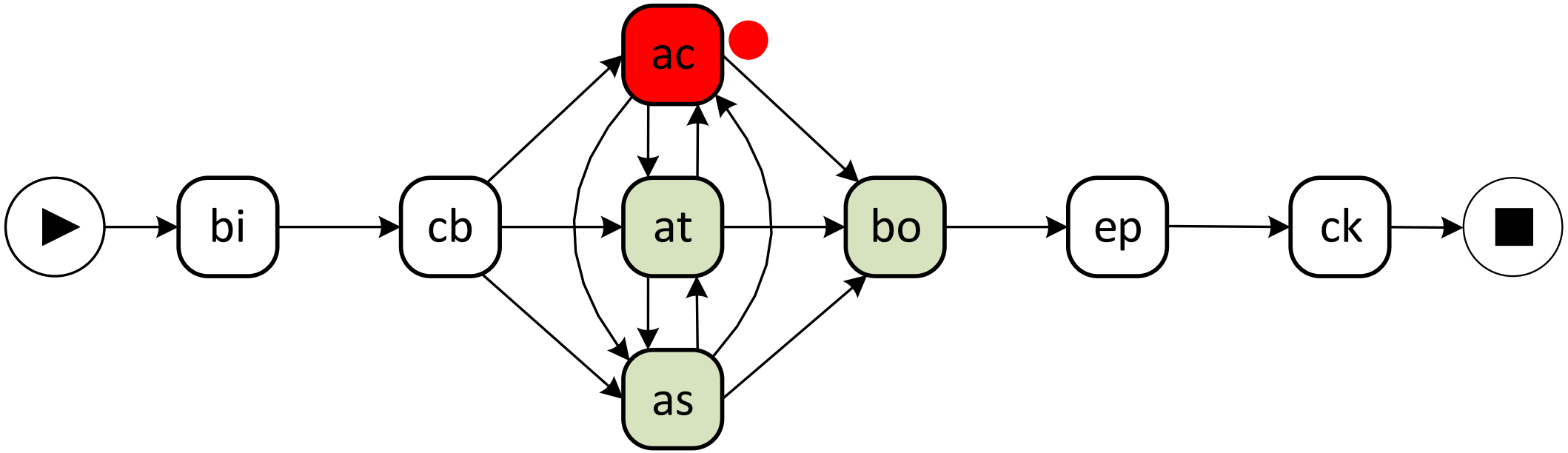
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the DFG(5/9)



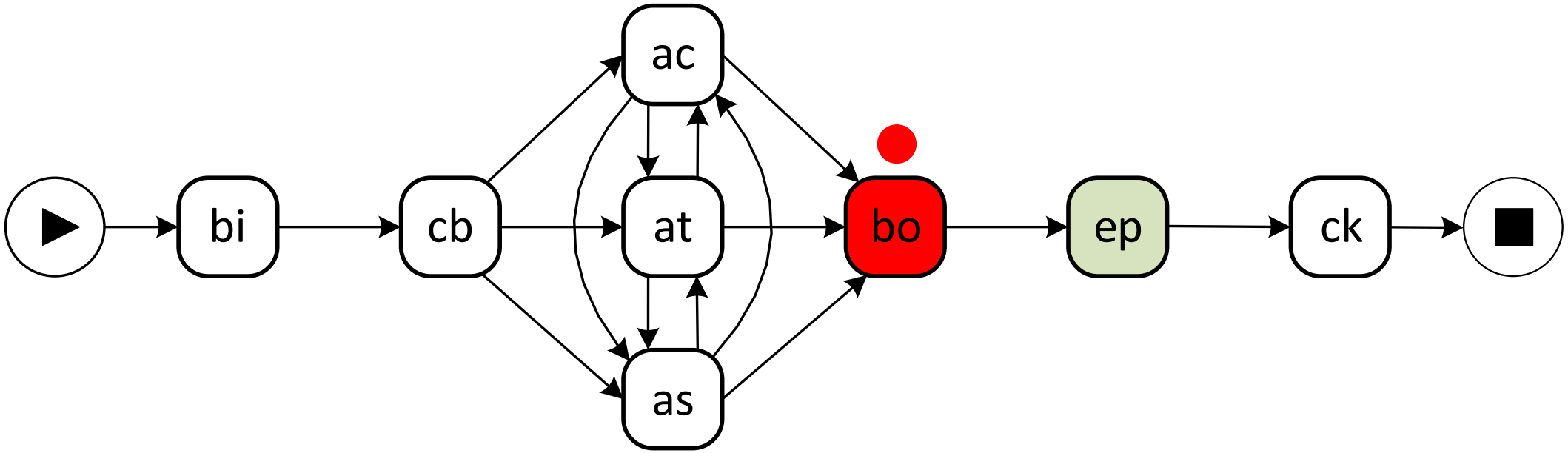
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the DFG (6/9)



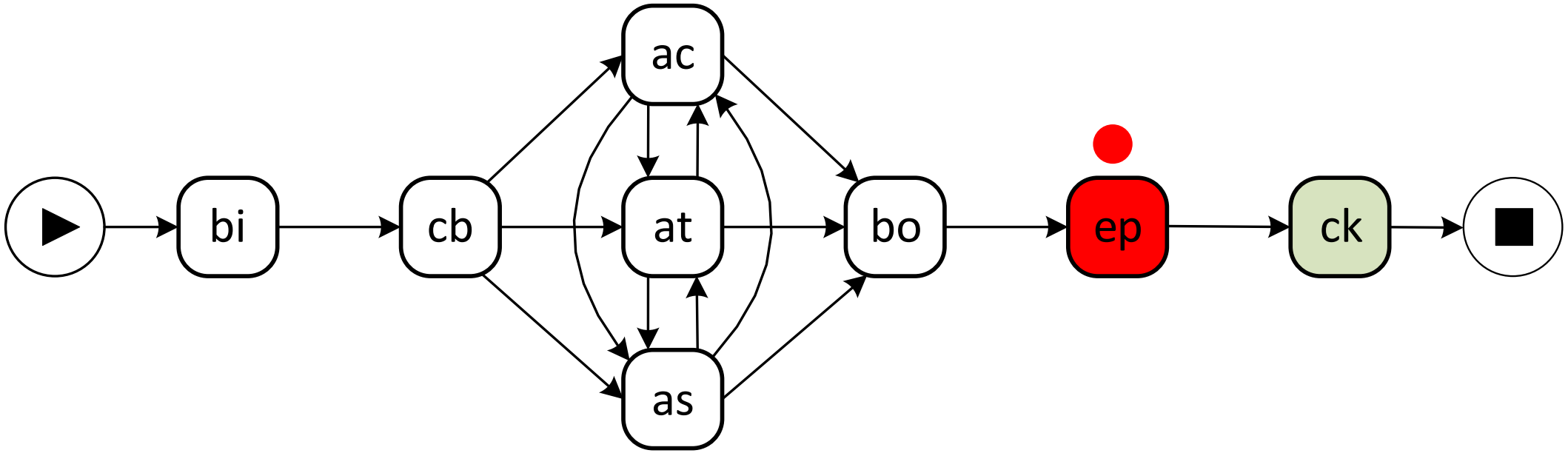
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the DFG (7/9)



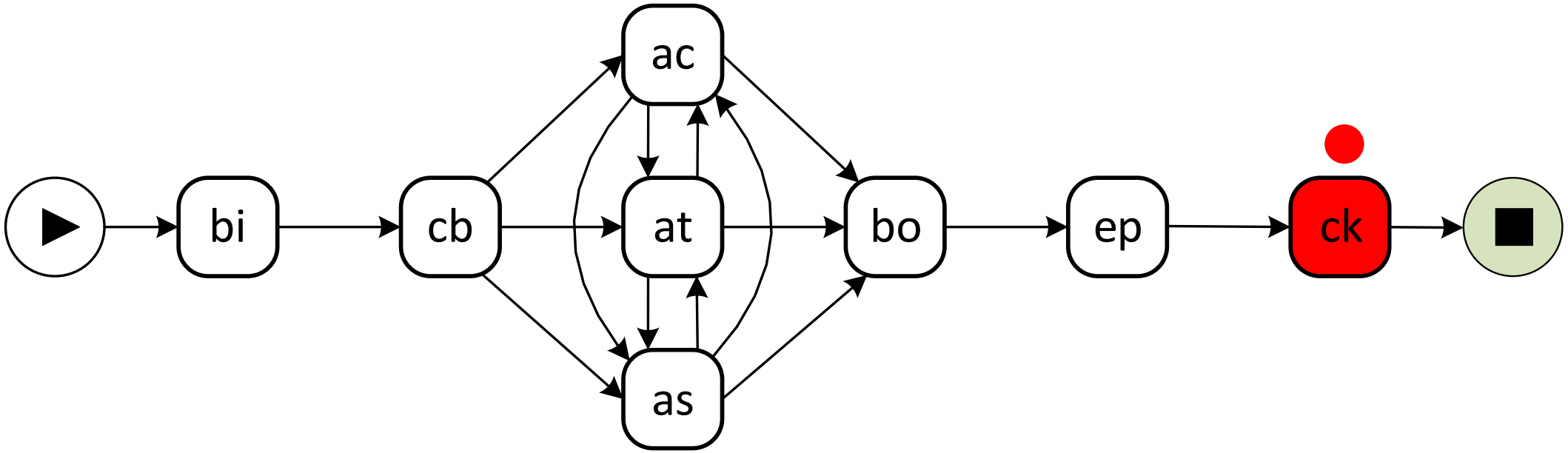
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One execution of the DFG (8/9)



Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

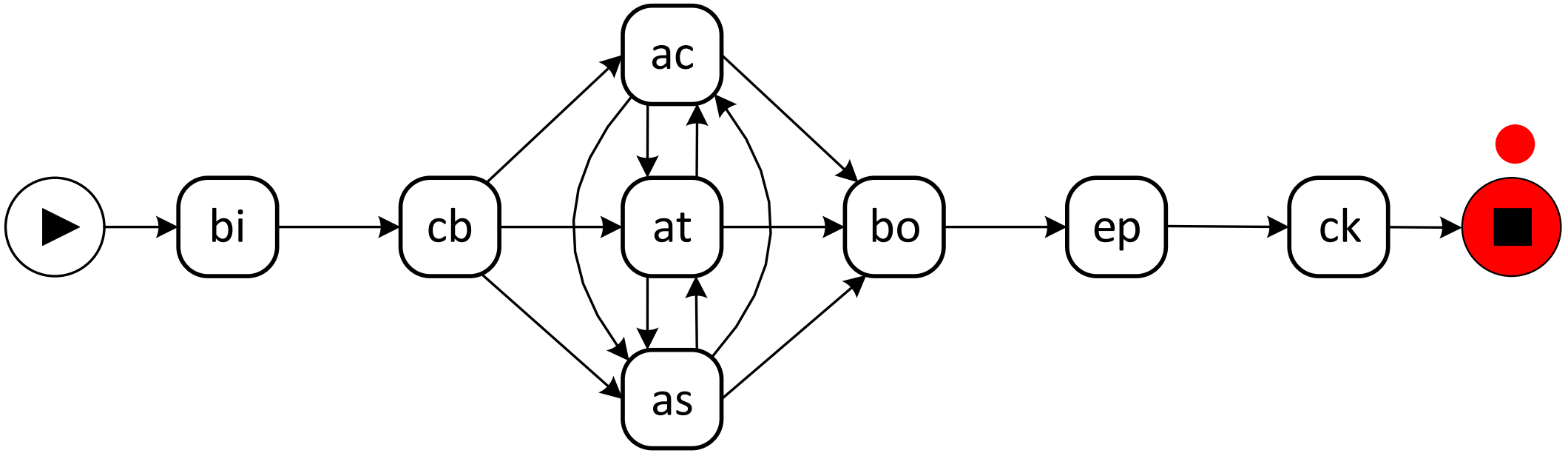
One execution of the DFG (9/9)



bi cb at as ac bo ep ck

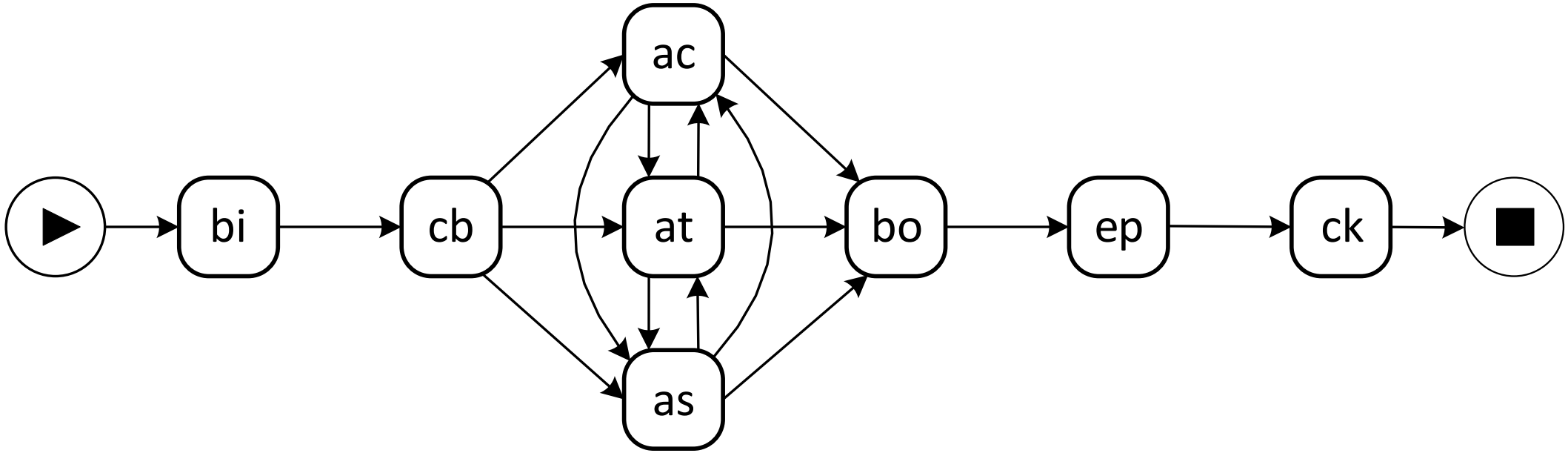
Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

One complete execution of the DFG



Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

The DFG allows for many more traces



bi cb at bo ep ck

bi cb at as at as at bo ep ck

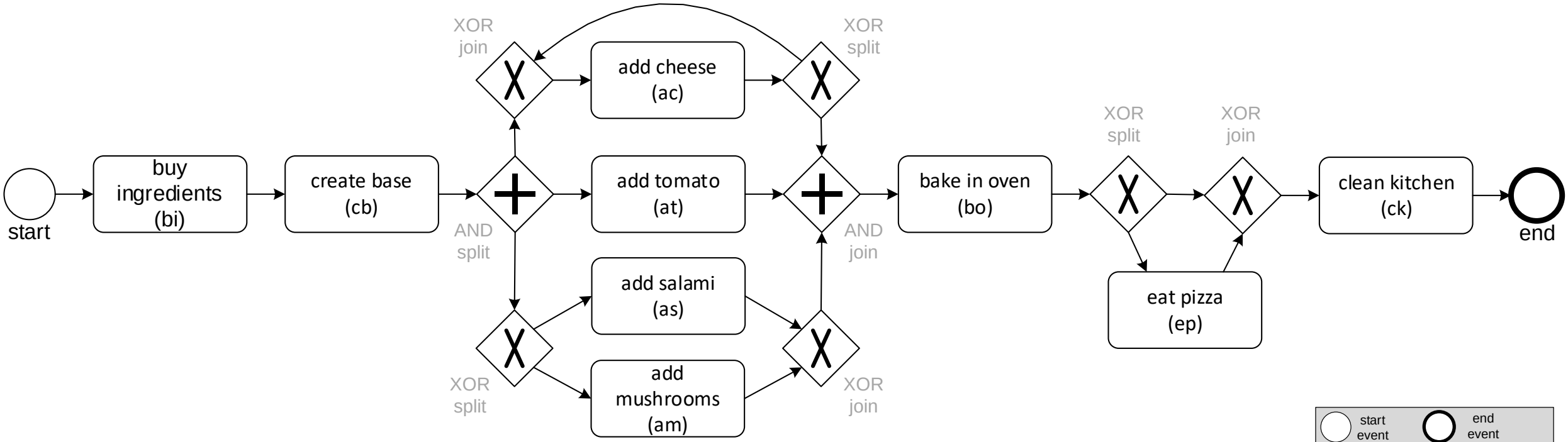
Infinitely many possible traces!

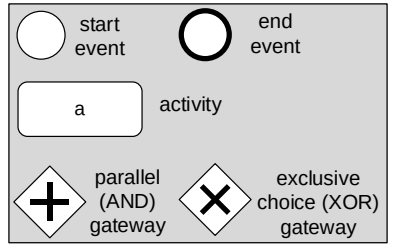
Chair of Process and Data Science

Extended process

Differences: (1) choice between salami and mushrooms, (2) cheese can be added multiple times, and (3) one can skip eating the pizza.

Alternative BPMN model





Differences: (1) choice between salami and mushrooms, (2) cheese can be added multiple times, and (3) one can skip eating the pizza.

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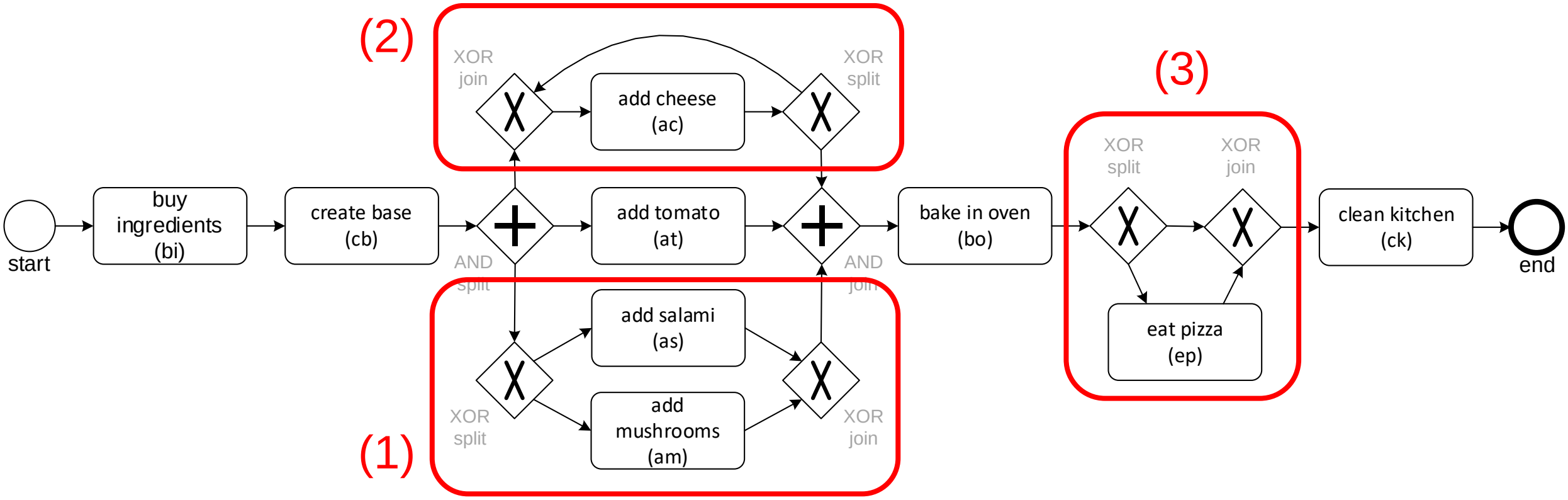
Alternative BPMN model



Differences: (1) choice between salami and mushrooms, (2) cheese can be added multiple times, and (3) one can skip eating the pizza.

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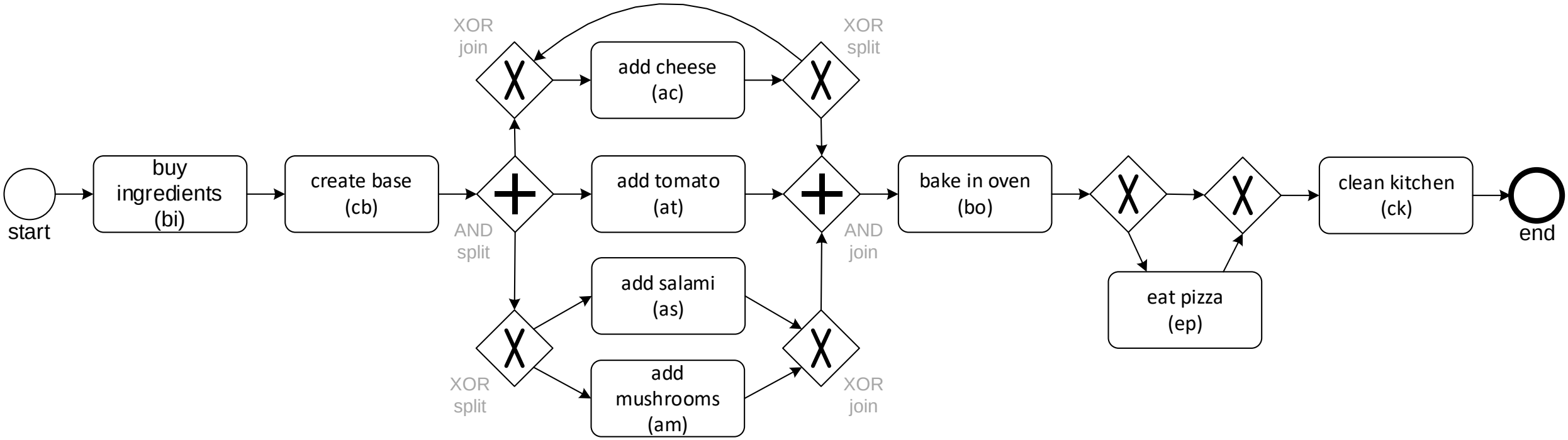
How many traces?



