

Genuine Process Improvements Using Object-Centric Process Mining

Virtual Lecture Series on Business Process Management,
Universität Würzburg, 30.11.2020

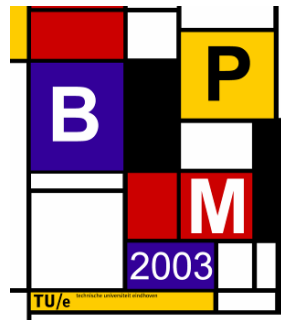
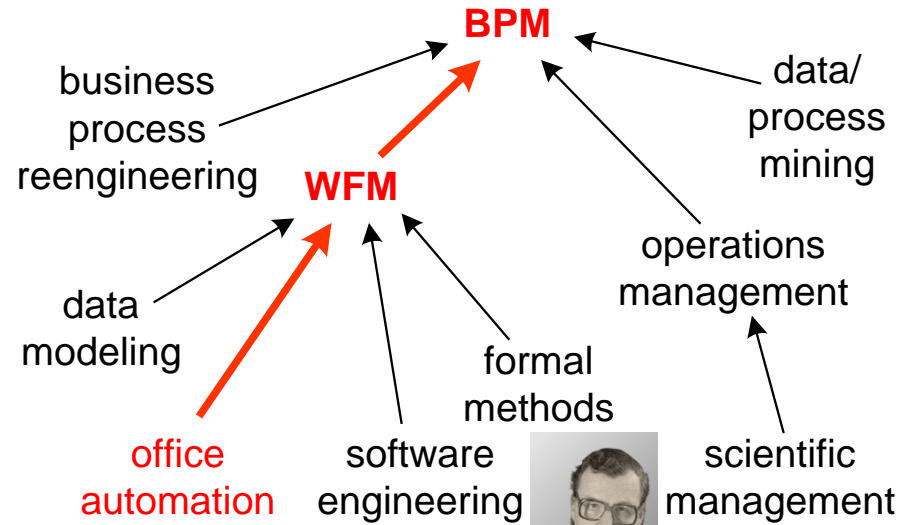
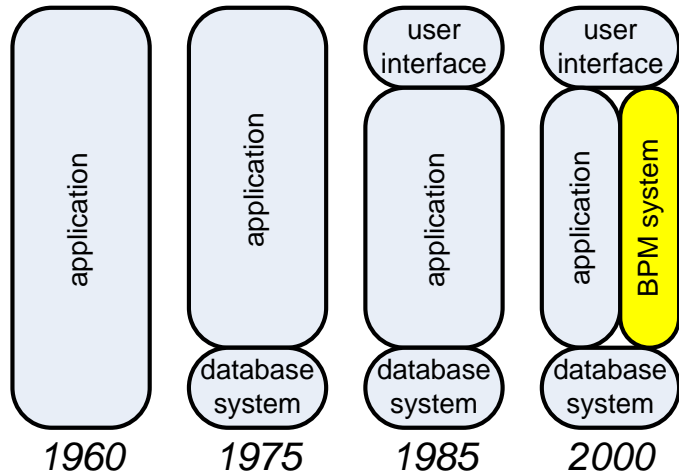
prof.dr.ir. Wil van der Aalst
RWTH Aachen University
W: vdaalst.com T: @wvdaalst



Business Process Management
Virtual Lecture Series



History and Origins of BPM until 2003



Observations

- Shift from **formalisms and modeling** to **enactment and systems** to **data and process mining**.
- Adoption of **WFM/BPM technology** was limited.
- **Process modeling** turned out to be a waste of time.
- SAP, Oracle, Salesforce, Microsoft, Infor, etc. are **data-driven** and not **process-centric**.
- **Robotic Process Automation (RPA)** and **Process Mining** are driving innovations in BPM.
- Here, we focus on the latter.