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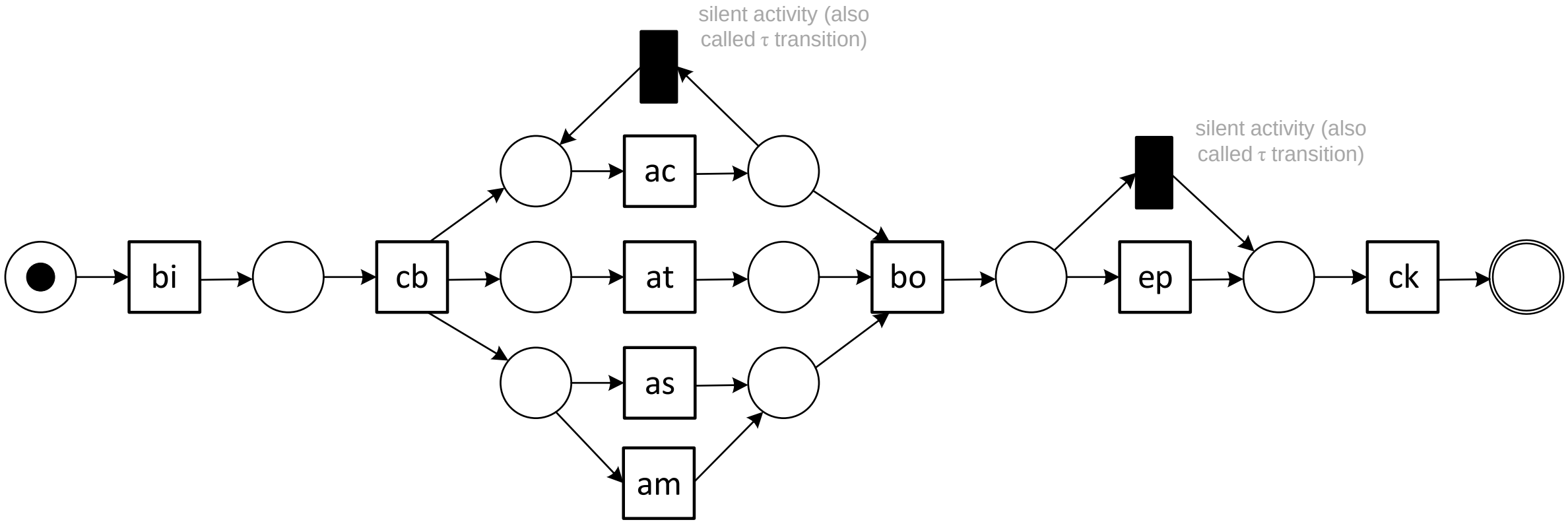
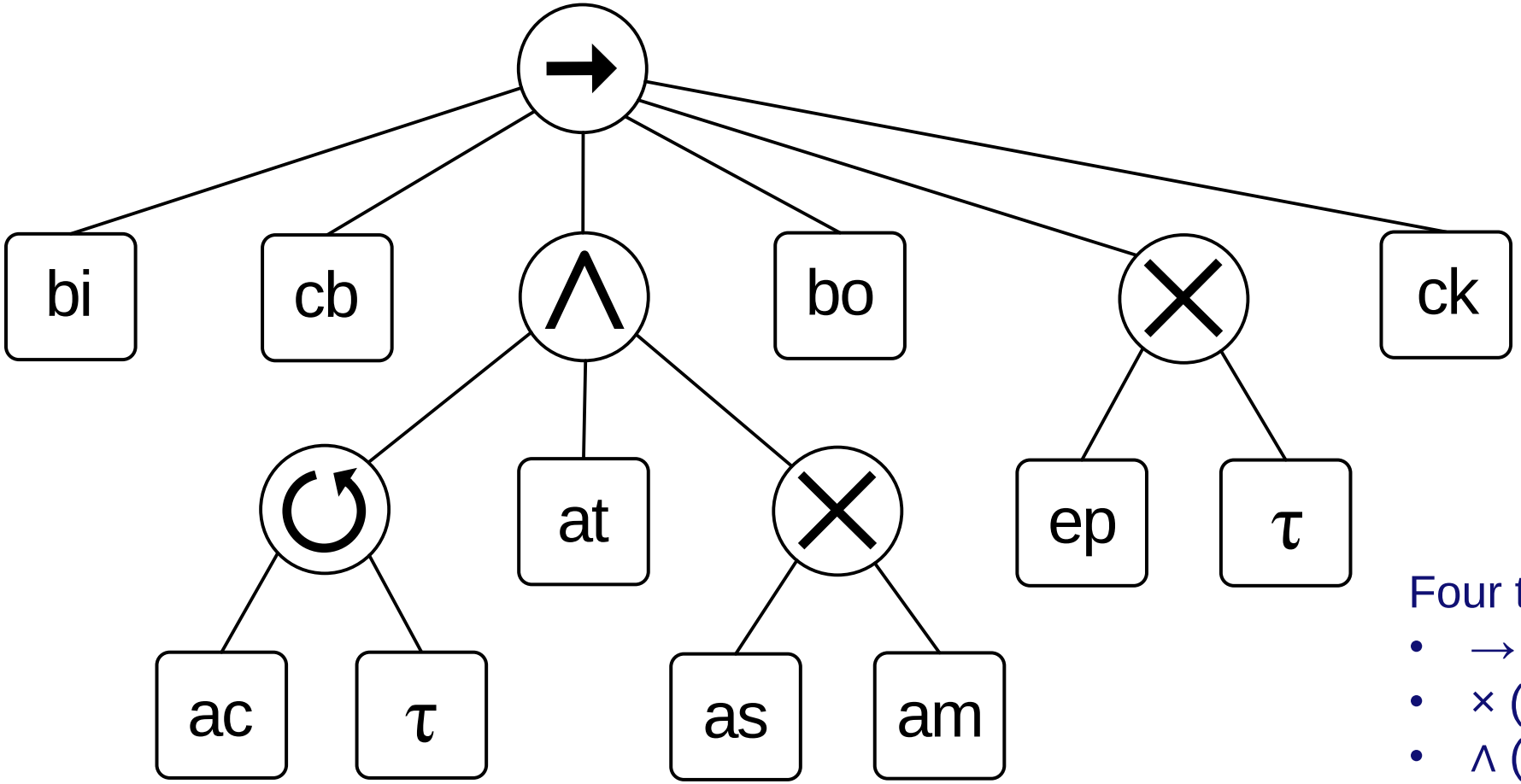
Corresponding Petri net



Same differences: (1) choice between salami and mushrooms, (2) cheese can be added multiple times, and (3) one can skip eating the pizza.

Corresponding process tree

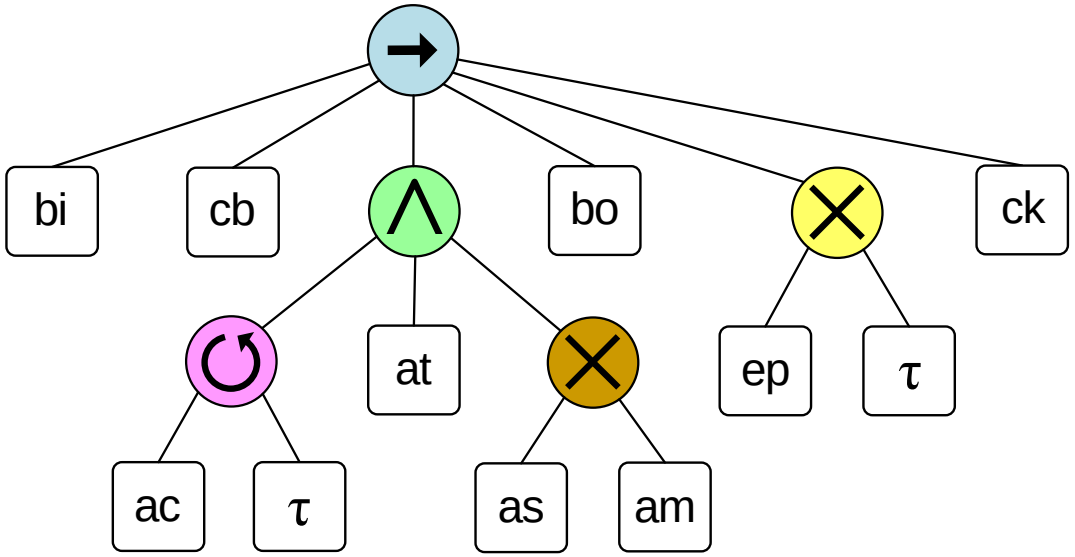


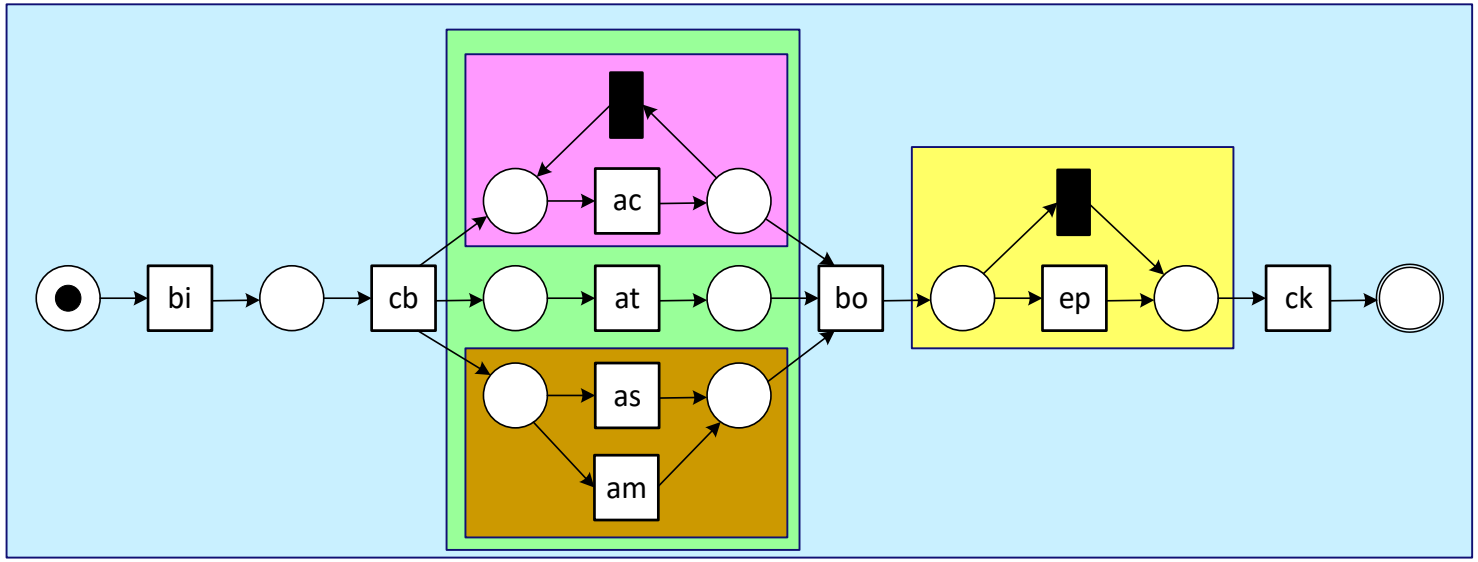
Four types of operators:

- → (sequential composition),
- × (exclusive choice),
- ∧ (parallel composition), and
- ↺ (redo loop).

Same differences.

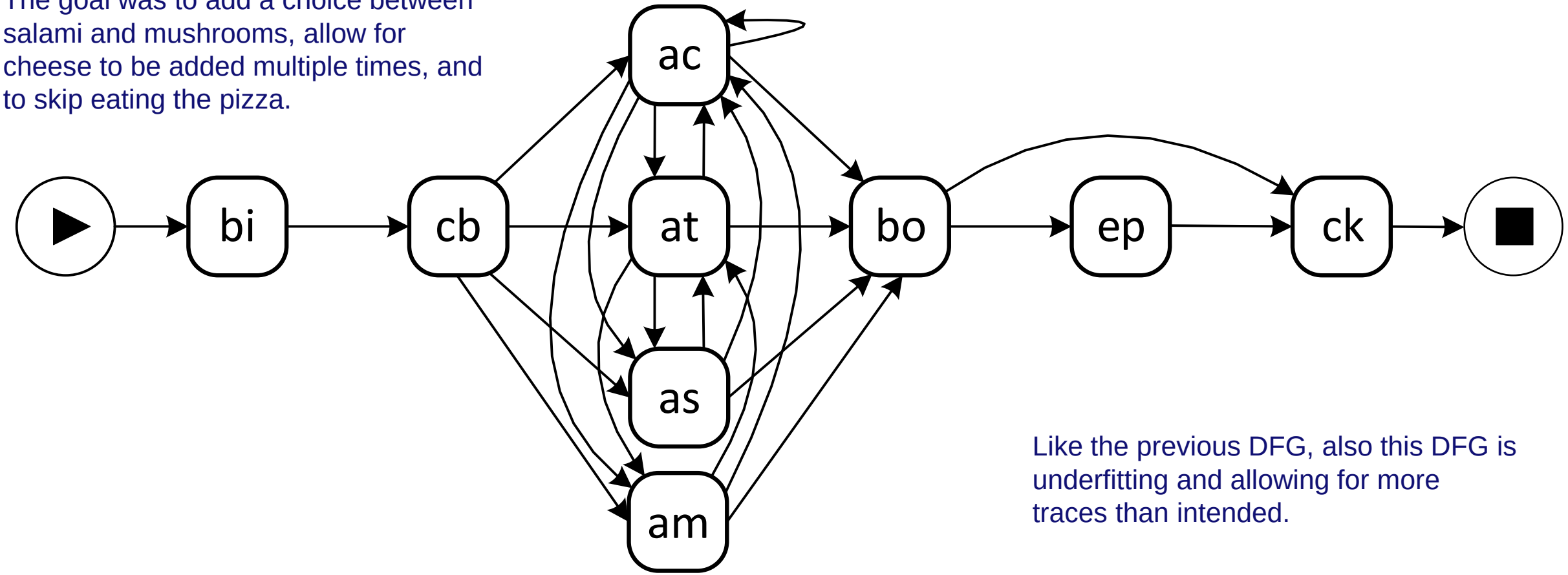
Semantics





The corresponding DFG

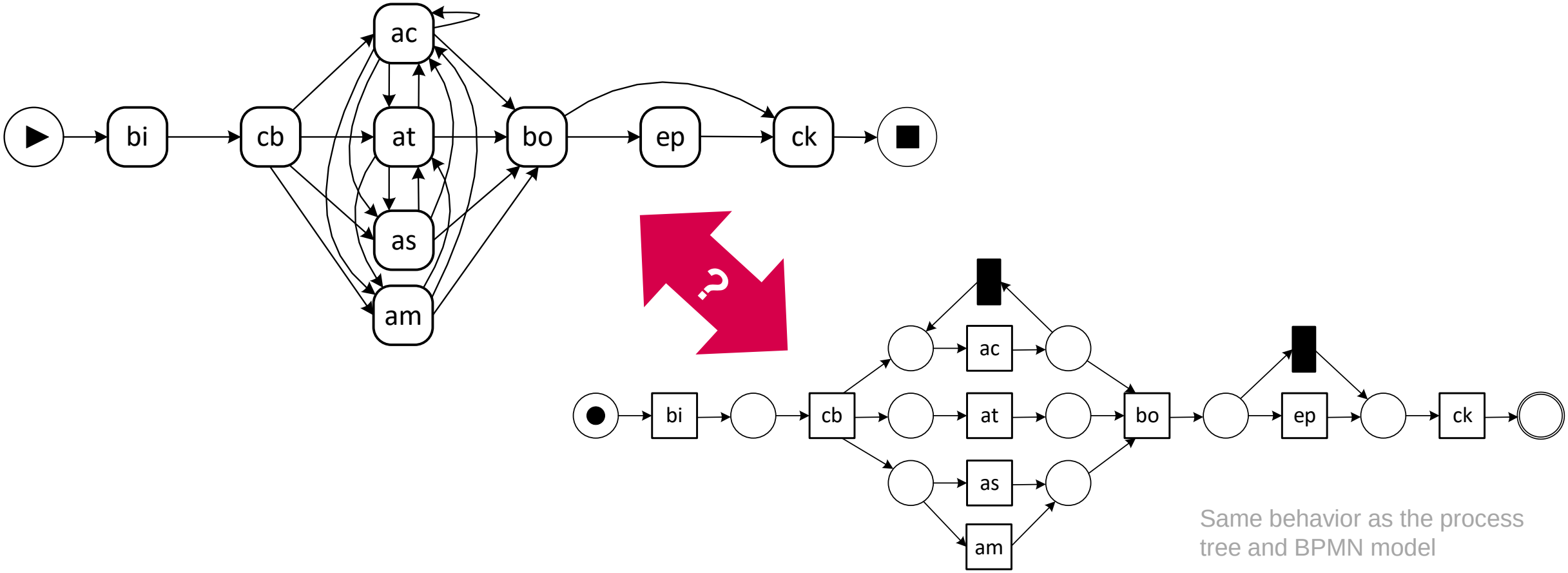
The goal was to add a choice between salami and mushrooms, allow for cheese to be added multiple times, and to skip eating the pizza.



Like the previous DFG, also this DFG is underfitting and allowing for more traces than intended.

Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), add mushrooms (am), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

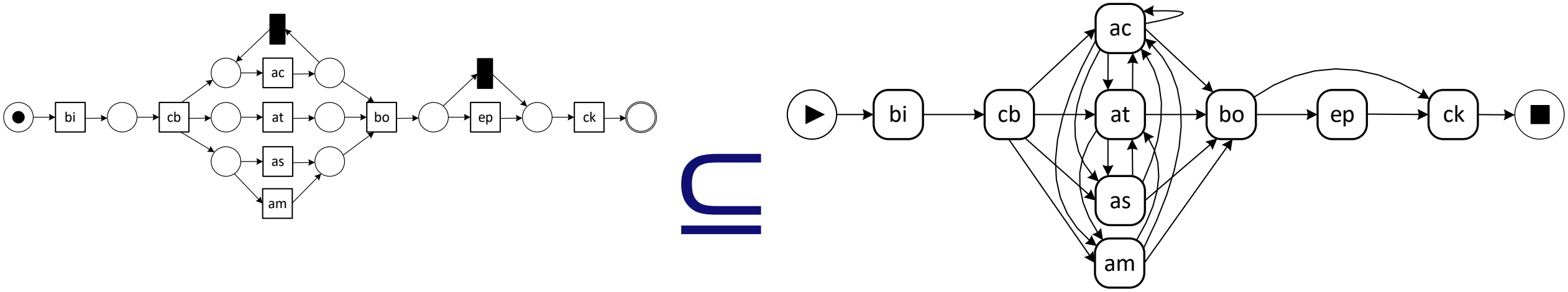
What are differences in behavior?



Same behavior as the process tree and BPMN model

Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), add mushrooms (am), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

What are differences in behavior?



The DFG also allows for:

- Not adding cheese.
- Not adding tomato.
- Adding both salami and mushrooms.
- Adding tomato, salami, and mushrooms multiple times.

Using short names: buy ingredients (bi), create base (cb), add cheese (ac), add tomato (at), add salami (as), add mushrooms (am), bake in oven (bo), eat pizza (ep), and clean kitchen (ck).

Four types of basic process models

BPMN: The industry standard (here we just use a subset)

Petri nets: The oldest model for concurrent processes and the de facto standard in process mining research

Process trees: Frequently used in process mining because it is block structured and sound by construction

DFGs: Supported by all process mining tools (simple, but no concurrency)

Chair of Process and Data Science

RWTH AACHEN UNIVERSITY

Two basic representations

Normal event log and simplified event log

case	activity	timestamp	resource	customer
...	...	...	...	...
pizza-56	buy ingredients (bi)	18:10	Stefano	Valentina
pizza-57	buy ingredients (bi)	18:12	Stefano	Giulia
pizza-57	create base (cb)	18:16	Mario	Giulia
pizza-56	create base (cb)	18:19	Mario	Valentina
pizza-57	add tomato (at)	18:21	Mario	Giulia
pizza-57	add cheese (ac)	18:27	Mario	Giulia
pizza-56	add cheese (ac)	18:34	Mario	Valentina
pizza-56	add tomato (at)	18:44	Mario	Valentina
pizza-56	add salami (as)	18:45	Mario	Valentina
pizza-56	bake in oven (bo)	18:48	Stefano	Valentina
pizza-57	add salami (as)	18:50	Mario	Giulia
pizza-56	eat pizza (ep)	19:10	Valentina	Valentina
pizza-58	buy ingredients (bi)	19:17	Stefano	Laura
pizza-57	bake in oven (bo)	19:23	Stefano	Giulia
pizza-57	eat pizza (ep)	19:27	Giulia	Giulia
pizza-57	clean kitchen (ck)	19:44	Mario	Giulia
pizza-58	create base (cb)	19:48	Mario	Laura
pizza-58	add salami (as)	19:49	Mario	Laura
pizza-58	add tomato (at)	19:55	Mario	Laura
pizza-56	clean kitchen (ck)	20:08	Mario	Valentina
pizza-				aura
pizza-				aura
pizza-				aura
pizza-58	clean kitchen (ck)	20:51	Mario	Laura
...	...	...	...	...

normal event log (events with case, activity, time, etc. attributes)

case: pizza-56

case: pizza-57

case: pizza-58

simplified event log (cases are represented as sequences of activities, ignoring all other attributes)

Chair of Process and Data Science

Formalization: Normal event log

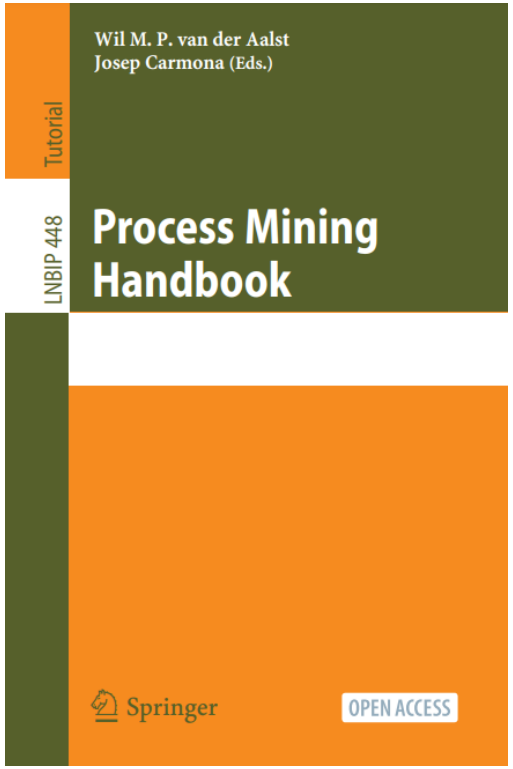
Definition 1 (Universes). *$\mathcal{U}_{ev}$ is the universe of events, $\mathcal{U}_{act}$ is the universe of activities, $\mathcal{U}_{case}$ is the universe of cases, $\mathcal{U}_{time}$ is the universe of timestamps, $\mathcal{U}_{att} = \{act, case, time, \ldots\}$ is the universe of attributes, $\mathcal{U}_{val}$ is the universe of values, and $\mathcal{U}_{map} = \mathcal{U}_{att} \not\to \mathcal{U}_{val}$ is the universe of attribute-value mappings. We assume that $\mathcal{U}_{act} \cup \mathcal{U}_{case} \cup \mathcal{U}_{time} \subseteq \mathcal{U}_{val}$, $\bot \notin \mathcal{U}_{val}$, and for any $f \in \mathcal{U}_{map}$: $f(act) \in \mathcal{U}_{act} \cup \{\bot\}$, $f(case) \in \mathcal{U}_{case} \cup \{\bot\}$, and $f(time) \in \mathcal{U}_{time} \cup \{\bot\}$.*

Definition 2 (Event Log). *An event log is a tuple $L = (E, \#, \prec)$ consisting of a set of events $E \subseteq \mathcal{U}_{ev}$, a mapping $\# \in E \to \mathcal{U}_{map}$, and a strict partial ordering $\prec \subseteq E \times E$ on events.*

For any $e \in E$ and $att \in dom(\#(e))$: $\#_{att}(e) = \#(e)(att)$ is the value of attribute att for event e. For example, $\#_{act}(e)$, $\#_{case}(e)$, and $\#_{time}(e)$ are the activity, case, and timestamp of an event e.

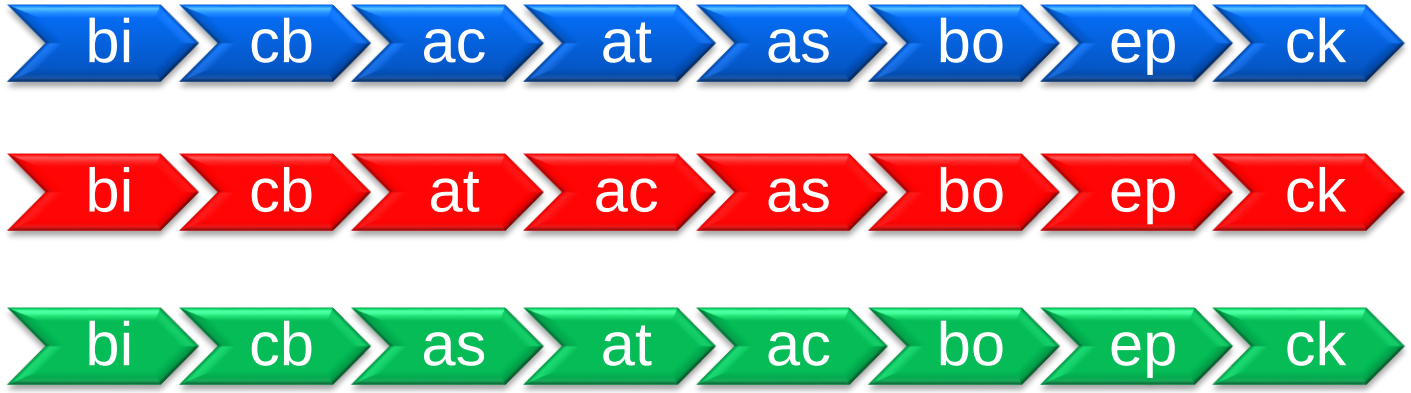
The ordering of events respects time, i.e., if $e_1, e_2 \in E$, $\#_{time}(e_1) \neq \bot$, $\#_{time}(e_2) \neq \bot$, and $\#_{time}(e_1) < \#_{time}(e_2)$, then $e_2 \not\prec e_1$.