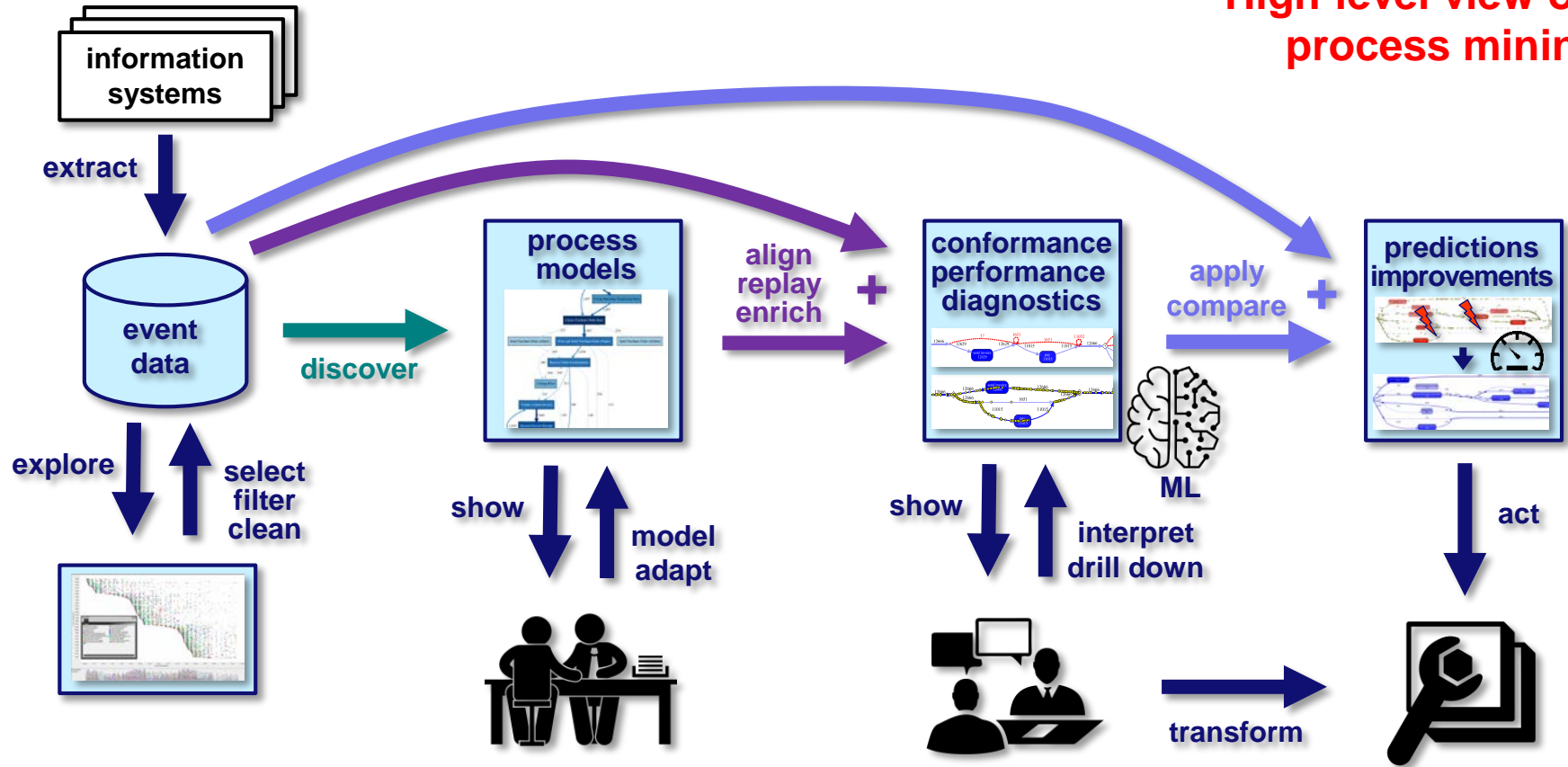
Object-Centric Process Mining

- **Object-Centric Process Mining** aims to learn from the failures in the past:
 - Subjective oversimplified models lead to problems.
 - Need to combine data-driven and process-centric.
 - BPM needs to be cost-effective and provide real improvements.
 - Reality \neq BPMN !
- An event can refer to **any number of objects** and processes are **intertwined**.