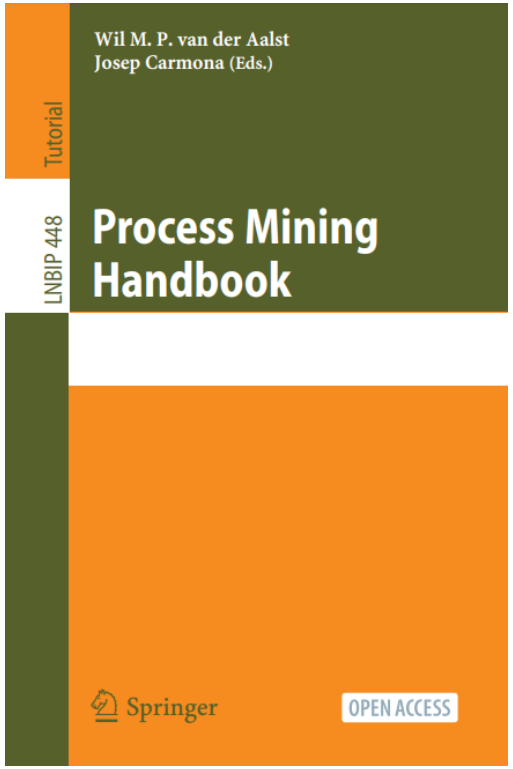
events have case, activity, time, and possibly other attributes



Formalization: Simple event log

Definition 3 (Simplified Event Log). *A simplified event log* $L \in \mathcal{B}(\mathcal{U}_{act}{}^{*})$ *is a multiset of traces. A trace* $\sigma = \langle a_1, a_2, \ldots a_n \rangle \in \mathcal{U}_{act}{}^{*}$ *is a sequence of activities.* $L(\sigma)$ *is the number of times trace* σ *appears in event log* L.

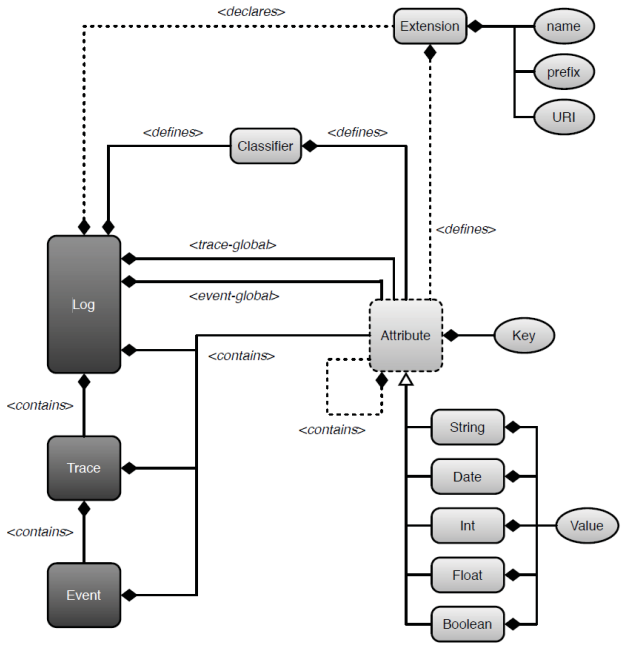




- Multiset: the same trace may appear any number of times!
- See Definition 4 for the conversion of normal event logs to simple event logs.

Chair of Process and Data Science

XES (eXtensible Event Stream)



- **Official IEEE standard since 2016 (development started in 2010).**
- **Supported by 15+ tools (e.g., ProM)**
- **Compared to normal event logs:**
  - **Case attributes**
  - **Lifecycle information (start, complete, etc.)**
  - **Classifiers**
  - **Resources, roles, and groups**
  - **Costs**
  - **Etc.**

Not enough: Object-Centric Event Data

activity	timestamp	pizza	resource	customer	location
...	...	...	...	...	...
buy ingredients (bi)	*18:10*	{pizza-56, pizza-57, pizza-58}	{Stefano}	{Valentina, Giulia, Laura}	{supermarket}
create base (cb)	18.16	{pizza-57}	{Mario, Stefano}	{Giulia}	{kitchen-1}
create base (cb)	18.19	{pizza-56}	{Mario, Stefano}	{Valentina}	{kitchen-1}
add tomato (at)	18.21	{pizza-57}	{Mario}	{Giulia}	{kitchen-1}
add cheese (ac)	18.27	{pizza-57}	{Mario}	{Giulia}	{kitchen-1}
add cheese (ac)	18.34	{pizza-56}	{Mario}	{Valentina}	{kitchen-1}
add tomato (at)	18.44	{pizza-56}	{Mario}	{Valentina}	{kitchen-1}
add salami (as)	18.45	{pizza-56}	{Mario}	{Valentina}	{kitchen-1}
bake in oven (bo)	18.48	{pizza-56}	{Stefano}	{Valentina}	{kitchen-1}
add salami (as)	18.50	{pizza-57}	{Mario}	{Giulia}	{kitchen-1}
eat pizza (ep)	19.10	{pizza-56}	{Valentina}	{Valentina}	{restaurant}
bake in oven (bo)	19.23	{pizza-57}	{Stefano}	{Giulia}	{kitchen-1}
eat pizza (ep)	19.27	{pizza-57}	{Giulia}	{Giulia}	{restaurant}
create base (cb)	19.48	{pizza-58}	{Mario, Stefano}	{Laura}	{kitchen-2}
add salami (as)	19.49	{pizza-58}	{Mario}	{Laura}	{kitchen-2}
add tomato (at)	19.55	{pizza-58}	{Mario}	{Laura}	{kitchen-2}
clean kitchen (ck)	20.08	$\emptyset$	{Mario}	$\emptyset$	{kitchen-1}
add cheese (ac)	20.13	{pizza-58}	{Mario}	{Laura}	{kitchen-2}
bake in oven (bo)	20.29	{pizza-58}	{Stefano}	{Laura}	{kitchen-2}
eat pizza (ep)	20.48	{pizza-58}	{Laura}	{Laura}	{restaurant}
clean kitchen (ck)	20.51	$\emptyset$	{Mario}	$\emptyset$	{kitchen-2}
...	...	...	...	...	...

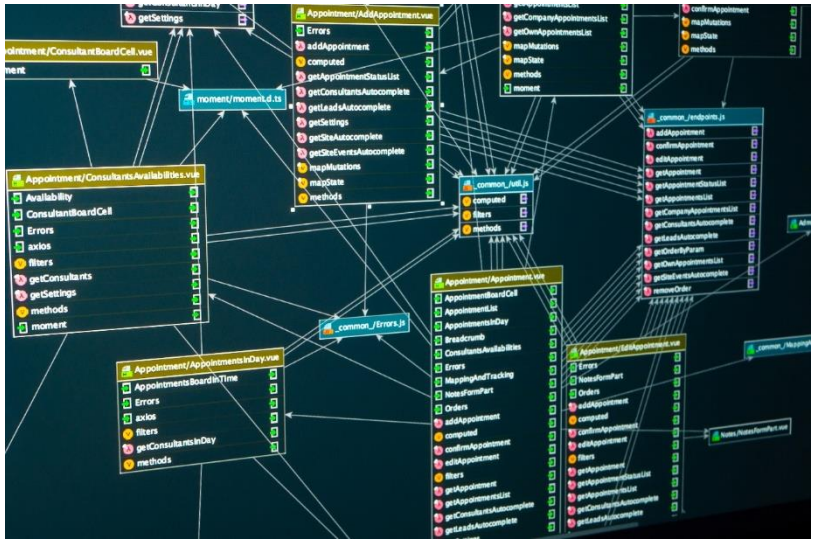
- **Events may involve multiple objects of different types.**
- **This lecture: 1 room, 1 lecturer, 1 summer school, 130 participants, 150 chairs, 10 tweets (#pmschool22), etc.**
- **One can always flatten into a normal event log** (see Definition 5, Chapter 1)

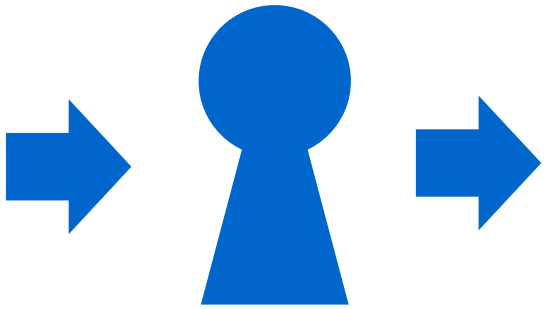
More examples

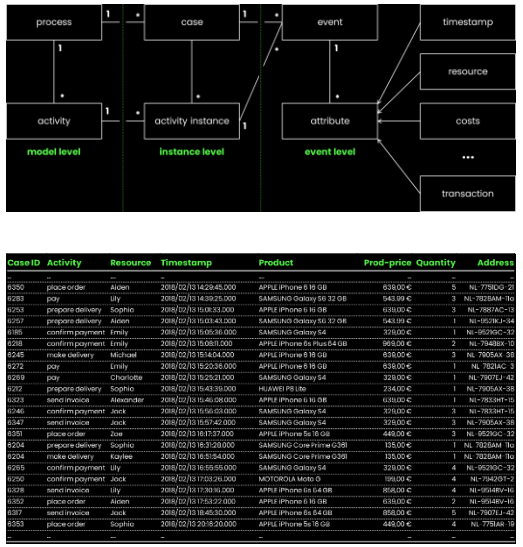
- **Place order: 1 order, 5 items, 1 customer, 1 payment.**
- **Deliver package: 1 package, 2 orders, 4 items, 1 customer.**
- **PhD defense: 1 candidate, 4 professors, 1 thesis.**
- **Check-in: 1 passenger, 2 suitcases, 1 flight, 1 employee.**
- **Etc.**

This is the normal situation!

Pushing an elephant through a keyhole





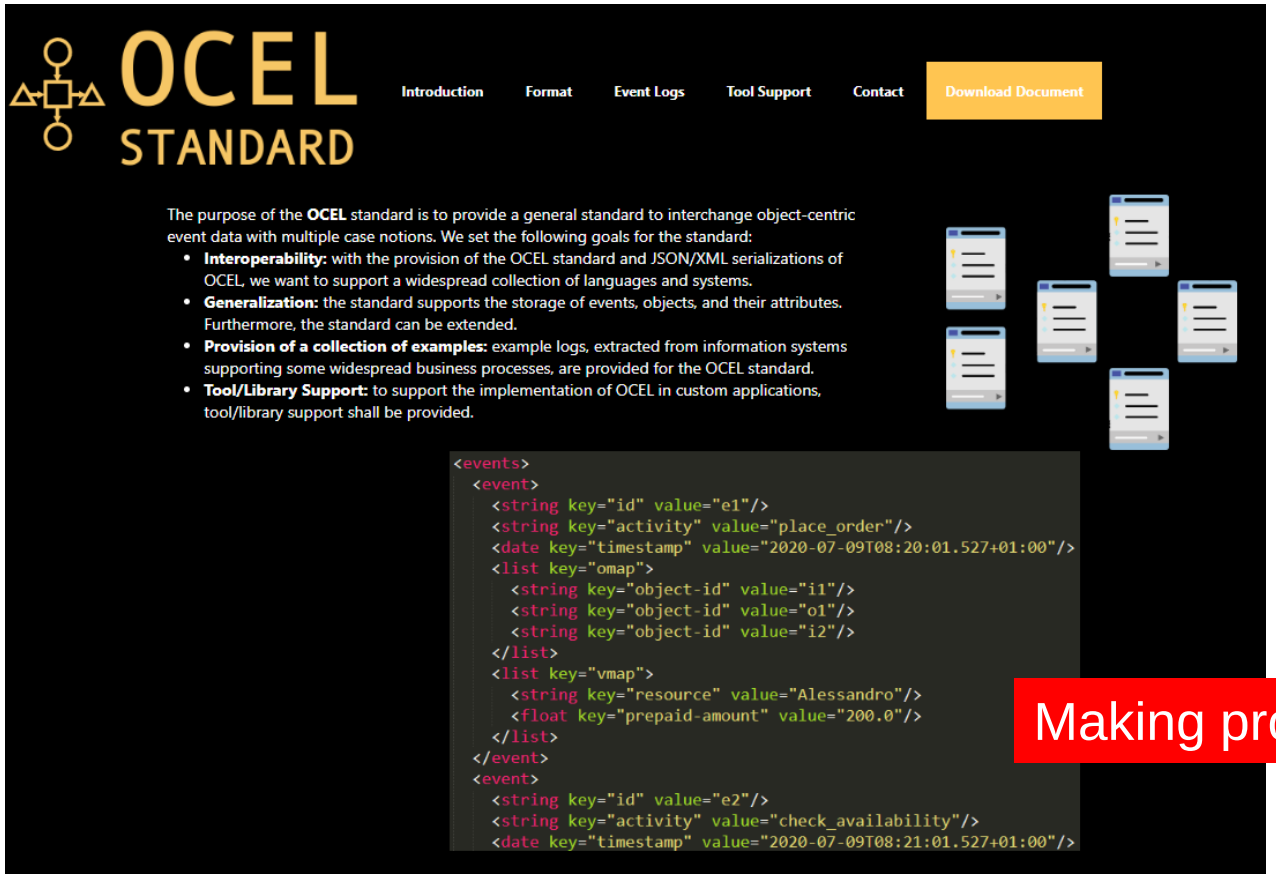


80% of time is spent on data extraction and transformation …

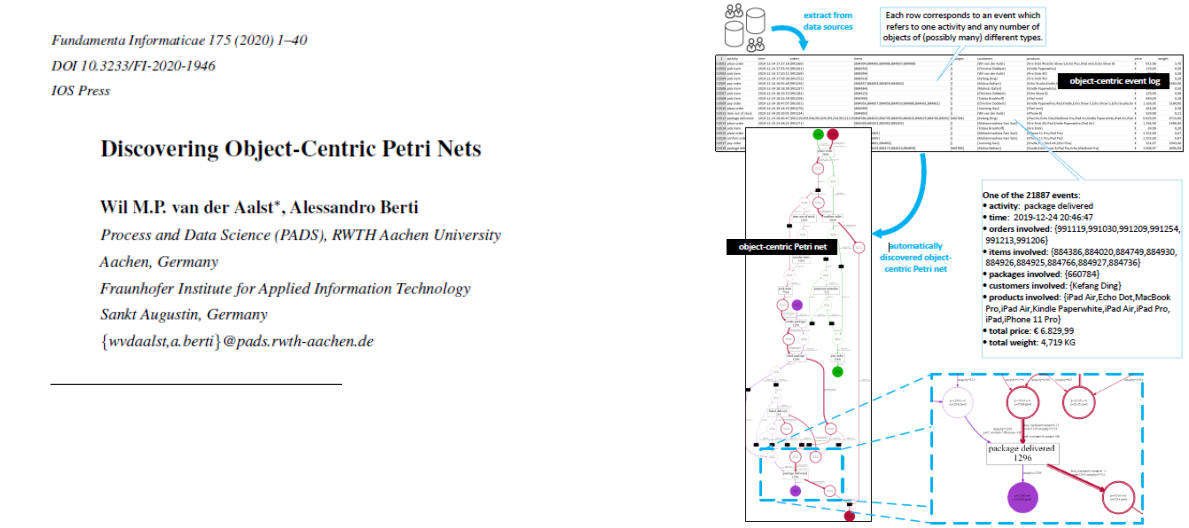
… to create a single viewpoint

Chair of Process and Data Science

Interested in Object-Centric Process Mining?



http://ocel-standard.org/


Fundamenta Informaticae 175 (2020) 1–40
DOI 10.3233/FI-2020-1946
IOS Press

Discovering Object-Centric Petri Nets

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Abstract. Techniques to discover Petri nets from event data assume precisely one case identifier per event. These case identifiers are used to correlate events, and the resulting discovered Petri net aims to describe the life-cycle of individual cases. In reality, there is not one possible case notion, but multiple intertwined case notions. For example, events may refer to mixtures of orders, items, [illegible] that may consume and produce collections of objects of different types. Object-centric Petri nets visualize the complex relationships among objects from different types. This paper discusses a novel process discovery approach implemented in PM4Py. As will be demonstrated, it is indeed feasible to discover holistic process models that can be used to drill-down into specific viewpoints if needed.

https://doi.org/10.3233/FI-2020-1946

Making process mining tools and techniques future proof!

Several PhDs in the PADS groups are working on this!

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Four levels of event logs

Simple event log: Multiset of traces.

XES logs: Various extensions (e.g., case attributes) but still a single case notion.

Normal event log: Events with attributes (e.g., stored as a CSV file).

Object-centric event logs: Any number of objects per event.

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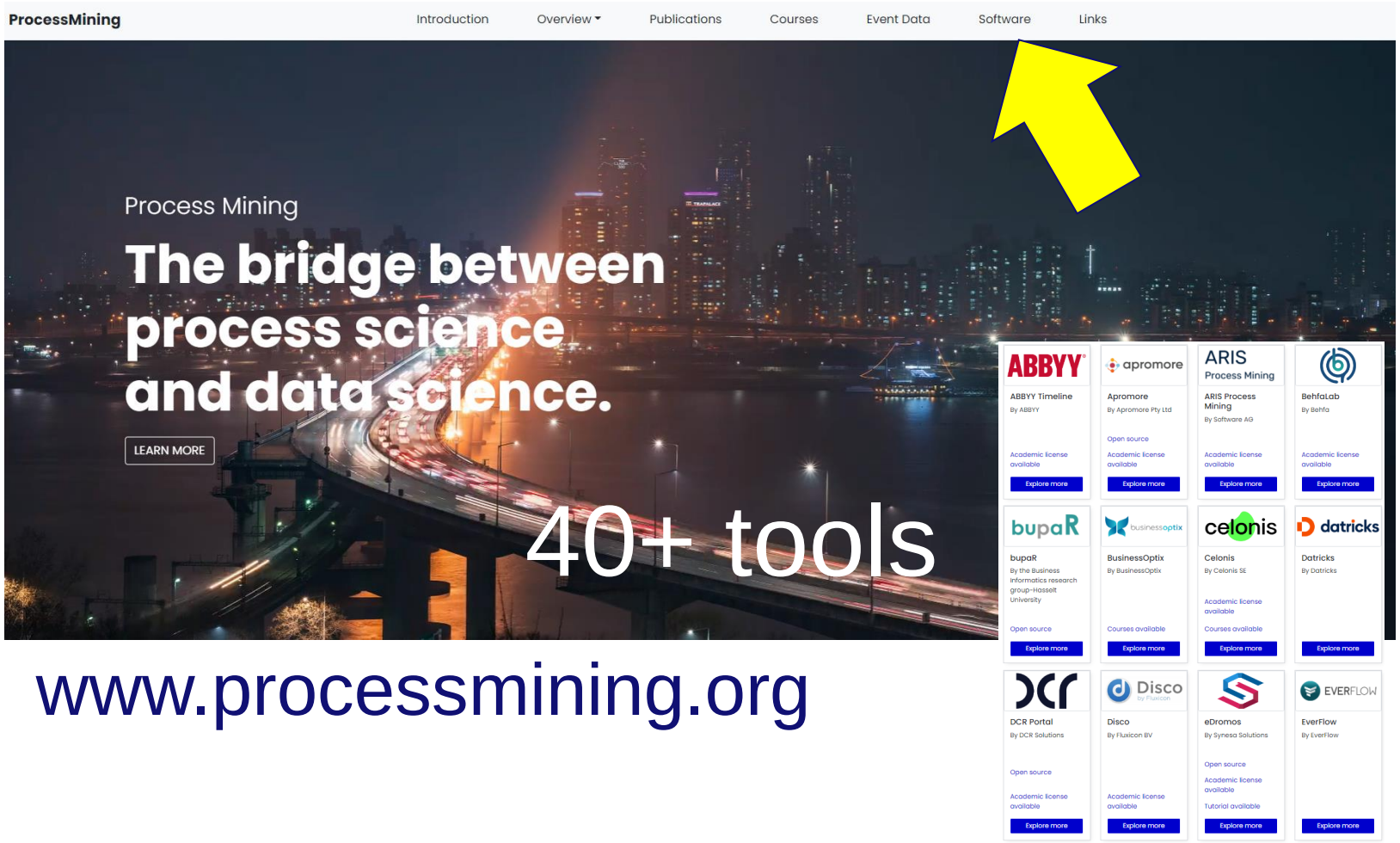
RWTH AACHEN UNIVERSITY

Many process mining tools are available

Vendor	Tool	Website	Acad. ver.
Abbyy	ABBYY Timeline	www.abbyy.com	No
Appian (Lana Labs)	LANA Process Mining	lanalabs.com	No
Apromore	Apromore Enterprise Edition	apromore.org	Yes
bupaR	bupaR	bupar.net	Yes
businessOptix	businessOptix	businessoptix.com	Yes
Celonis	Celonis EMS	celonis.com	Yes
Datricks	Datricks	datricks.com	Yes
DCR	DCR Portal	www.dcrsolutions.net	Yes
Deloitte	Process X-ray	processxray.deloitte.com	No
EverFlow	EverFlow	everflow.ai	No
Fluxicon	Disco	fluxicon.com	Yes
FortressIQ	FortressIQ	fortressiq.com	No
Fraunhofer FIT	PM4Py	pm4py.fit.fraunhofer.de	Yes
Hyland	Onbase	www.hyland.com	No
IBM (myInvenio)	myInvenio	my-invenio.com	No
Integris	Explora Process	integris.it	No
Kofax	Kofax Insight	www.kofax.com	No
livejourney	livejourney	www.livejourney.com	No
Logpickr	Logpickr Process Explorer 360	www.logpickr.com	No
Mavim	Mavim	www.mavim.co	No
Mehrwerk GmbH	MPM	mpm-processmining.com	No
Mindzie	mindzie	mindzie.com	Yes
Minit (Microsoft)	Minit	www.minit.io	Yes
Nintex UK ltd	Nintex	www.nintex.com	No
Oniq	IQ/A	www.oniq.com	No
PAFnow (Celonis)	PAFnow	pafnow.com	No
Process.science	process.science	www.process.science	No
ProcessDiamond	ProcessDiamond	processdiamond.com	Yes
ProcessM	PmBI	processm.com	Yes
Puzzle Data	ProDiscovery	www.puzzledata.com	No
QPR Software	QPR ProcessAnalyzer	www.qpr.com	No
SAP (Signavio)	SAP Signavio	www.signavio.com	Yes
Skan AI	Skan	www.skan.ai	No
Software AG	Aris	aris-process-mining.com	Yes
Soroco	Scout Platform	soroco.com	No
StereoLogic	StereoLogic Process Mining	www.stereologic.com	No
TU/e	ProM	www.promtools.org	Yes
TU/e	RapidProM	www.rapidprom.org	Yes
UI Path	UI Path Process Mining	www.uipath.com	Yes
UltimateSuite	UltimateSuite TM/RPA	www.ultimatesuite.com	No
Upflux	Upflux	upflux.net	No
Worksoft	Worksoft	www.worksoft.com	No

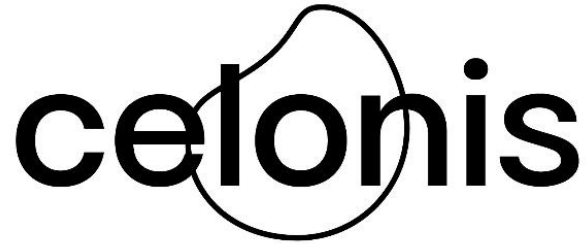


www.processmining.org

Chair of Process and Data Science

Two example tools used to illustrate the concepts

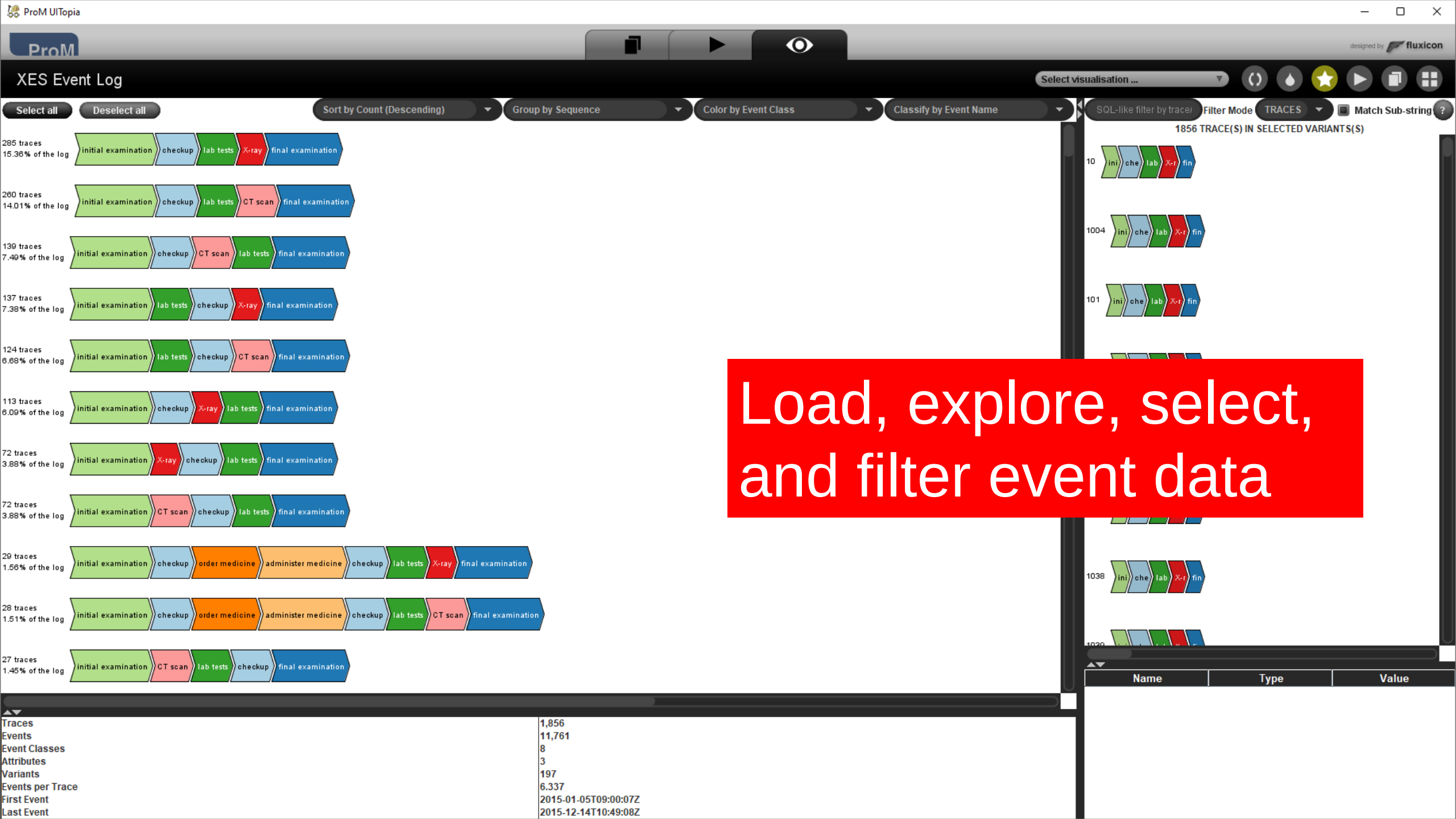
open source
academic
local installation
single user
focus on experts



closed source
commercial
cloud based
multiple users
also for non-experts

Example of an open-source tool: ProM

- Download from www.promtools.org.
- ProM 1.1, released in 2004, had 29 plug-ins.
- ProM 6.11 has over 1500 plug-ins.
- Created to avoid reinventing the wheel in science.
- Different flavors: ProM, ProM Lite, Nightly Builds, RapidProM.
- GNU Public License (GPL) for core and Lesser GNU Public License (L-GPL) for most of the plug-ins.


ProM UITopia
ProM
designed by fluxicon
XES Event Log
Select visualisation ...
Select all
Deselect all
Sort by Count (Descending)
Group by Sequence
Color by Event Class
Classify by Event Name
SQL-like filter by trace/
Filter Mode
TRACES
Match Sub-string
1856 TRACE(S) IN SELECTED VARIANTS(S)
285 traces 15.36% of the log
initial examination checkup lab tests X-ray final examination
260 traces 14.01% of the log
initial examination checkup lab tests CT scan final examination
139 traces 7.49% of the log
initial examination checkup CT scan lab tests final examination
137 traces 7.38% of the log
initial examination lab tests checkup X-ray final examination
124 traces 6.68% of the log
initial examination lab tests checkup CT scan final examination
113 traces 6.09% of the log
initial examination checkup X-ray lab tests final examination
72 traces 3.88% of the log
initial examination X-ray checkup lab tests final examination
72 traces 3.88% of the log
initial examination CT scan checkup lab tests final examination
29 traces 1.56% of the log
initial examination checkup order medicine administer medicine checkup lab tests X-ray final examination
28 traces 1.51% of the log
initial examination checkup order medicine administer medicine checkup lab tests CT scan final examination
27 traces 1.45% of the log
initial examination CT scan lab tests checkup final examination
10
1004
101
1038
Load, explore, select, and filter event data
Name
Type
Value
Traces 1,856
Events 11,761
Event Classes 8
Attributes 3
Variants 197
Events per Trace 6.337
First Event 2015-01-05T09:00:07Z
Last Event 2015-12-14T10:49:08Z


ProM UITopia
ProM
designed by fluxicon
XES Event Log
Select visualisation ...
X Axis Attribute
E: time:timestamp
Y Axis Attribute
T: concept:name
Trace Sorting
Sort on time:startTime of trace.
Color Attribute
C: Event Name
Shape Attribute
Attribute Statistics
Connect events
Traces sorted.(in 14 ms)
Inspector
Info
Legend
CT scan
X-ray
administer medicine
checkup
final examination
initial examination
lab tests
order medicine
all
Trace: concept:name
Event: time:timestamp
28-Apr
30-Apr
2-May
4-May
6-May
8-May
10-May
12-May
14-May
16-May
18-May
20-May
22-May
24-May
26-May
28-May
30-May
100 % rendered
in 0.01 sec.
Load, explore, select,
and filter event data

ProM UITopia

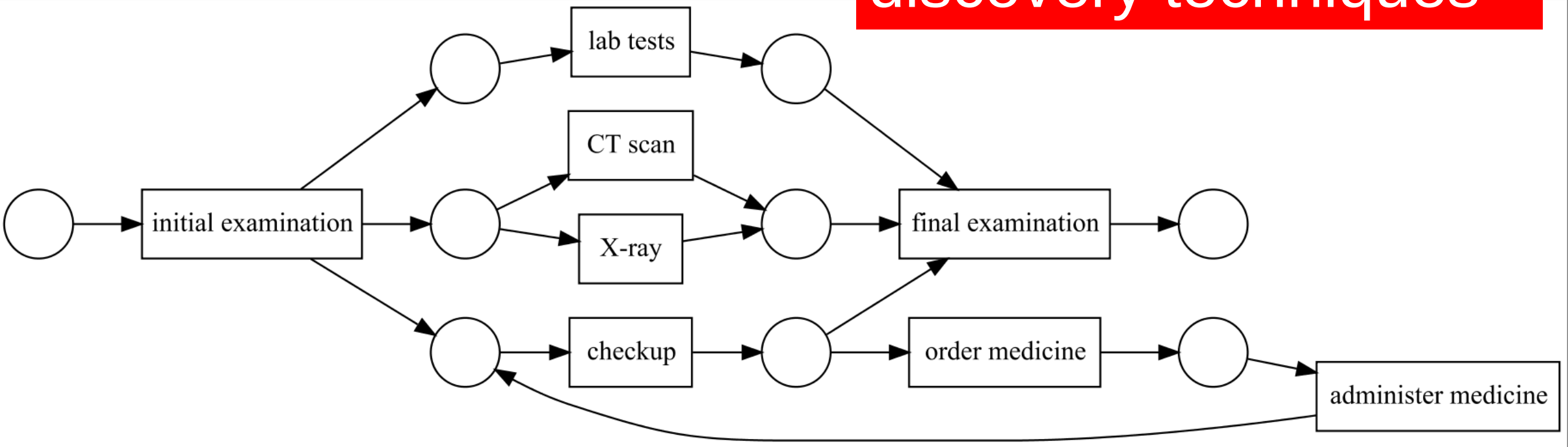
ProM

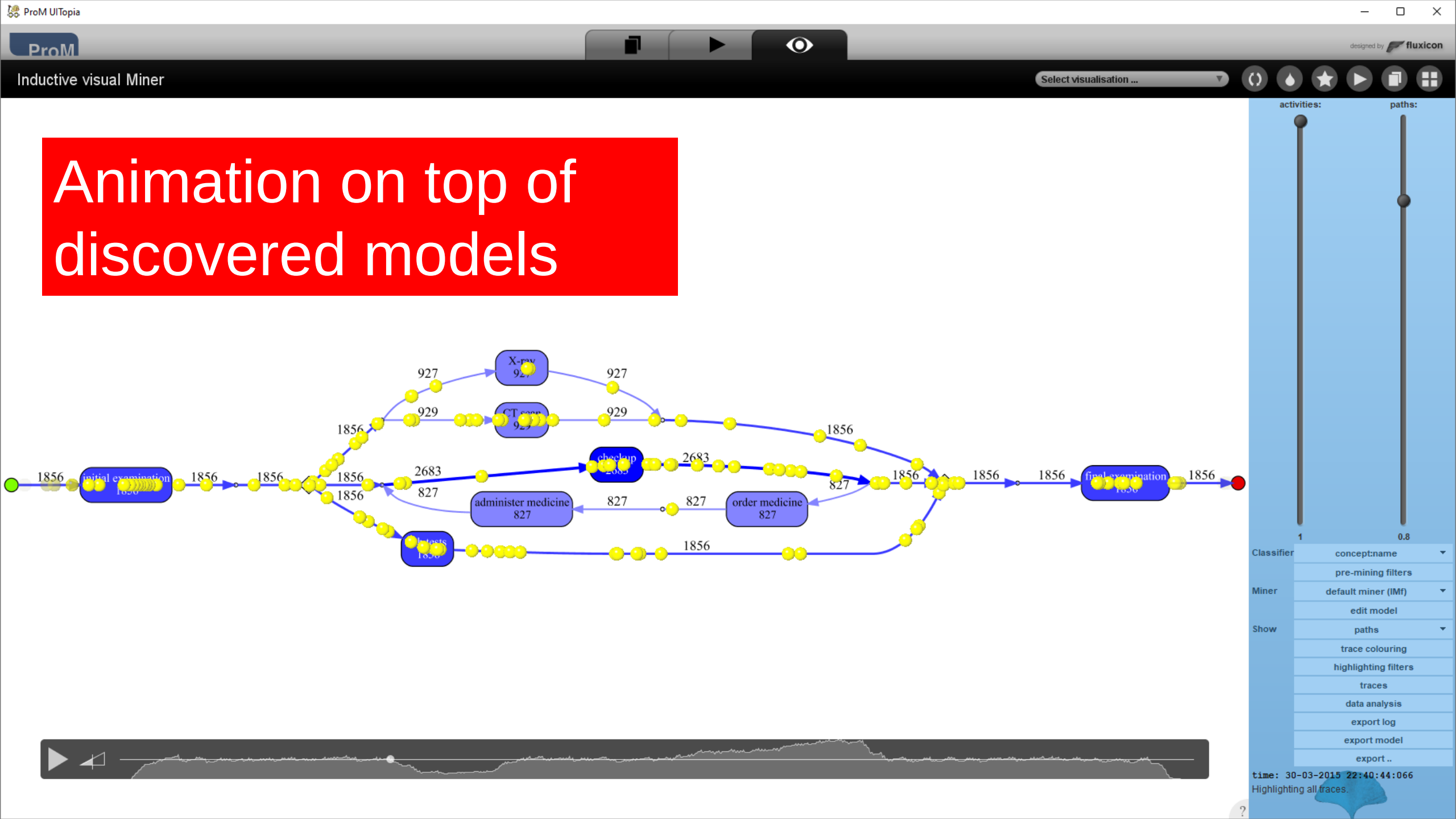
designed by fluxicon

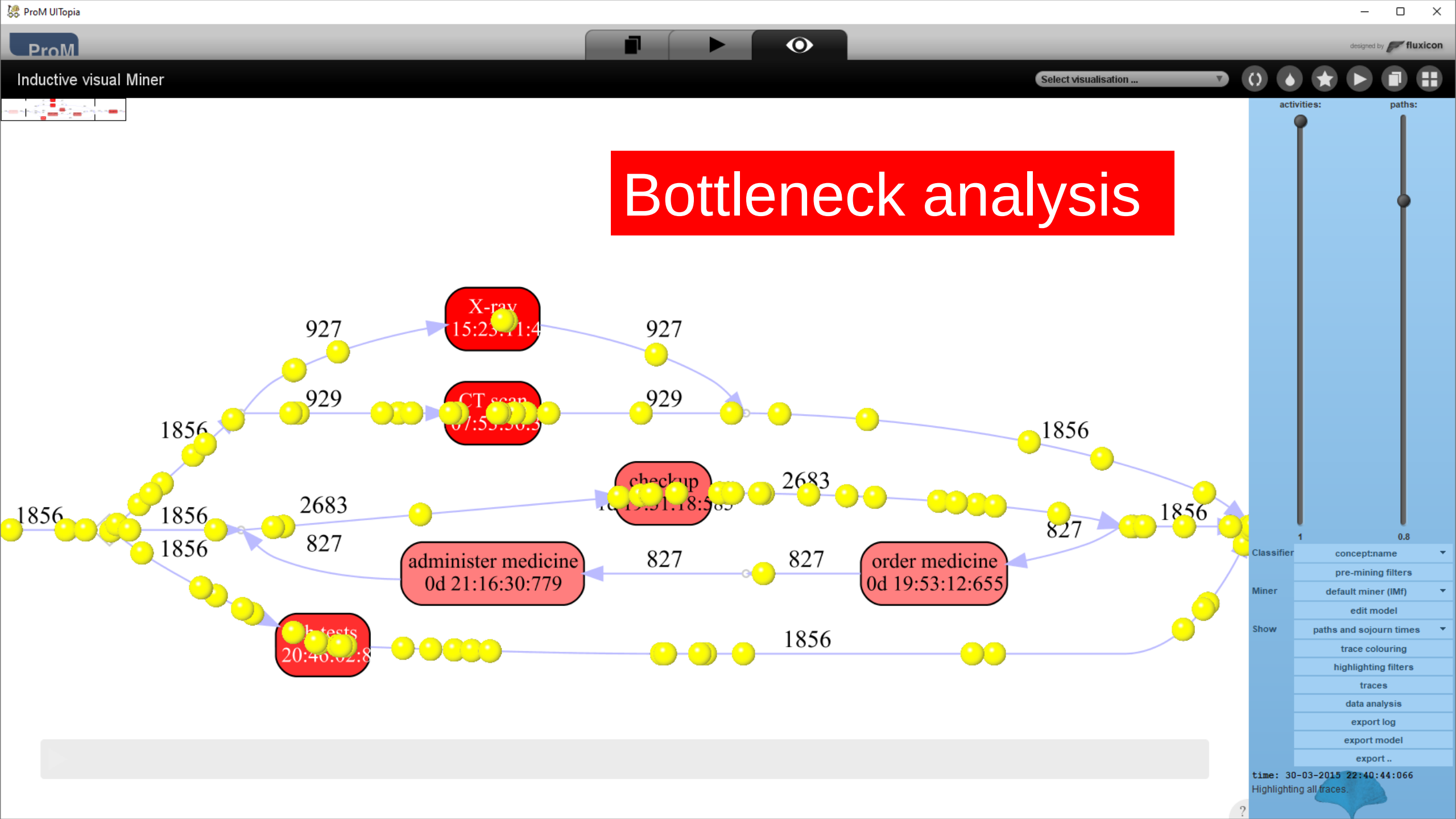
Petrinet

Select visualisation ...

Dozens of process discovery techniques




ProM UITopia
ProM
designed by fluxicon
Inductive visual Miner
Select visualisation ...
Animation on top of discovered models
activities:
paths:
1
0.8
Classifier
concept:name
pre-mining filters
Miner
default miner (IMf)
edit model
Show
paths
trace colouring
highlighting filters
traces
data analysis
export log
export model
export ..
time: 30-03-2015 22:40:44:066
Highlighting all traces.
initial examination
X-ray
CT scan
checkup
administer medicine
order medicine
final examination
1856
927
929
2683
827


ProM UITopia
ProM
designed by fluxicon
Inductive visual Miner
Select visualisation ...
Bottleneck analysis
activities:
paths:
1
0.8
X-ray
927
927
CT scan
929
929
1856
1856
checkup
2683
2683
1856
1856
1856
827
827
1856
administer medicine
0d 21:16:30:779
827
827
order medicine
0d 19:53:12:655
1856
Classifier
concept:name
pre-mining filters
Miner
default miner (IMf)
edit model
Show
paths and sojourn times
trace colouring
highlighting filters
traces
data analysis
export log
export model
export ..
time: 30-03-2015 22:40:44:066
Highlighting all traces.

ProM UITopia

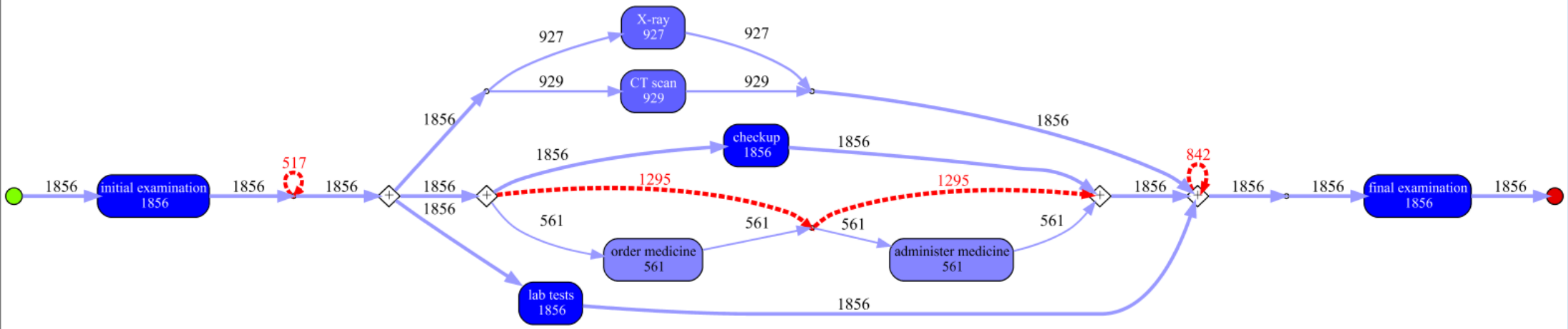
ProM

designed by fluxicon

Inductive visual Miner

Select visualisation ...

Conformance checking



activities: paths:

1 1

Classifier concept:name

pre-mining filters

Miner default miner (IMf)

edit model

Show paths and deviations

trace colouring

highlighting filters

traces

data analysis

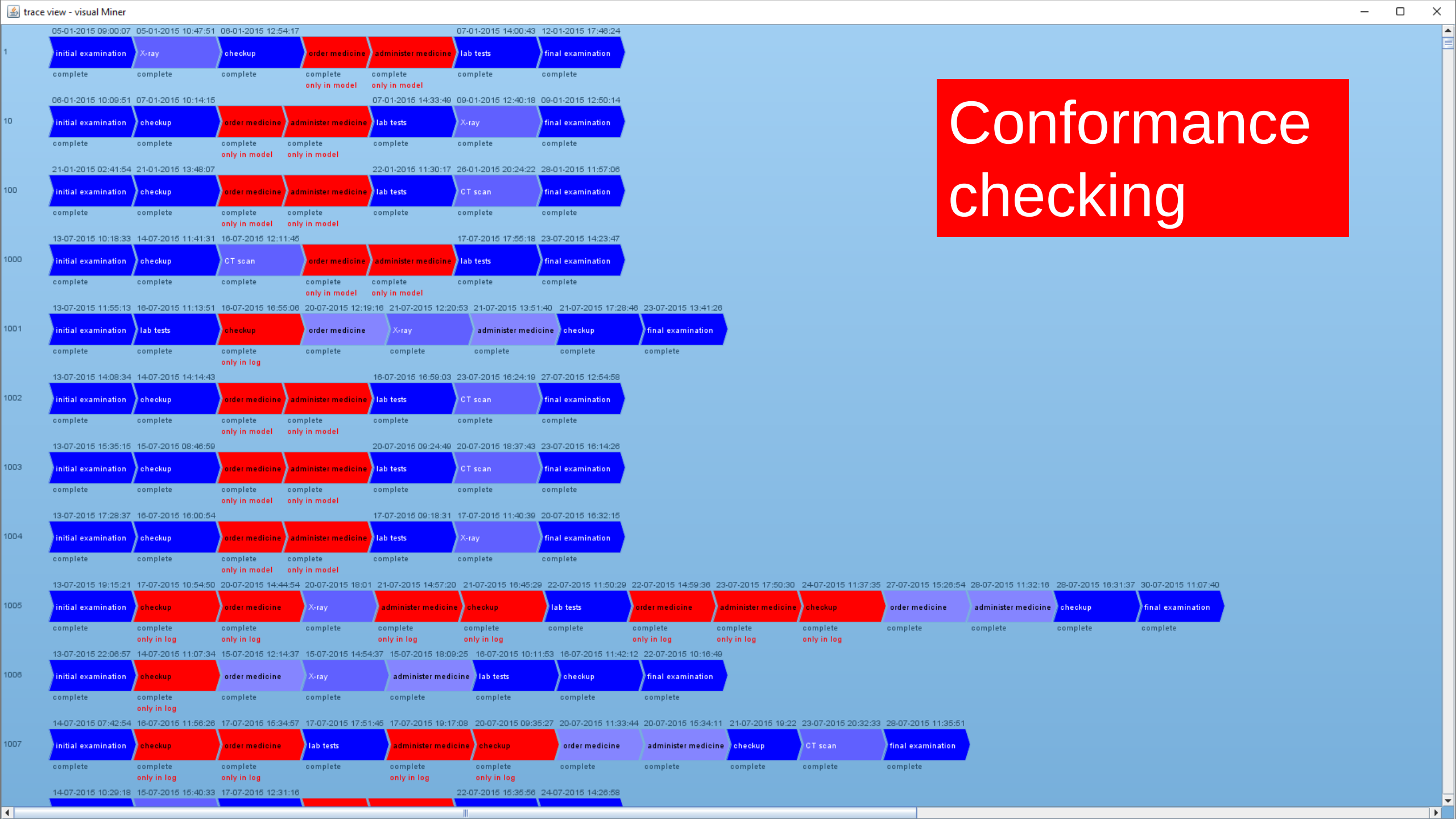
export log

export model

export ..

time: 01-01-2015 11:26:09:034

Highlighting all traces.