Let's talk about process mining

High-level view on process mining

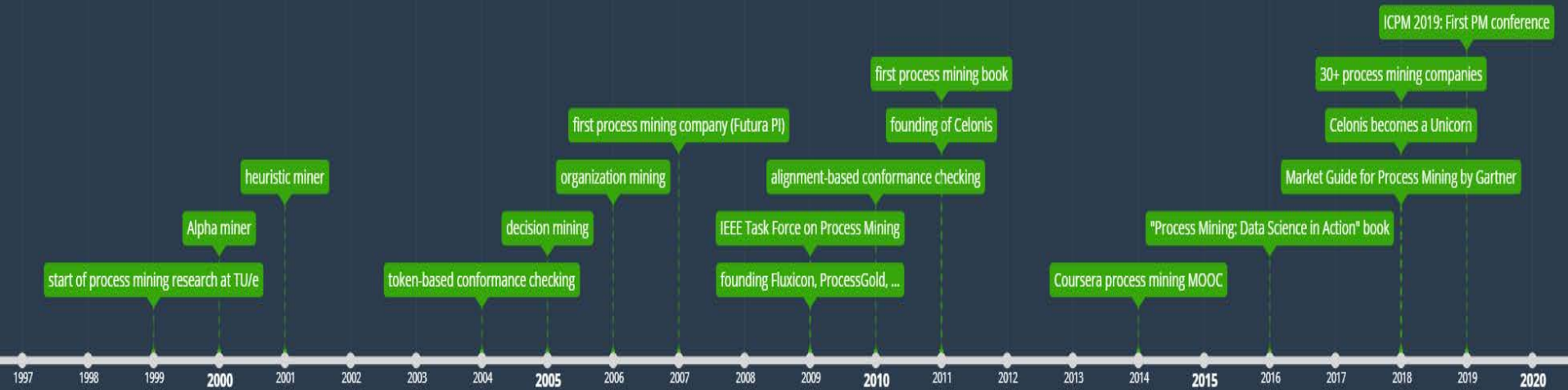




1999 start of process mining research at TU/e
2000-2002 Alpha and Heuristic miner
2004 first version of ProM
2004-2006 token-based conformance checking,
organization mining, decision mining, etc.
2007 first process mining company (Futura PI)
2009 IEEE Task Force on Process Mining
2009 founding Fluxicon, ProcessGold, ...
2010 alignment-based conformance checking
2011 founding of Celonis
2011 first process mining book
2014 Coursera process mining MOOC
2016 Process Mining: Data Science in Action book
2018 Market Guide for Process Mining by Gartner
2018 30+ process mining companies
2018 Celonis becomes a Unicorn
2019 ICPM 2019: First PM conference
2020 ICPM 2020 has 2000 participants

research

commercial tools



adoption



 **IEEE** TASK FORCE ON PROCESS MINING

www.tf-pm.org

Over >700 members and
supported by >80 organizations.



Chair of Process
and Data Science



icpmconference.org



UNIVERSITÀ
DEGLI STUDI
DI PADOVA

International Conference on Process Mining (ICPM 2020)

4-9 October 2020

Over 2000 participants

Over 30 process mining vendors today





“Flat” Processes & Event Data

“using a single case notion”

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
...



71,043 events
12,666 cases
7 activities

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 6s 16 GB	639,00 €	3	NL-7905AX-38
6272	pay	Emily	2018/02/13 15:20:36.000	APPLE iPhone 6s 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 6s 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 Galaxy S4	329,00 €	1	NL-7828AM-11a
6204	make delivery	Kaylee	2018/02/13 16:51:54.000	SAMSUNG Galaxy S4	329,00 €	2	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 =
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



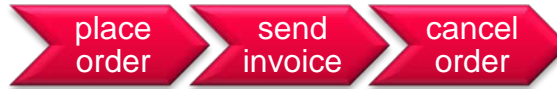
Let's look at orders 6350, 6351, and 6352