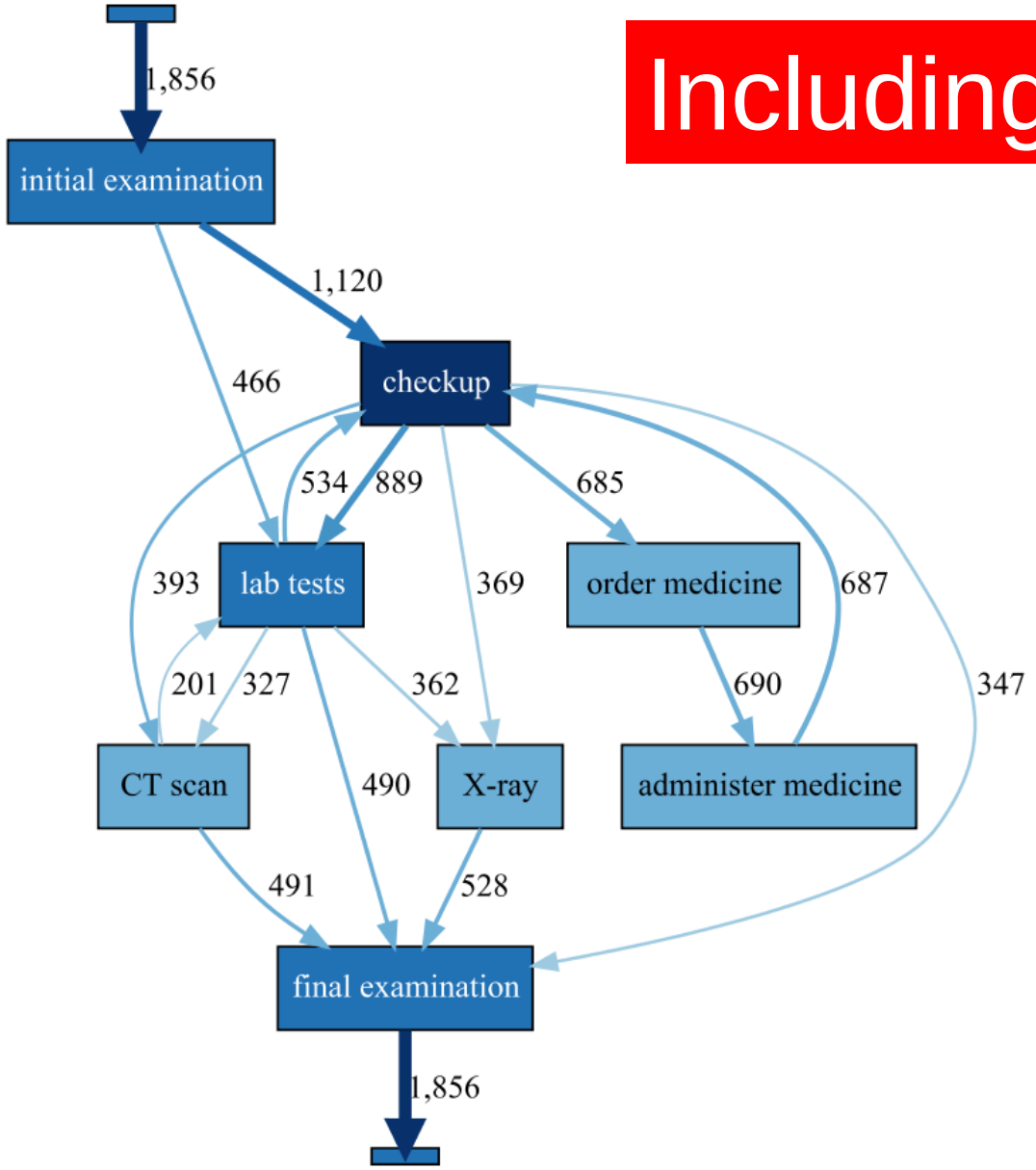

trace view - visual Miner
Conformance checking
1
initial examination
X-ray
checkup
order medicine
administer medicine
lab tests
final examination
10
initial examination
checkup
order medicine
administer medicine
lab tests
X-ray
final examination
100
initial examination
checkup
order medicine
administer medicine
lab tests
CT scan
final examination
1000
initial examination
checkup
CT scan
order medicine
administer medicine
lab tests
final examination
1001
initial examination
lab tests
checkup
order medicine
X-ray
administer medicine
checkup
final examination
1002
initial examination
checkup
order medicine
administer medicine
lab tests
CT scan
final examination
1003
initial examination
checkup
order medicine
administer medicine
lab tests
CT scan
final examination
1004
initial examination
checkup
order medicine
administer medicine
lab tests
X-ray
final examination
1005
initial examination
checkup
order medicine
X-ray
administer medicine
checkup
lab tests
order medicine
administer medicine
checkup
order medicine
administer medicine
checkup
final examination
1006
initial examination
checkup
order medicine
X-ray
administer medicine
lab tests
checkup
final examination
1007
initial examination
checkup
order medicine
lab tests
administer medicine
checkup
order medicine
administer medicine
checkup
CT scan
final examination

ProM UITopia

Interactive Data-aware Heuristic Miner for XES Event Log

Base Model

Including DFGs



INPUT: TRACES

attribute = "value" (use right click to view available attribu

Using 1,856/1,856 traces, 15,473/15,473 events

OUTPUT: PROCESS MODEL

Directly-follows Graph | Export model

SELECTED HEURISTICS

OPTIONS & THRESHOLDS

Frequency:

0.1

Using 18/35 directly-follows relations occuring at least 186 times

Expert Options

LEGEND

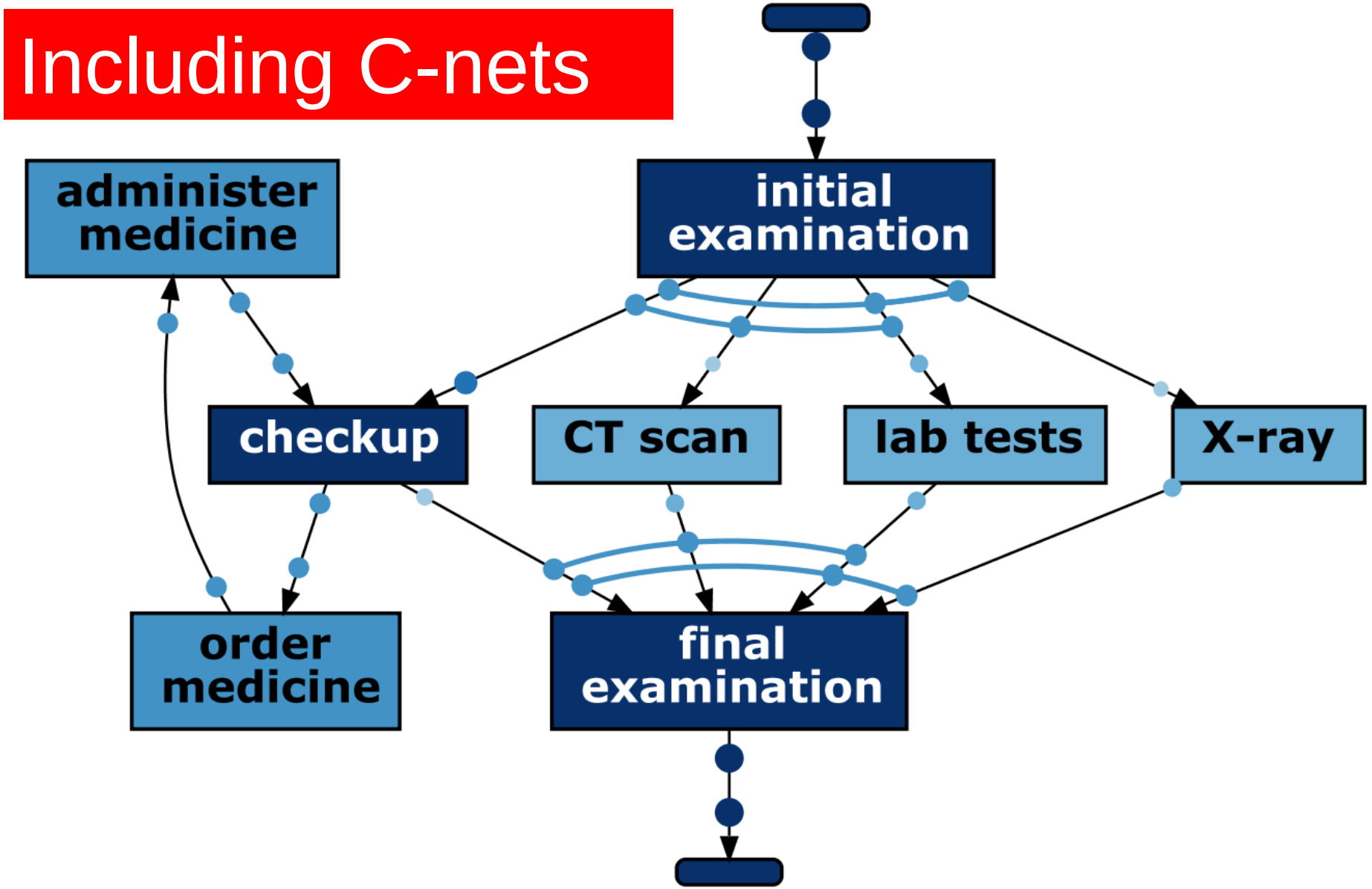
none 0 0.2 0.4 0.6 0.8

ProM UITopia

Interactive Data-aware Heuristic Miner for XES Event Log

Base Model

Including C-nets



INPUT: TRACES

attribute = "value" (use right click to view available attributes)

Using 1,856/1,856 traces, 15,473/15,473 events

OUTPUT: PROCESS MODEL

Causal net (C-net) | Export model

SELECTED HEURISTICS

Dependency Heuristic	Flexible Heuristics Miner
Conditional Heuristic	C4.5 (Cohen's Kappa)
Bindings Heuristic	Nearest Activity (FHM)
Conformance Heuristic	None

OPTIONS & THRESHOLDS

Frequency:	Dependency:	Bindings:	Conditions:
0.1	0.9	0.1	0.5

Using 18/35 directly-follows relations occuring at least 186 times

Long Term Dependencies | Data-aware Config

All Tasks Connected | Expert Options

Accepted Connected

LEGEND

none 0 0.2 0.4 0.6 0.8

ProM Tools

Processes are an integral part of today's world, driving services and internal functionalities in businesses, governmental bodies, and organizations around the globe. While there are plenty of systems available for supporting the execution of such processes, the current practices for monitoring and analyzing this execution in the organizational reality still leaves a lot to be desired. **Process Mining** is able to fill that gap, providing revolutionary means for the analysis and monitoring of real-life processes.

Process Mining research is concerned with the **extraction of knowledge about a (business) process from its process execution logs**. Process Mining strives to gain insight into various perspectives, such as the process (or control flow) perspective, the performance, data, and organizational perspective (The processmining.org web site has more in-depth information and scientific publications available).

ProM is an **extensible** framework that supports a wide variety of process mining techniques in the form of plug-ins. It is **platform** ort **practical**

These were just 5 of 1500 plug-ins, just try some more yourself.

Ask Eric Verbeek and/or PADS members if you get stuck.

Example of a commercial tool: Celonis

- Most successful commercial process mining tool.
- Celonis was founded in 2011 by Alex, Basti, and Martin.
- Characteristics:
  - The first process mining tool aiming at non data-scientists (using dashboards, cloud, apps, adapters).
  - Highly scalable (SaolaDB in-memory database).
  - Process Query Language (PQL) is at the core.
  - The first to support action-oriented process mining (Integromat/Make connects to 1000+ systems).

Inbox (1,356) - w.van-der-aalst@ | Overview | Data Integration

wvdaalst.eu-1.celonis.cloud/integration/ui/pools/3a60992e-cfa1-48bc-981a-53fc80dc9410/overview

Data Pools › summerschool

- Overview
- Execution History
- Versions

System administration

- Data Connections
- File Uploads
- Extractor Builder

Data configuration

- Data Jobs
- Replication Cockpit
- Process Data Models

Advanced Settings

- Data Pool Parameters
- Task Templates
- Scheduling

Data Transfer

- Export
- Import

Overview

Create your first Data Connection to get started.

Use Data Connections to connect to a large variety of source systems. You will need to establish a data connection first, before you can extract data.

New Data Connection

You have not executed any Data Jobs yet.

Data Jobs combine extraction and transformation tasks and allow you to execute them in sequence. For extractions, you first need to establish a Data Connection.

Go To Data Jobs

Process Data Models

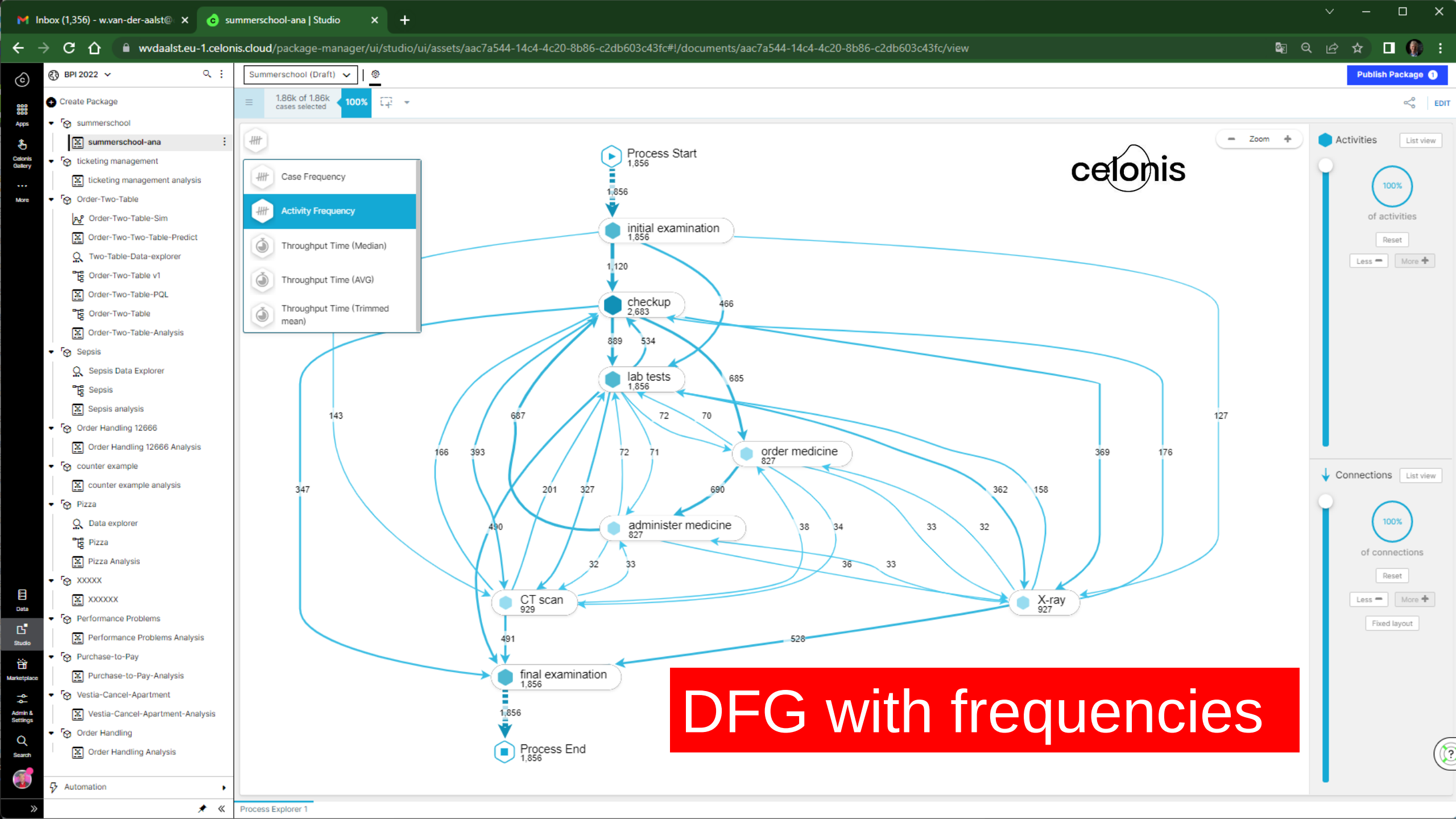
summerschool 2022-06-29 19:31:39

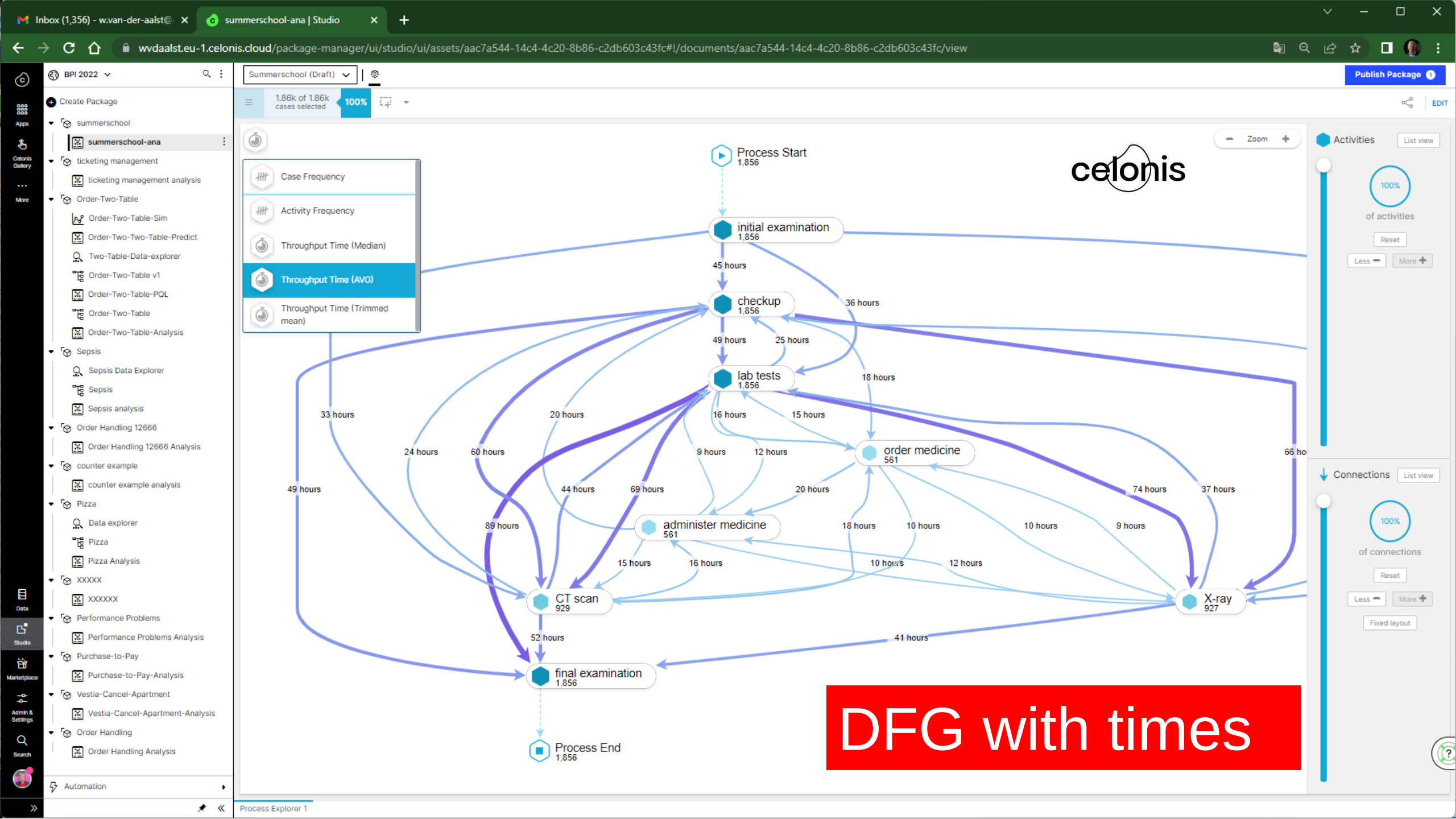
New Data Model

celonis

cloud based

Loading and transforming data (event and case tables in a snowflake schema)


Inbox (1,356) - w.van-der-aalst@
summerschool-ana | Studio
wvdaalst.eu-1.celonis.cloud/package-manager/ui/studio/ui/assets/aac7a544-14c4-4c20-8b86-c2db603c43fc#!/documents/aac7a544-14c4-4c20-8b86-c2db603c43fc/view
BPI 2022
Create Package
summerschool
summerschool-ana
ticketing management
ticketing management analysis
Order-Two-Table
Order-Two-Table-Sim
Order-Two-Two-Table-Predict
Two-Table-Data-explorer
Order-Two-Table v1
Order-Two-Table-PQL
Order-Two-Table
Order-Two-Table-Analysis
Sepsis
Sepsis Data Explorer
Sepsis
Sepsis analysis
Order Handling 12666
Order Handling 12666 Analysis
counter example
counter example analysis
Pizza
Data explorer
Pizza
Pizza Analysis
XXXXX
XXXXXX
Performance Problems
Performance Problems Analysis
Purchase-to-Pay
Purchase-to-Pay-Analysis
Vestia-Cancel-Apartment
Vestia-Cancel-Apartment-Analysis
Order Handling
Order Handling Analysis
Automation
Summerschool (Draft)
Publish Package
1.86k of 1.86k cases selected
100%
EDIT
Zoom
Case Frequency
Activity Frequency
Throughput Time (Median)
Throughput Time (AVG)
Throughput Time (Trimmed mean)
Process Start 1,856
initial examination 1,856
checkup 2,683
lab tests 1,856
order medicine 827
administer medicine 827
CT scan 929
X-ray 927
final examination 1,856
Process End 1,856
1,856
1,120
466
889
534
685
143
687
72
70
127
166
393
72
71
369
176
347
201
327
690
362
158
490
38
34
33
32
32
33
36
33
491
528
1,856
celonis
Activities
List view
100%
of activities
Reset
Less
More
Connections
List view
100%
of connections
Reset
Less
More
Fixed layout
DFG with frequencies
Process Explorer 1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Case Frequency
Activity Frequency
Throughput Time (Median)
Throughput Time (AVG)
Throughput Time (Trimmed mean)
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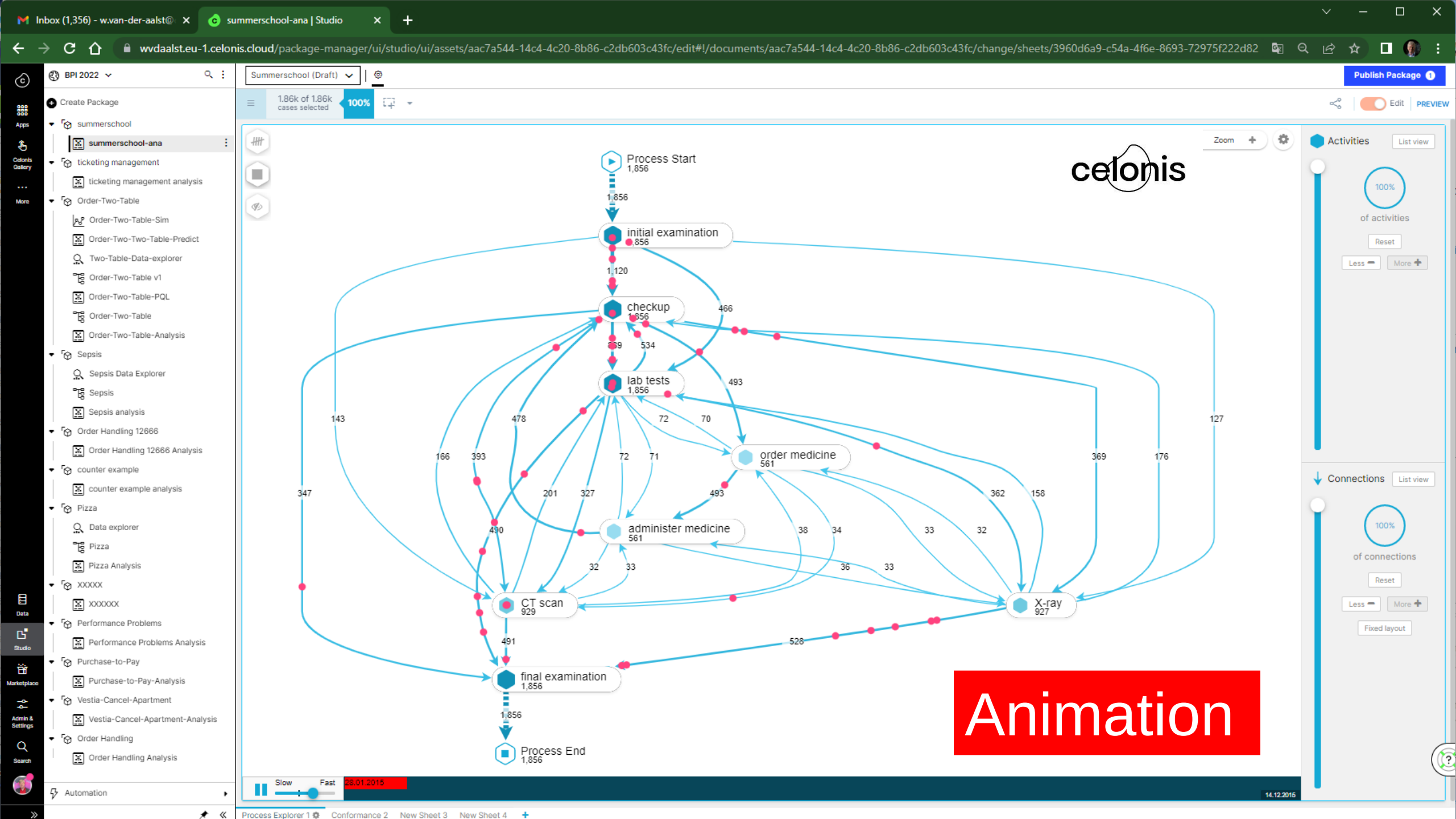
initial examination 1,856
checkup 1,856
lab tests 1,856
order medicine 561
administer medicine 561
CT scan 929
X-ray 927
final examination 1,856
Process End 1,856
45 hours
36 hours
49 hours
25 hours
18 hours
33 hours
20 hours
16 hours
15 hours
24 hours
60 hours
9 hours
12 hours
66 ho
49 hours
44 hours
69 hours
20 hours
74 hours
37 hours
89 hours
18 hours
10 hours
10 hours
9 hours
15 hours
16 hours
10 hours
12 hours
52 hours
41 hours
celonis
Activities
List view
100%
of activities
Reset
Less
More
Connections
List view
100%
of connections
Reset
Less
More
Fixed layout
DFG with times
Process Explorer 1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administer medicine 561
CT scan 929
X-ray 927
final examination 1,856
Process End 1,856
Activities
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of activities
Reset
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More
Connections
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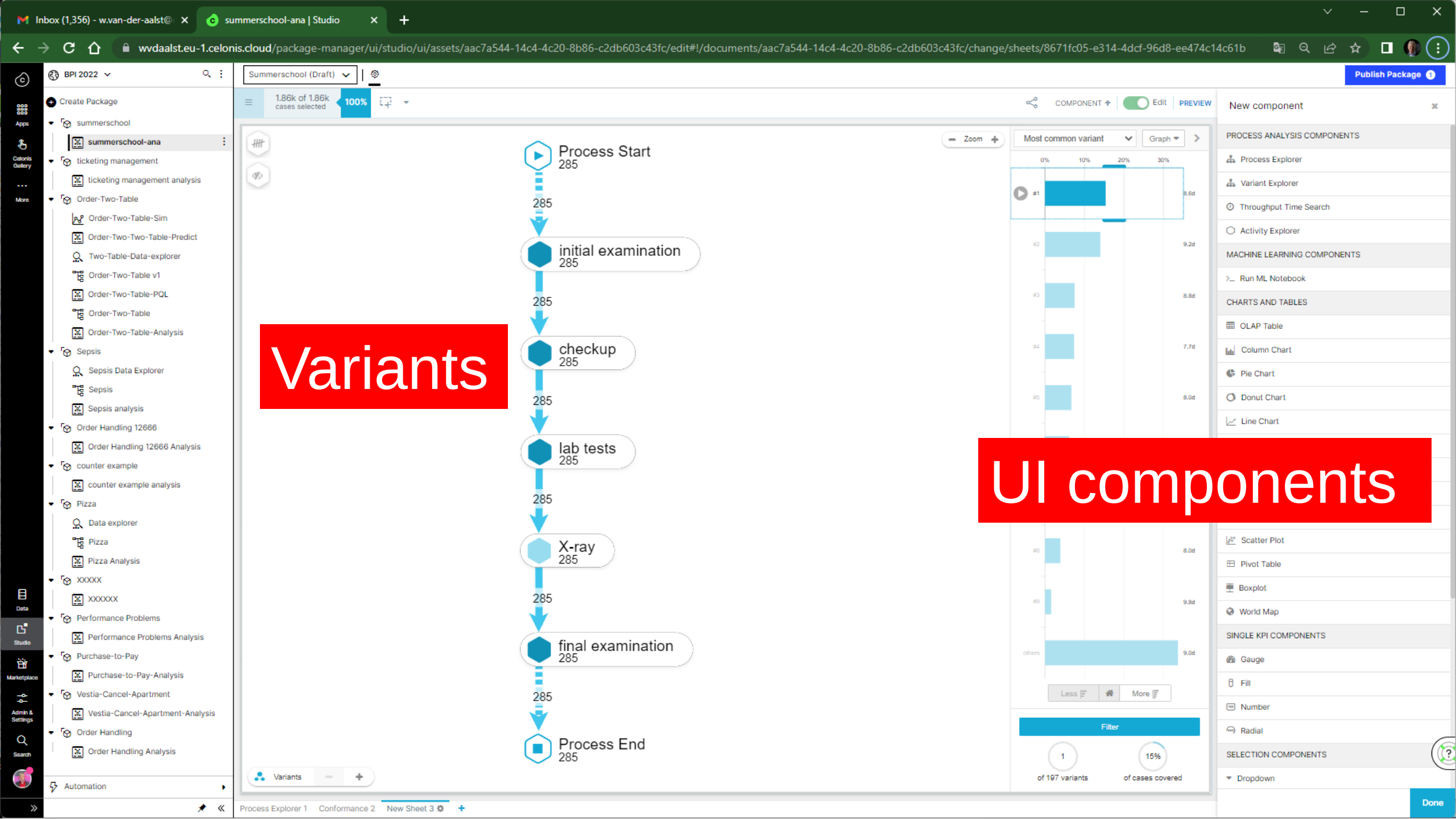
Fixed layout
Slow
Fast
28.01.2015
14.12.2015
Animation
Process Explorer 1
Conformance 2
New Sheet 3
New Sheet 4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Vestia-Cancel-Apartment-Analysis
Order Handling
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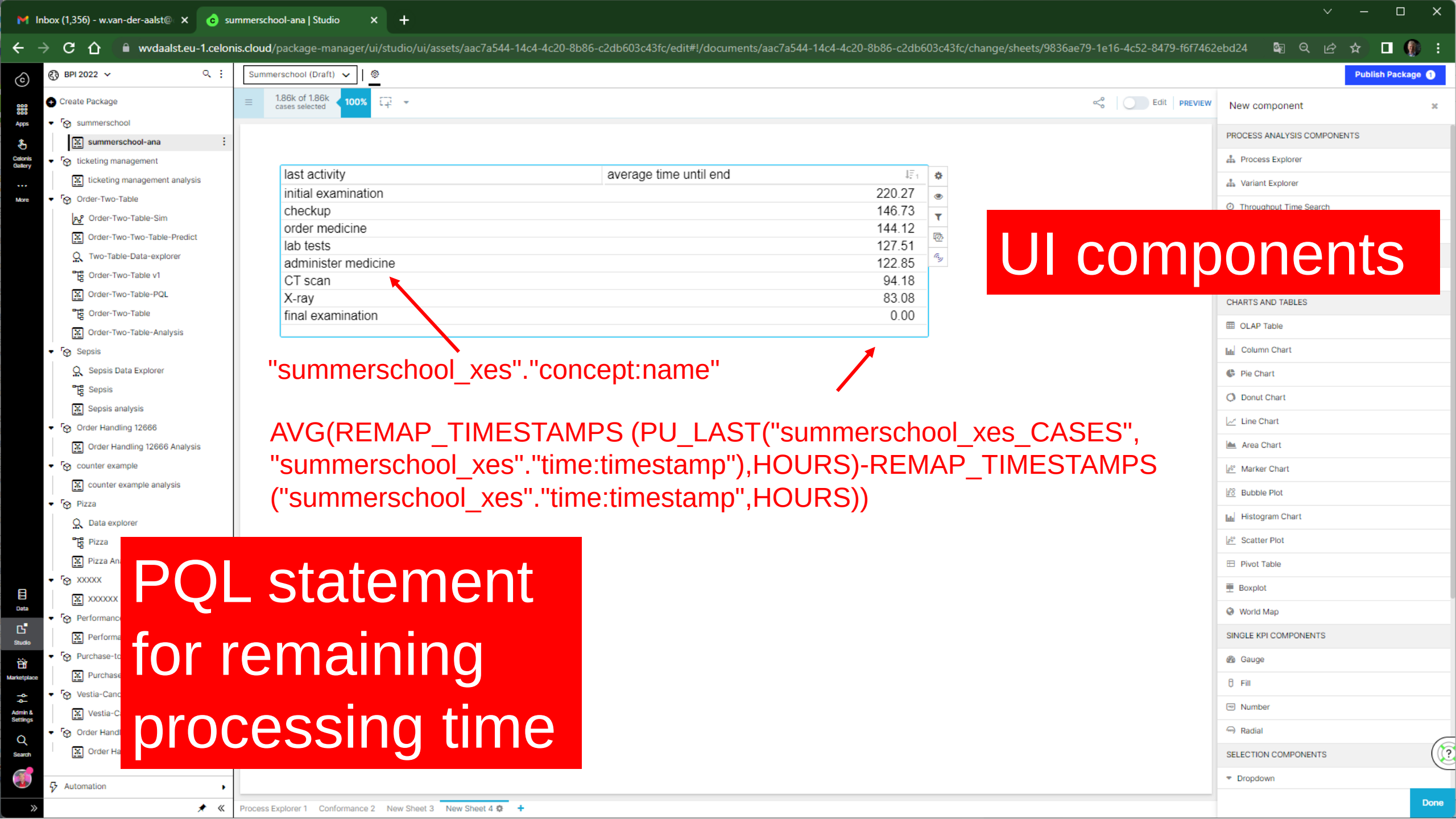
Automation
Summerschool (Draft)
Publish Package
1.86k of 1.86k cases selected
100%
COMPONENT
Edit
PREVIEW
Process Start 285
285
initial examination 285
285
checkup 285
285
lab tests 285
285
X-ray 285
285
final examination 285
285
Process End 285
Variants
Zoom
Most common variant
Graph
Filter
1
of 197 variants
15%
of cases covered
New component
PROCESS ANALYSIS COMPONENTS
Process Explorer
Variant Explorer
Throughput Time Search
Activity Explorer
MACHINE LEARNING COMPONENTS
Run ML Notebook
CHARTS AND TABLES
OLAP Table
Column Chart
Pie Chart
Donut Chart
Line Chart
Scatter Plot
Pivot Table
Boxplot
World Map
SINGLE KPI COMPONENTS
Gauge
Fill
Number
Radial
SELECTION COMPONENTS
Dropdown
Done
Process Explorer 1
Conformance 2
New Sheet 3
Variants
UI components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Create Package
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Order Handling 12666
Order Handling 12666 Analysis
counter example
counter example analysis
Pizza
Data explorer
Pizza
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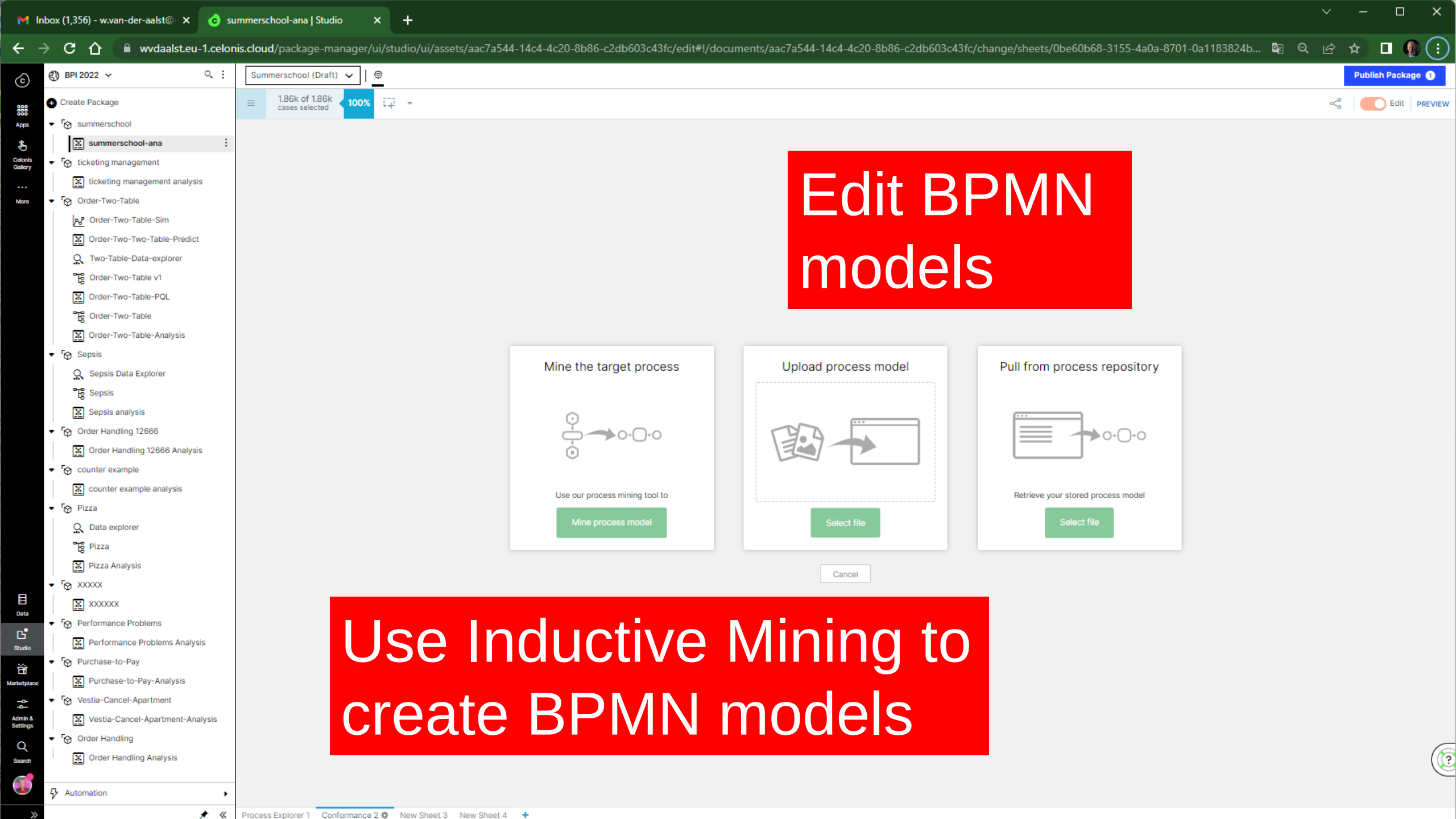
Automation
Summerschool (Draft)
Publish Package
1.86k of 1.86k cases selected
100%
Edit
PREVIEW
last activity
average time until end
initial examination 220.27
checkup 146.73
order medicine 144.12
lab tests 127.51
administer medicine 122.85
CT scan 94.18
X-ray 83.08
final examination 0.00
"summerschool_xes"."concept:name"
AVG(REMAP_TIMESTAMPS (PU_LAST("summerschool_xes_CASES", "summerschool_xes"."time:timestamp"),HOURS)-REMAP_TIMESTAMPS ("summerschool_xes"."time:timestamp",HOURS))
PQL statement for remaining processing time
UI components
New component
PROCESS ANALYSIS COMPONENTS
Process Explorer
Variant Explorer
Throughput Time Search
CHARTS AND TABLES
OLAP Table
Column Chart
Pie Chart
Donut Chart
Line Chart
Area Chart
Marker Chart
Bubble Plot
Histogram Chart
Scatter Plot
Pivot Table
Boxplot
World Map
SINGLE KPI COMPONENTS
Gauge
Fill
Number
Radial
SELECTION COMPONENTS
Dropdown
Done
Process Explorer 1
Conformance 2
New Sheet 3
New Sheet 4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BPI 2022
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Vestia-Cancel-Apartment-Analysis
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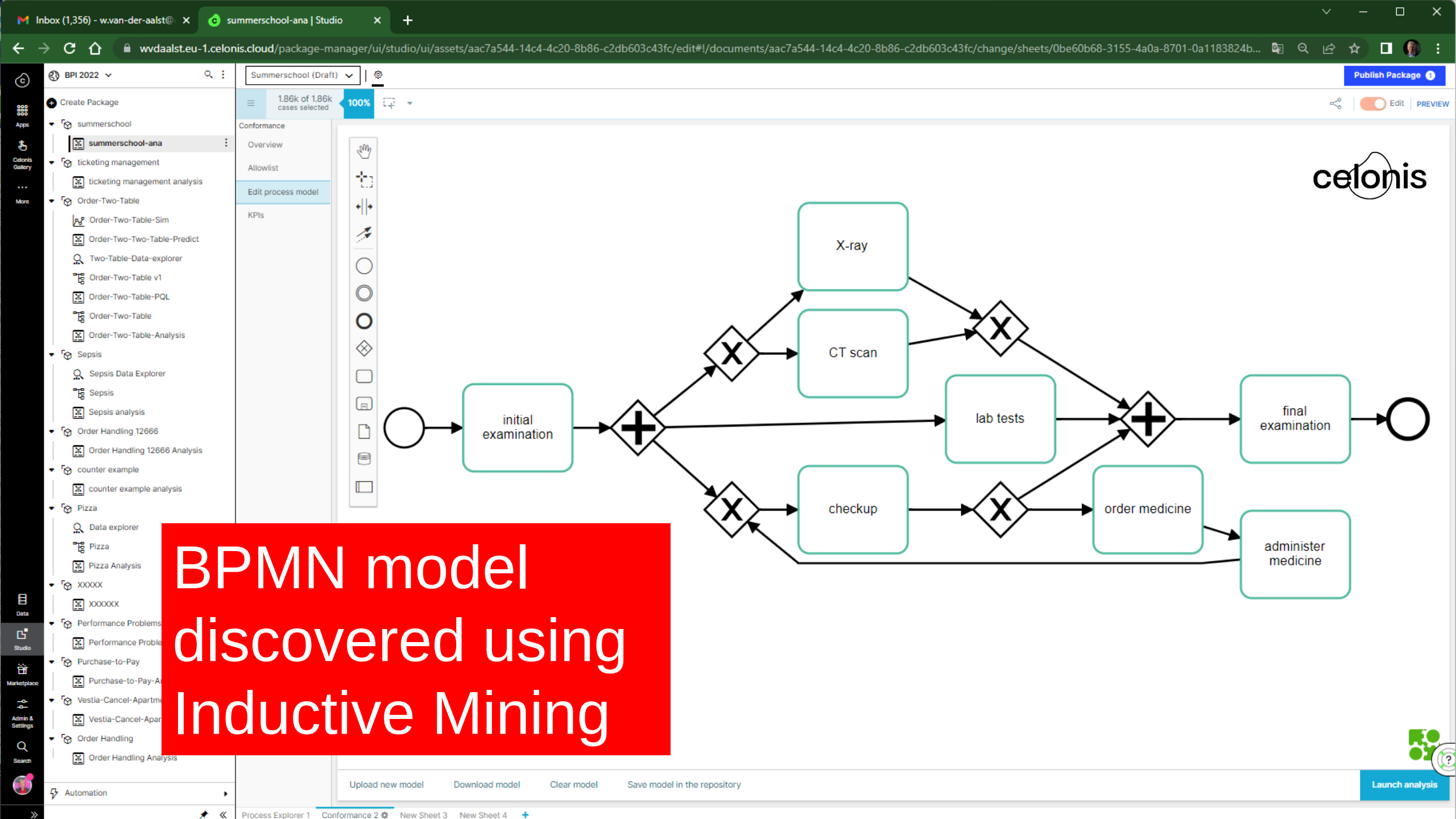
Order Handling Analysis
Automation
Summerschool (Draft)
Publish Package
1.86k of 1.86k cases selected
100%
Edit
PREVIEW
Edit BPMN models
Mine the target process
Use our process mining tool to
Mine process model
Upload process model
Select file
Pull from process repository
Retrieve your stored process model
Select file
Cancel
Use Inductive Mining to create BPMN models
Process Explorer 1
Conformance 2
New Sheet 3
New Sheet 4


Inbox (1,356) - w.van-der-aalst@
summerschool-ana | Studio
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BPI 2022
Create Package
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Performance Proble
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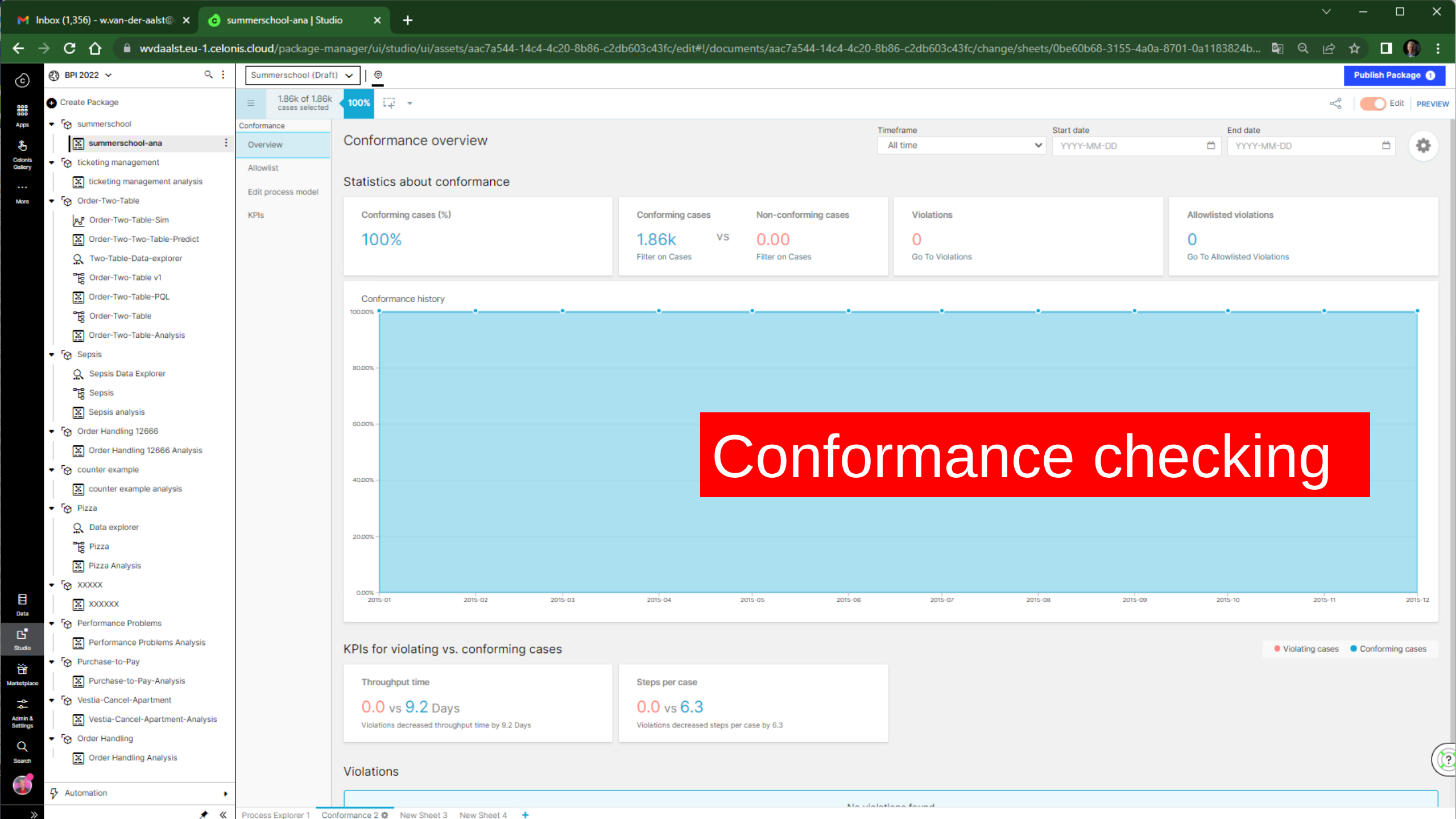
Purchase-to-Pay-A
Vestia-Cancel-Apartm
Vestia-Cancel-Apar
Order Handling
Order Handling Analysis
Automation
Summerschool (Draft)
1.86k of 1.86k cases selected
100%
Publish Package
Edit
PREVIEW
Conformance
Overview
Allowlist
Edit process model
KPIs
celonis
X-ray
CT scan
initial examination
lab tests
final examination
checkup
order medicine
administer medicine
BPMN model discovered using Inductive Mining
Upload new model
Download model
Clear model
Save model in the repository
Launch analysis
Process Explorer 1
Conformance 2
New Sheet 3
New Sheet 4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BPI 2022
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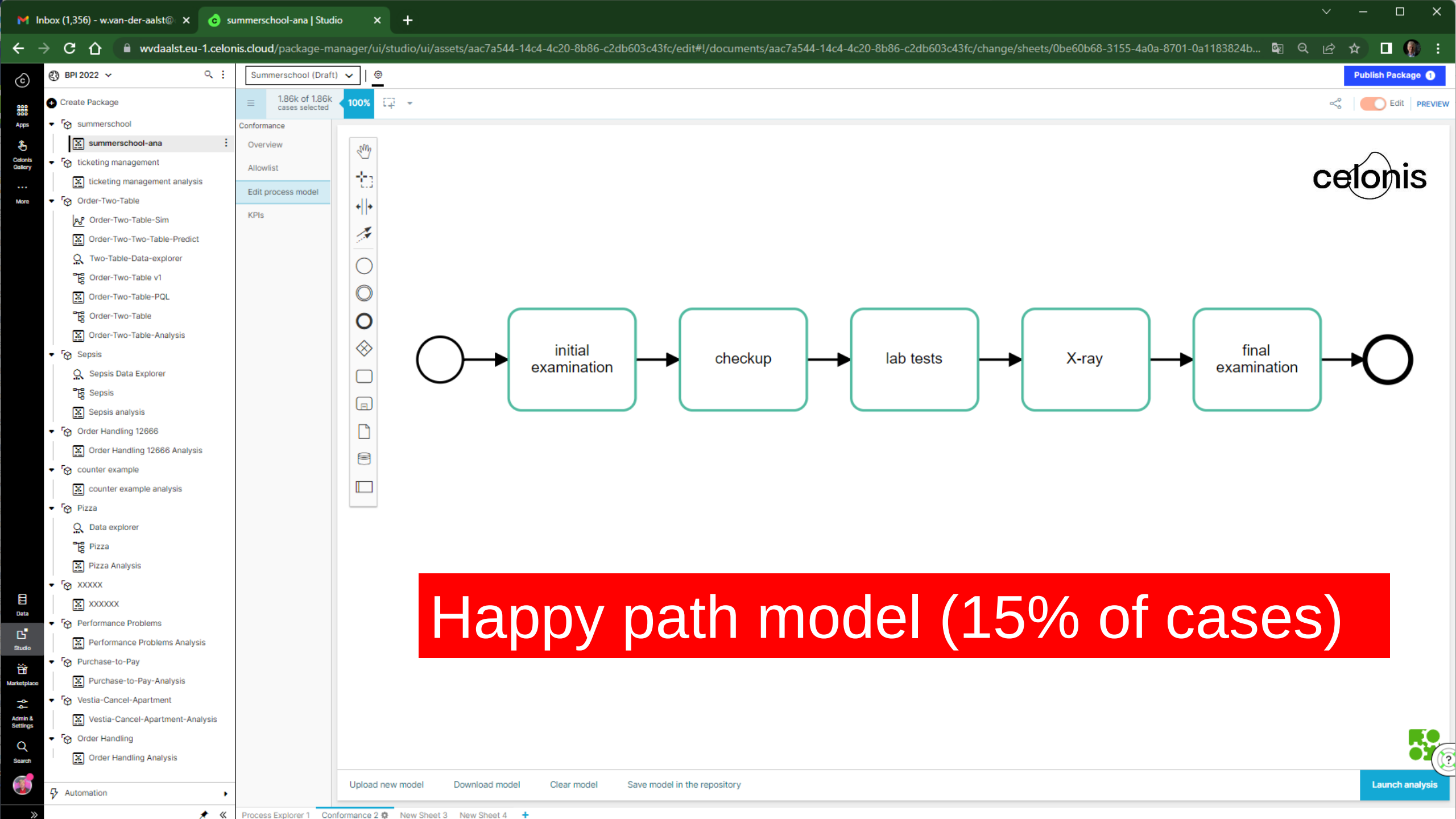
Vestia-Cancel-Apartment-Analysis
Order Handling
Order Handling Analysis
Automation
Summerschool (Draft)
Publish Package
1.86k of 1.86k cases selected
100%
Edit
PREVIEW
Conformance
Overview
Allowlist
Edit process model
KPIs
Conformance overview
Timeframe
All time
Start date
YYYY-MM-DD
End date
YYYY-MM-DD
Statistics about conformance
Conforming cases (%)
100%
Conforming cases
1.86k
Filter on Cases
vs
Non-conforming cases
0.00
Filter on Cases
Violations
0
Go To Violations
Allowlisted violations
0
Go To Allowlisted Violations
Conformance history
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
2015-01
2015-02
2015-03
2015-04
2015-05
2015-06
2015-07
2015-08
2015-09
2015-10
2015-11
2015-12
Conformance checking
KPIs for violating vs. conforming cases
Violating cases
Conforming cases
Throughput time
0.0 vs 9.2 Days
Violations decreased throughput time by 9.2 Days
Steps per case
0.0 vs 6.3
Violations decreased steps per case by 6.3
Violations
Process Explorer 1
Conformance 2
New Sheet 3
New Sheet 4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Performance Problems Analysis
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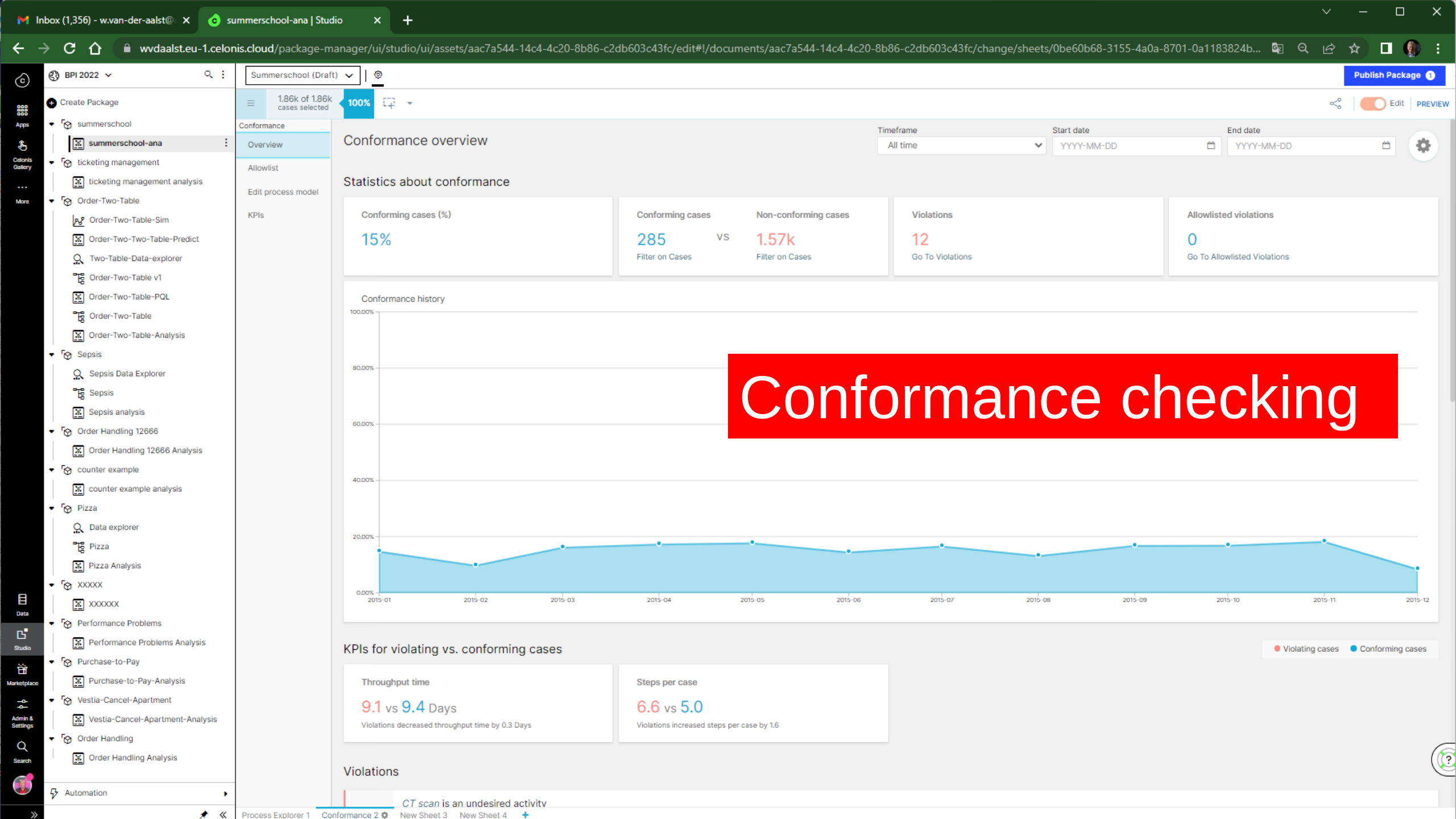
Vestia-Cancel-Apartment-Analysis
Order Handling
Order Handling Analysis
Automation
Summerschool (Draft)
Publish Package
1.86k of 1.86k cases selected
100%
Edit
PREVIEW
Conformance
Overview
Allowlist
Edit process model
KPIs
celonis
initial examination
checkup
lab tests
X-ray
final examination
Happy path model (15% of cases)
Upload new model
Download model
Clear model
Save model in the repository
Launch analysis
Process Explorer 1
Conformance 2
New Sheet 3
New Sheet 4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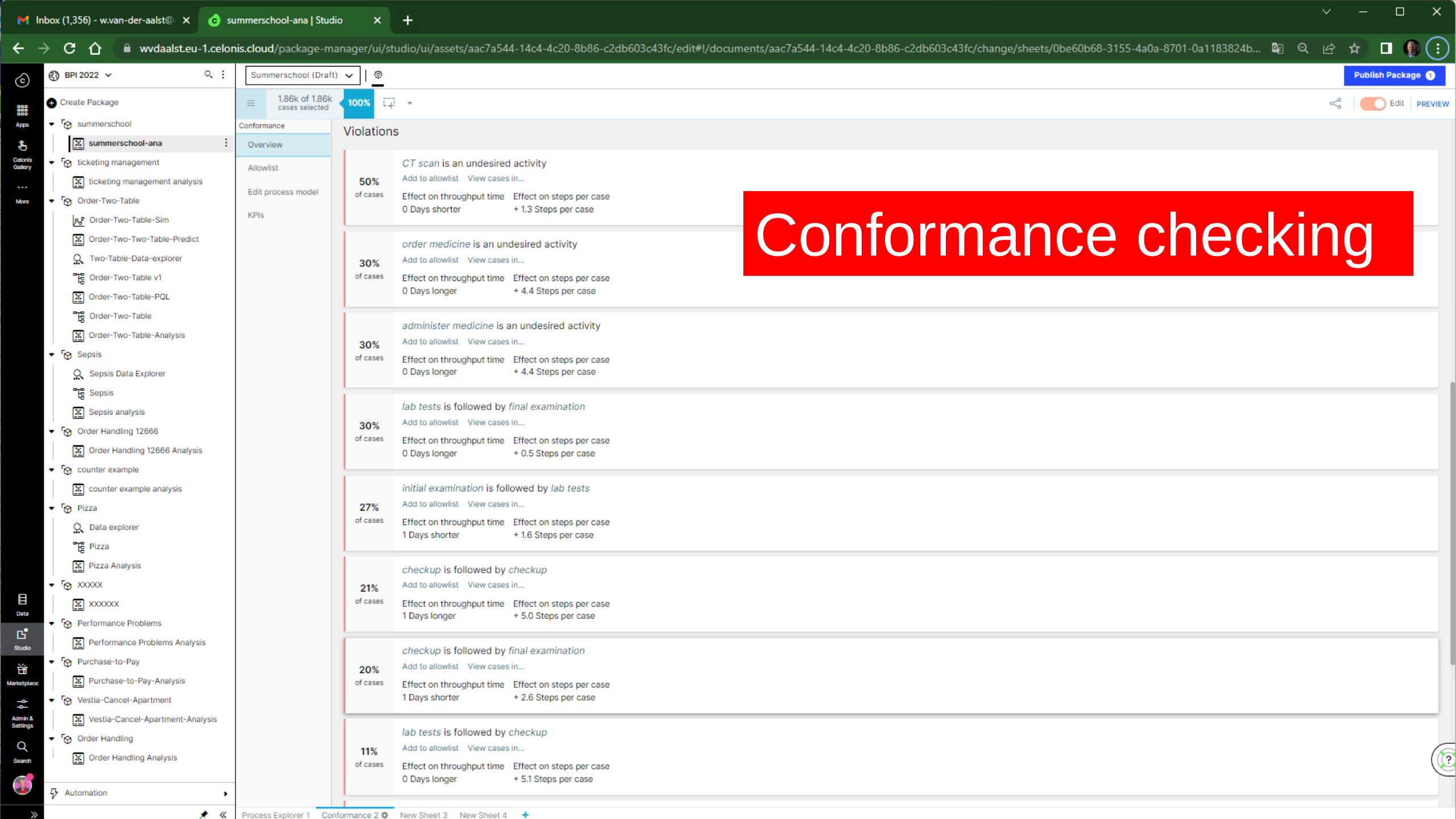
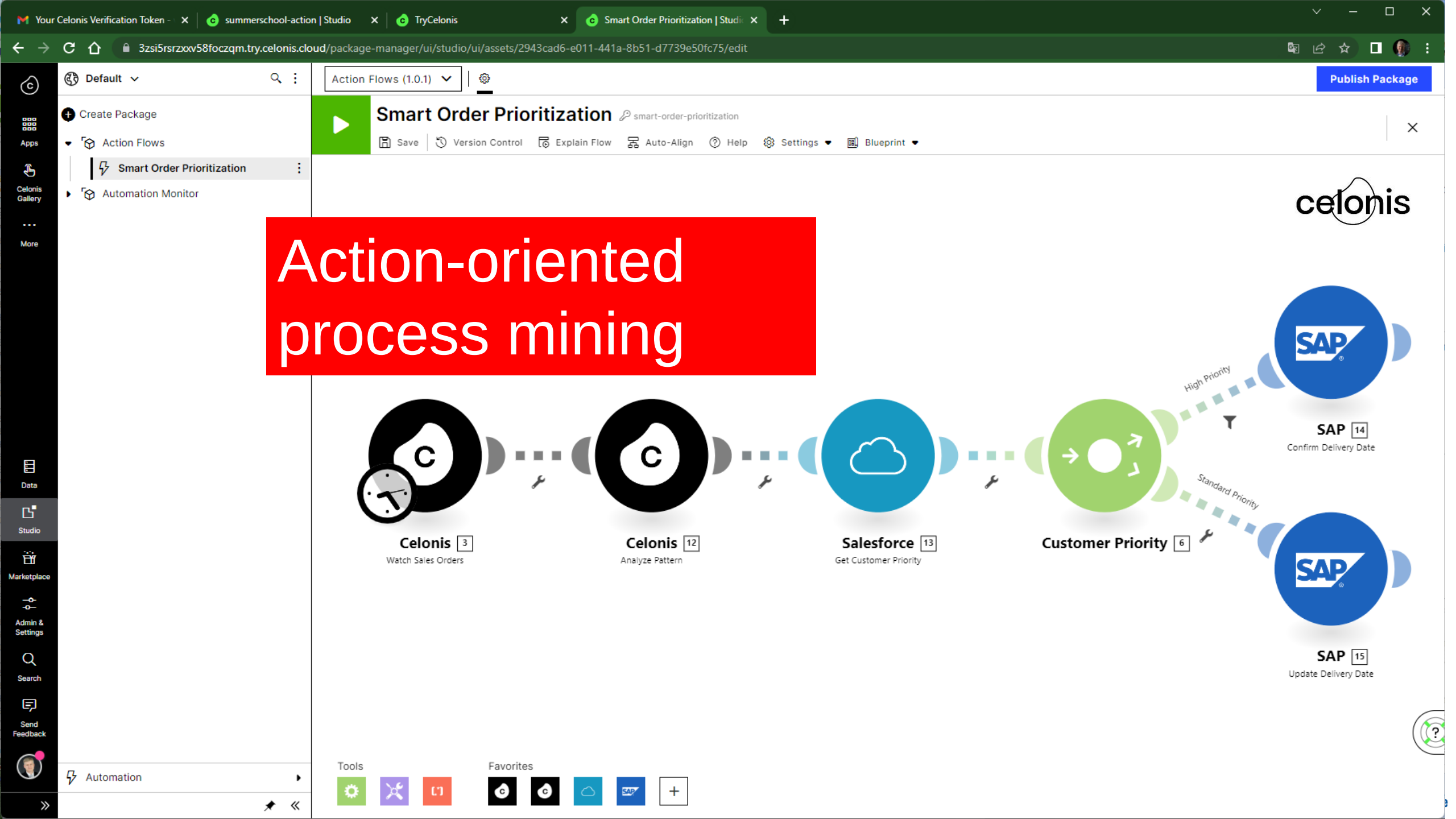
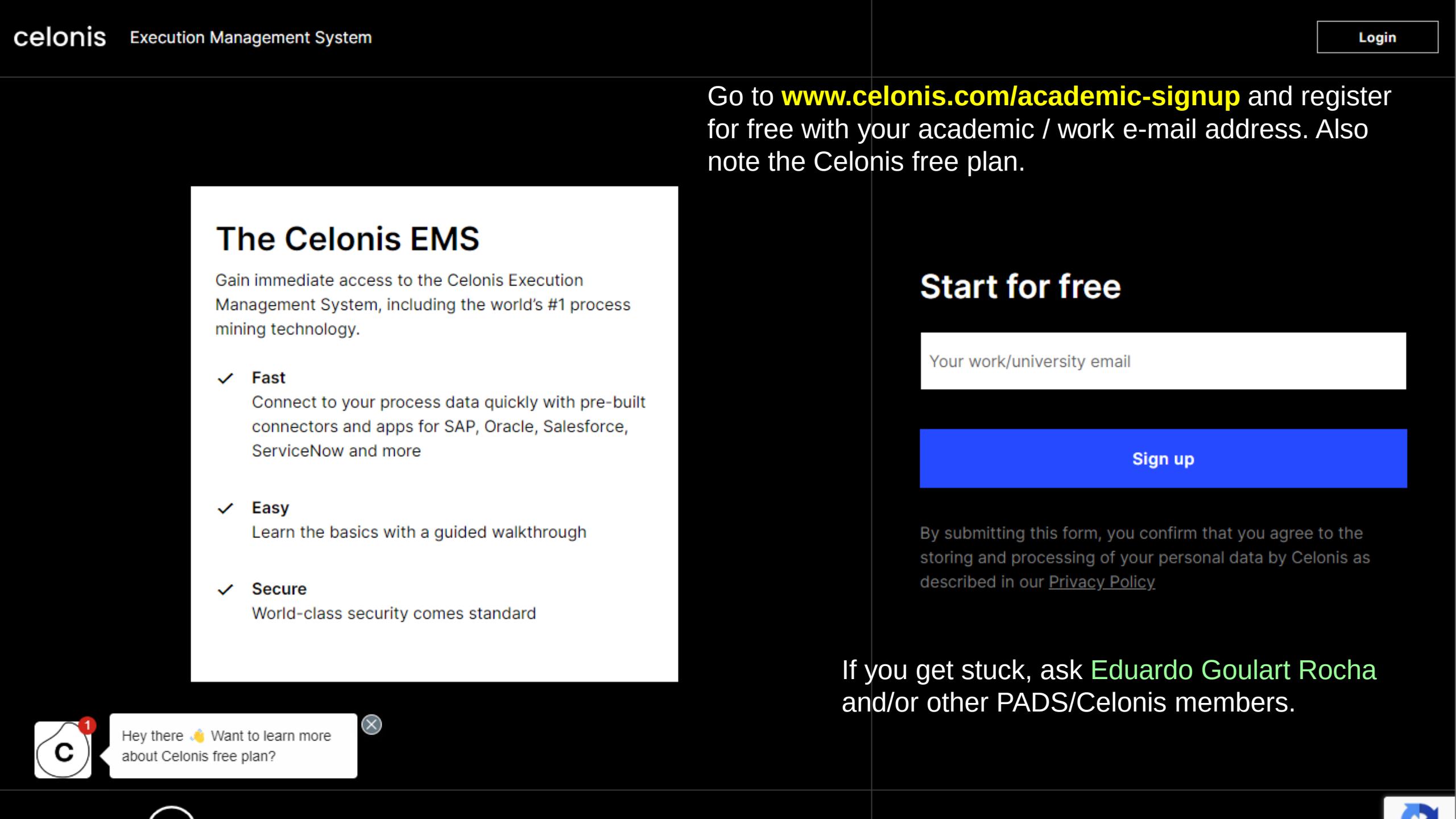
Summerschool (Draft)
Publish Package
1.86k of 1.86k cases selected
100%
Edit
PREVIEW
Conformance
Overview
Allowlist
Edit process model
KPIs
Conformance overview
Timeframe
All time
Start date
YYYY-MM-DD
End date
YYYY-MM-DD
Statistics about conformance
Conforming cases (%)
15%
Conforming cases
285
Filter on Cases
vs
Non-conforming cases
1.57k
Filter on Cases
Violations
12
Go To Violations
Allowlisted violations
0
Go To Allowlisted Violations
Conformance history
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
2015-01
2015-02
2015-03
2015-04
2015-05
2015-06
2015-07
2015-08
2015-09
2015-10
2015-11
2015-12
Conformance checking
KPIs for violating vs. conforming cases
Violating cases
Conforming cases
Throughput time
9.1 vs 9.4 Days
Violations decreased throughput time by 0.3 Days
Steps per case
6.6 vs 5.0
Violations increased steps per case by 1.6
Violations
CT scan is an undesired activity
Process Explorer 1
Conformance 2
New Sheet 3
New Sheet 4


Inbox (1,356) - w.van-der-aalst@
summerschool-ana | Studio
wvdaalst.eu-1.celonis.cloud/package-manager/ui/studio/ui/assets/aac7a544-14c4-4c20-8b86-c2db603c43fc/edit#!/documents/aac7a544-14c4-4c20-8b86-c2db603c43fc/change/sheets/0be60b68-3155-4a0a-8701-0a1183824b...
BPI 2022
Create Package
summerschool
summerschool-ana
ticketing management
ticketing management analysis
Order-Two-Table
Order-Two-Table-Sim
Order-Two-Two-Table-Predict
Two-Table-Data-explorer
Order-Two-Table v1
Order-Two-Table-PQL
Order-Two-Table
Order-Two-Table-Analysis
Sepsis
Sepsis Data Explorer
Sepsis
Sepsis analysis
Order Handling 12666
Order Handling 12666 Analysis
counter example
counter example analysis
Pizza
Data explorer
Pizza
Pizza Analysis
XXXXX
XXXXXX
Performance Problems
Performance Problems Analysis
Purchase-to-Pay
Purchase-to-Pay-Analysis
Vestia-Cancel-Apartment
Vestia-Cancel-Apartment-Analysis
Order Handling
Order Handling Analysis
Automation
Summerschool (Draft)
Publish Package
1.86k of 1.86k cases selected
100%
Edit
PREVIEW
Conformance
Overview
Allowlist
Edit process model
KPIs
Violations
50% of cases
CT scan is an undesired activity
Add to allowlist View cases in...
Effect on throughput time 0 Days shorter
Effect on steps per case + 1.3 Steps per case
30% of cases
order medicine is an undesired activity
Add to allowlist View cases in...
Effect on throughput time 0 Days longer
Effect on steps per case + 4.4 Steps per case
30% of cases
administer medicine is an undesired activity
Add to allowlist View cases in...
Effect on throughput time 0 Days longer
Effect on steps per case + 4.4 Steps per case
30% of cases
lab tests is followed by final examination
Add to allowlist View cases in...
Effect on throughput time 0 Days longer
Effect on steps per case + 0.5 Steps per case
27% of cases
initial examination is followed by lab tests
Add to allowlist View cases in...
Effect on throughput time 1 Days shorter
Effect on steps per case + 1.6 Steps per case
21% of cases
checkup is followed by checkup
Add to allowlist View cases in...
Effect on throughput time 1 Days longer
Effect on steps per case + 5.0 Steps per case
20% of cases
checkup is followed by final examination
Add to allowlist View cases in...
Effect on throughput time 1 Days shorter
Effect on steps per case + 2.6 Steps per case
11% of cases
lab tests is followed by checkup
Add to allowlist View cases in...
Effect on throughput time 0 Days longer
Effect on steps per case + 5.1 Steps per case
Process Explorer 1
Conformance 2
New Sheet 3
New Sheet 4
Conformance checking


Your Celonis Verification Token -
summerschool-action | Studio
TryCelonis
Smart Order Prioritization | Studi
3zsi5rsrzxxv58foczqm.try.celonis.cloud/package-manager/ui/studio/ui/assets/2943cad6-e011-441a-8b51-d7739e50fc75/edit
Default
Action Flows (1.0.1)
Publish Package
Create Package
Action Flows
Smart Order Prioritization
Automation Monitor
Smart Order Prioritization
smart-order-prioritization
Save
Version Control
Explain Flow
Auto-Align
Help
Settings
Blueprint
Apps
Celonis Gallery
More
Data
Studio
Marketplace
Admin & Settings
Search
Send Feedback
Automation
Action-oriented process mining
celonis
Celonis 3
Watch Sales Orders
Celonis 12
Analyze Pattern
Salesforce 13
Get Customer Priority
Customer Priority 6
High Priority
Standard Priority
SAP 14
Confirm Delivery Date
SAP 15
Update Delivery Date
Tools
Favorites



Go to **www.celonis.com/academic-signup** and register for free with your academic / work e-mail address. Also note the Celonis free plan.

If you get stuck, ask Eduardo Goulart Rocha and/or other PADS/Celonis members.

Chair of Process and Data Science

RWTH AACHEN UNIVERSITY

Process mining is used in all domains

- **finance and insurance** (Rabobank, Wells Fargo, Hypovereinsbank, Caixa General, ADAC, APG, Suncorp, VTB, etc.),
- **logistics and transport** (Uber, Deutsche Bahn, Lufthansa, Airbus, Schukat, Vanderlande, etc.),
- **production** (ABB, Siemens, BMW, Fiat, Bosch, AkzoNobel, Bayer, Neste, etc.),
- **healthcare, biomedicine, and pharmacy** (Uniklinik RWTH Aachen, Charite University Hospital, GE Healthcare, Philips, Medtronic, Pfizer, Bayer, AstraZeneca, etc.),
- **telecom** (Deutsche Telekom, Vodafone, A1 Telekom Austria, Telekom Italia, etc.),
- **food and retail** (Edeka, MediaMarkt, Globus, Zalando, AB InBev, etc.),
- **energy** (Uniper, Chevron, Shell, BP, E.ON, etc.),
- **IT services** (Dell, Xerox, IBM, Nokia, ServiceNow, etc.), and
- **consultancy** (Deloitte, Ernst & Young, KPMG, PwC, etc.)!

Some of the Celonis customers

Technology

Qualcomm, IBM, servicenow, Uber, workday., cisco, INGRAM, NOKIA, splunk>, salesforce, DELL, Tech Data

Financial Services & Insurance

citi, FARMERS INSURANCE, Deutsche Bank, ING, WELLS FARGO, THE HARTFORD, PostFinance, R+V, HomeEquity Bank

Life Sciences & Chemicals

lyondellbasell, SI Group, Chemours, SOLENIS, ASCEND, NOVARTIS, HEXION, AstraZeneca, FRESENIUS KABI, BAYER, Roche, AMGEN, gsk, DÖHLER, DOW, AkzoNobel

Consumer & Retail

The Coca-Cola Company, L'ORÉAL, Keurig DrPepper, Johnson & Johnson, Unilever, Kellogg's, MARS, CAMPARI, Kimberly-Clark, ABInBev, reckitt

Manufacturing

SIEMENS, molex, 3M, AIRBUS, Whirlpool, Honeywell, ABB, sysmex, RATIONAL, BMI, BOSCH, ZEISS, JOHN DEERE, LOCKHEED MARTIN

Telecommunications & Media

vodafone, VIACOMCBS, COMCAST, T··, 1&1, Telefónica, orange, MOTOROLA SOLUTIONS, Telia

Energy & Utilities

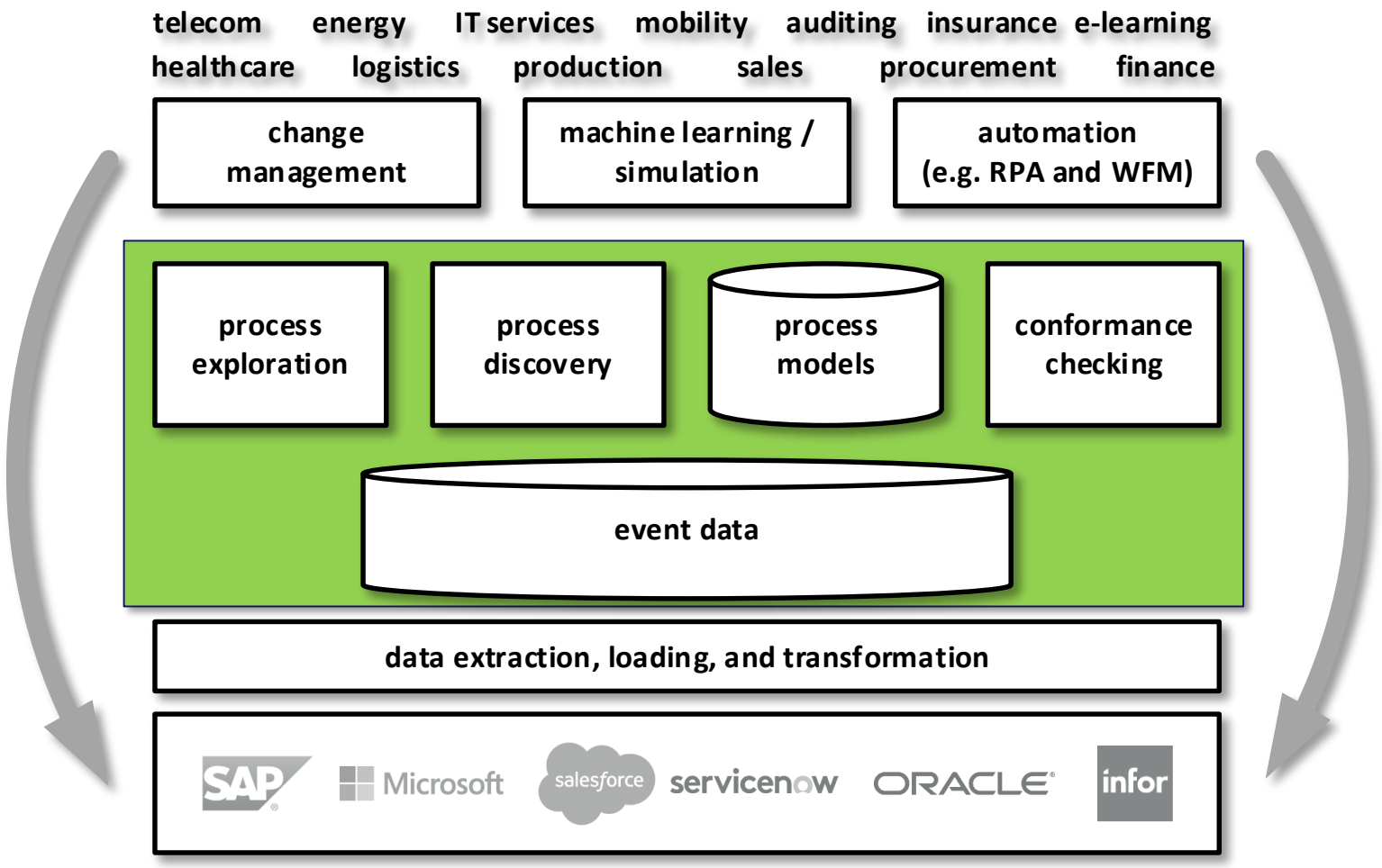
Statkraft, WIEN ENERGIE, enel, GENERAC, REWAG, EQUANS, uniper, EnBW, SaskPower, e·on

Oil & Gas

ExxonMobil, Schlumberger, Phillips 66, cenovus, bp, andeavor, CHART, MOL, Canadian Natural, NESTE, REPSOL

Thousands of large organizations are using Celonis (approx. 50% of Fortune 500) and in some of these there are thousands of active users (e.g., Siemens, BMW, etc.)

Bigger picture: Not just process mining



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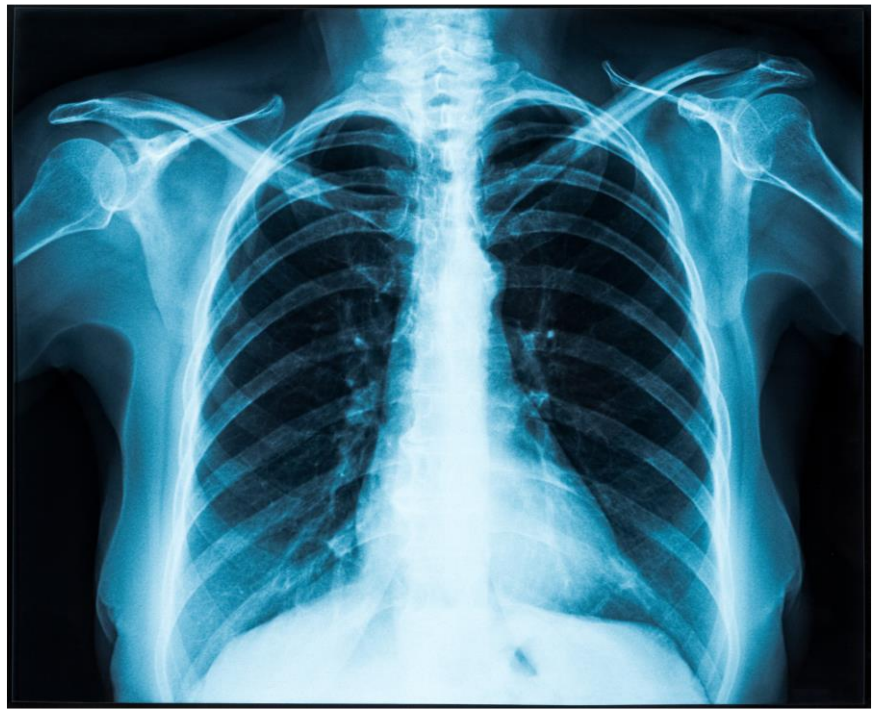
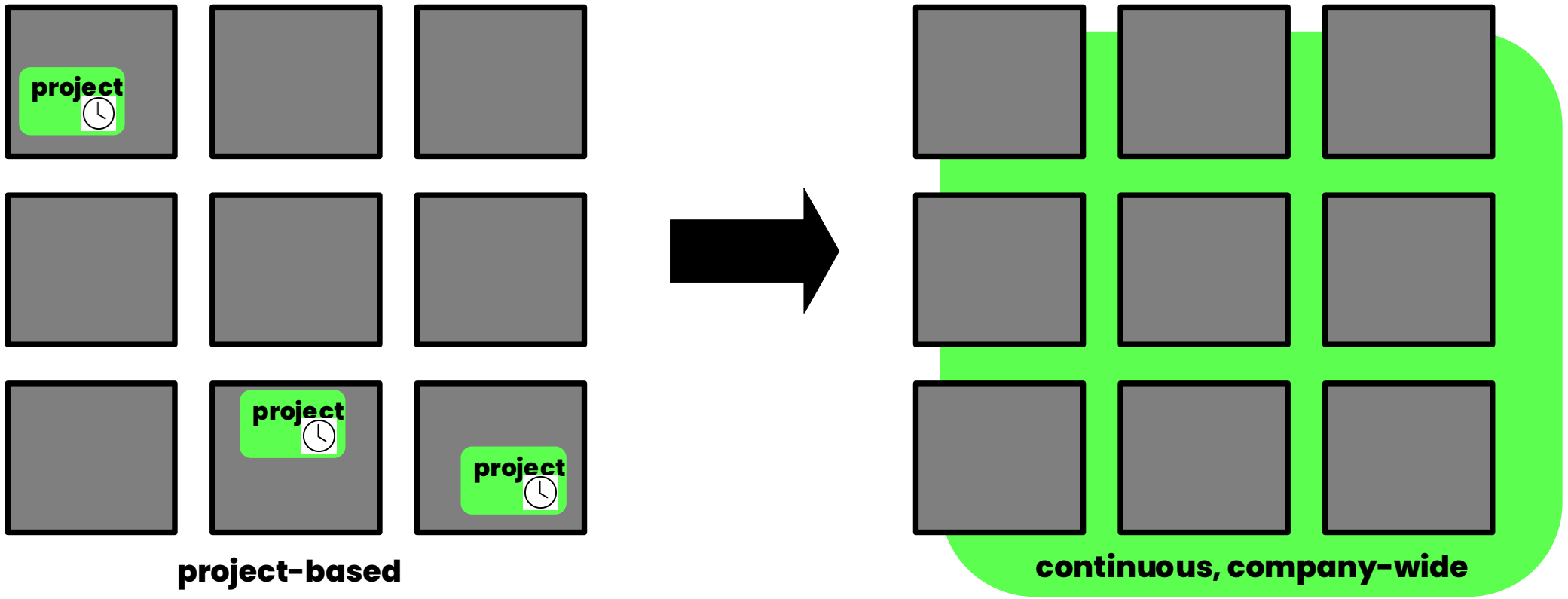
Trend: From insights to actions



insights

actions

Trend: Scaling process mining



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Summary and Outlook

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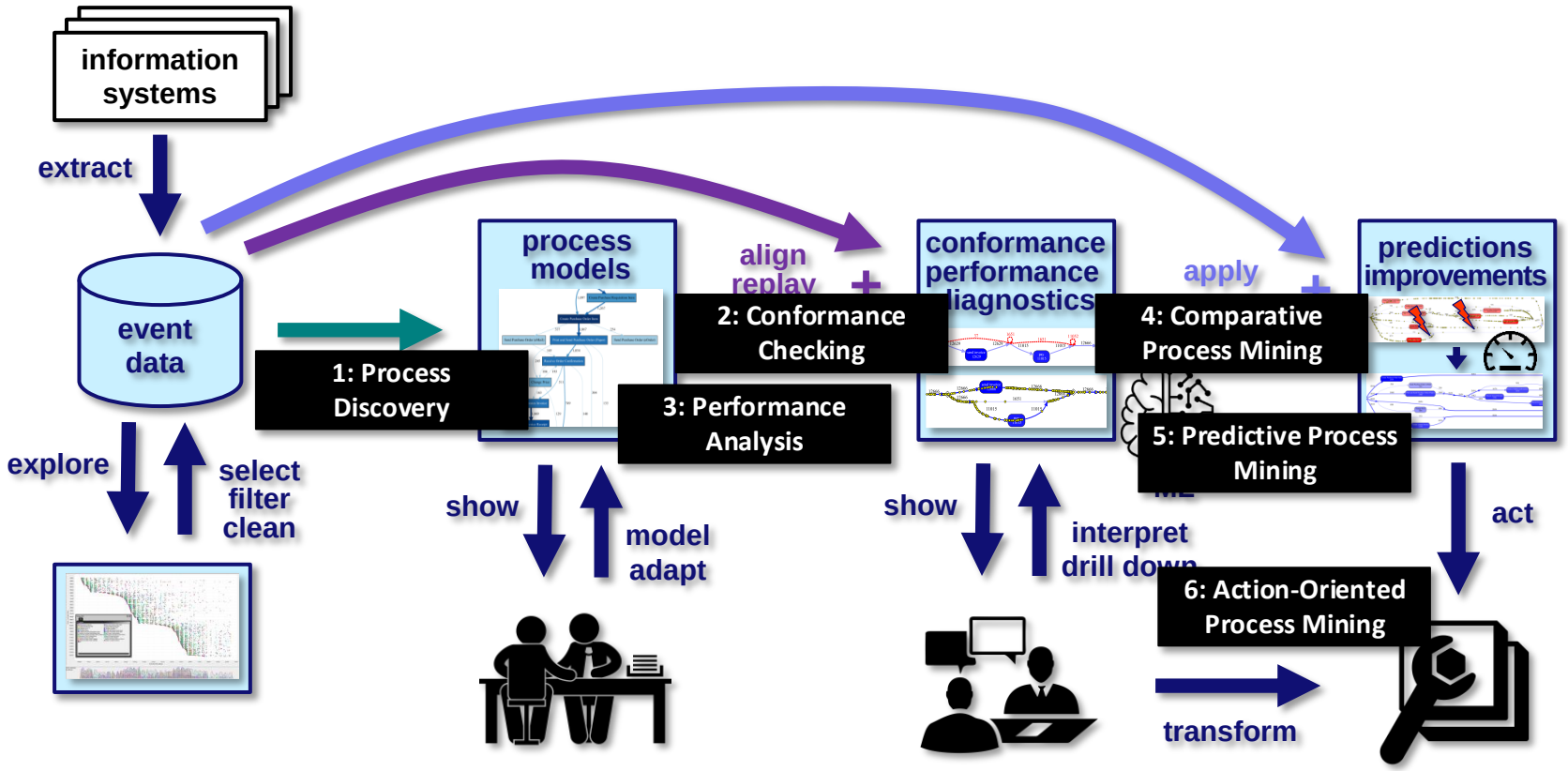
Summary



Four types of process models: BPMN, Petri nets, DFGs, and process trees.

next

Four types of event data: simplified event logs, standard event logs, XES, and object-centric event logs.

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Websites

- www.processmining.org
- www.process-mining-summer-school.org
- www.tf-pm.org
- www.promtools.org
- www.celonis.com/academic-signup
- xes-standard.org
- ocel-standard.org
- www.pads.rwth-aachen.de
- www.vdaalst.com

Online courses

- **Coursera course**
  “Process Mining: Data science in Action”
  Register via coursera.org/learn/process-mining (152.345 participants since 2015).

- **Celonis/RWTH course**
  “Process Mining: From Theory to Execution”
  Register via www.celonis.com/wils-process-mining-class.

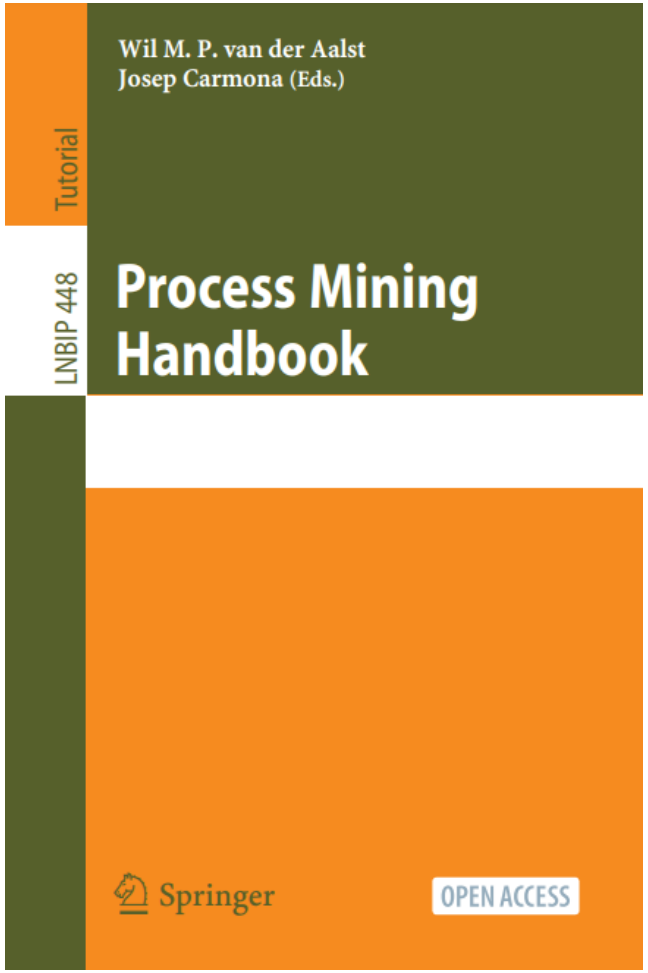
coursera TU/e

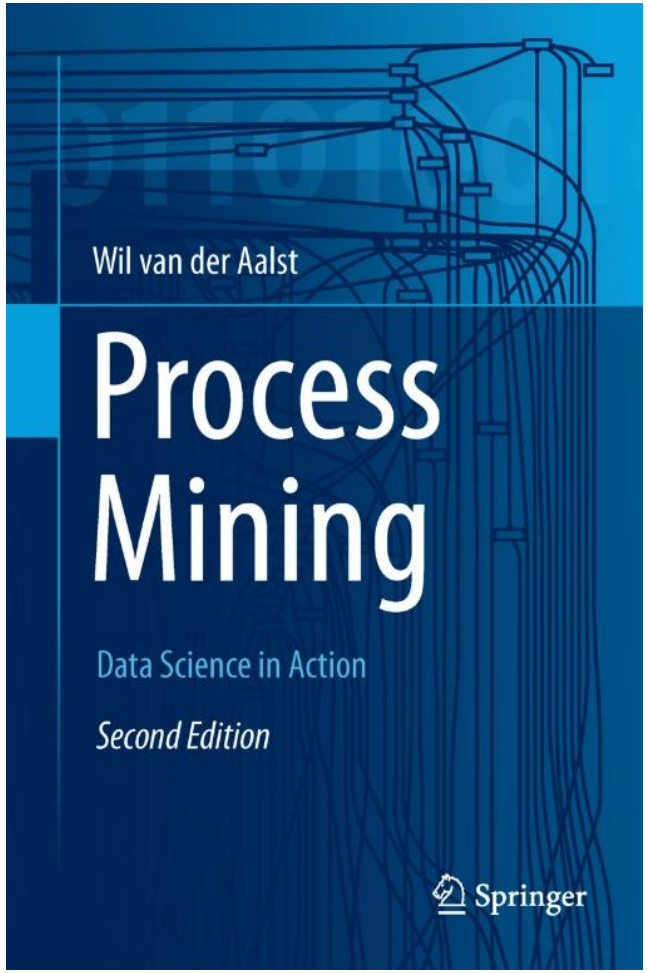
celonis RWTH RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN

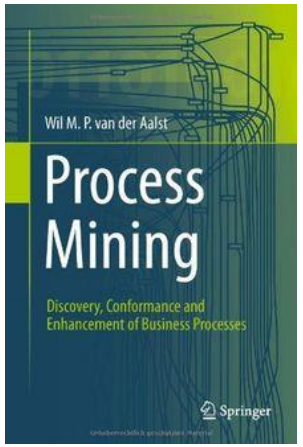
(edX is coming)

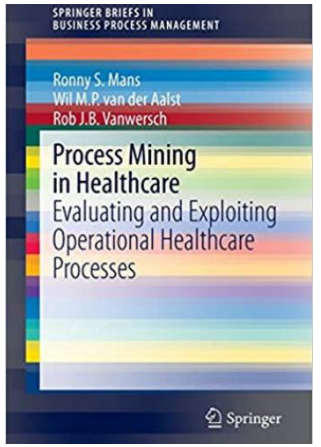
P D A S Chair of Process and Data Science

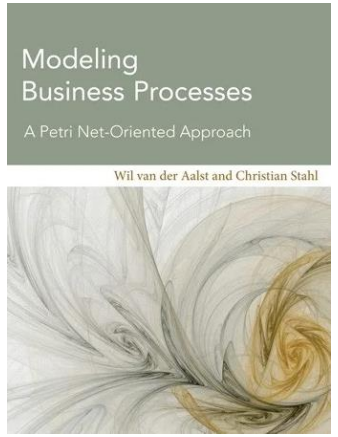
Books (not intended to be complete)

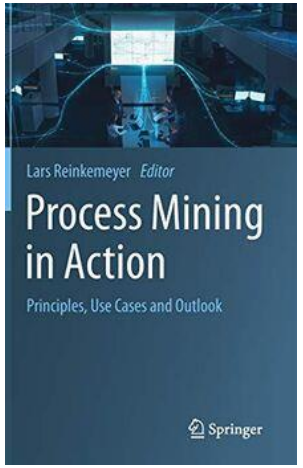


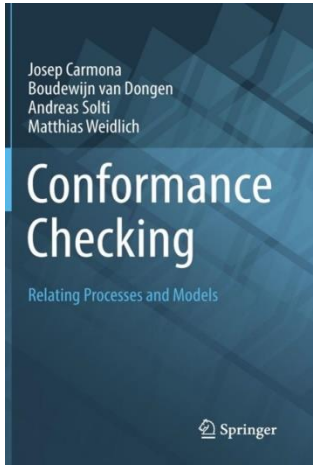


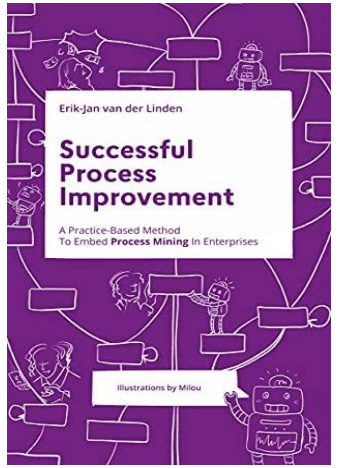












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