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



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



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



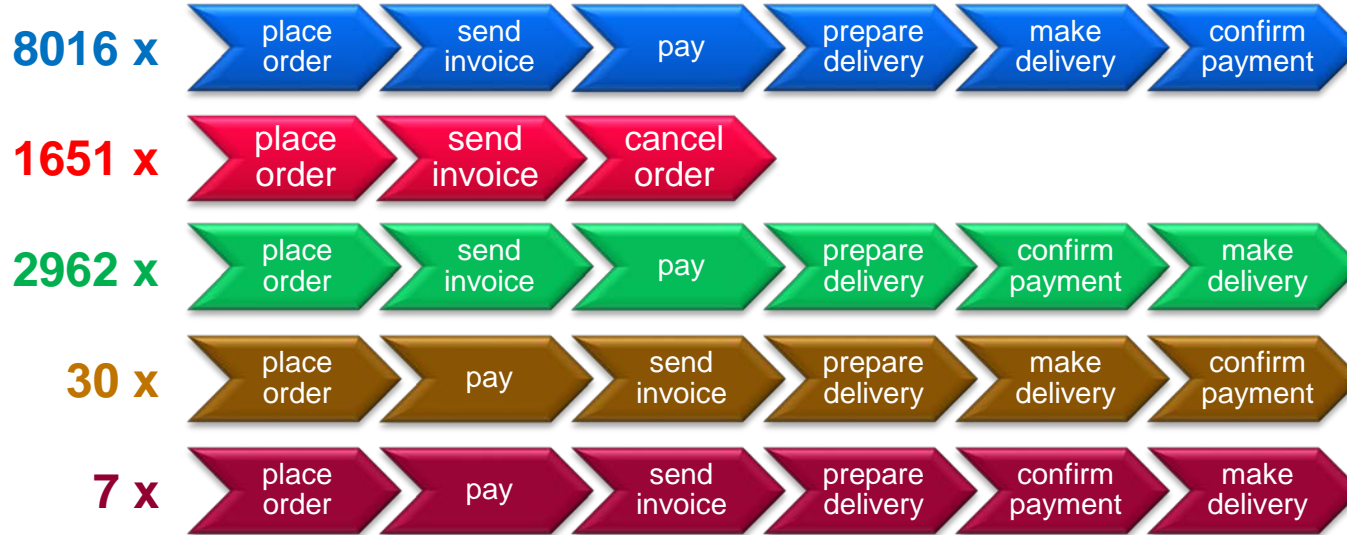
Order 6352



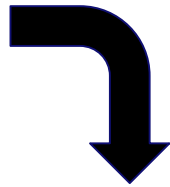
Let's look at the whole event log again

71,043 events
12,666 cases
7 activities

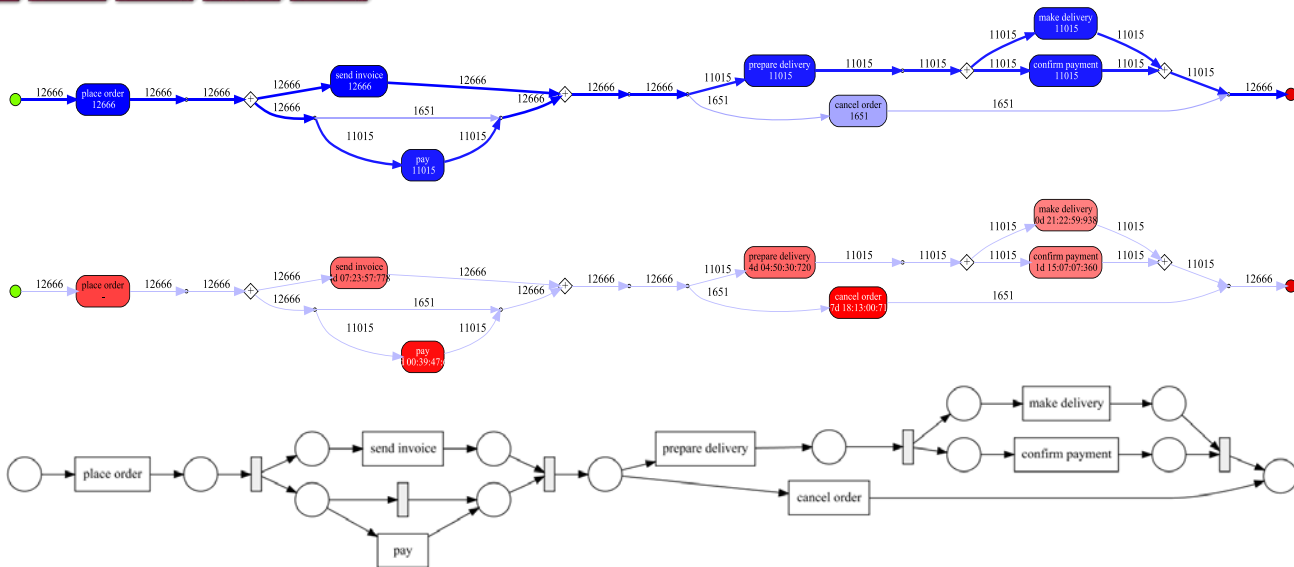
Case ID	Activity	Resource	Timestamp	Product	Priority	Quantity	Address
1	place order	...	...	...	...	...	...
1	send invoice	...	...	...	...	...	...
1	pay	...	...	...	...	...	...
1	prepare delivery	...	...	...	...	...	...
1	make delivery	...	...	...	...	...	...
1	confirm payment	...	...	...	...	...	...
2	place order	...	...	...	...	...	...
2	send invoice	...	...	...	...	...	...
2	cancel order	...	...	...	...	...	...
3	place order	...	...	...	...	...	...
3	send invoice	...	...	...	...	...	...
3	pay	...	...	...	...	...	...
3	prepare delivery	...	...	...	...	...	...
3	confirm payment	...	...	...	...	...	...
3	make delivery	...	...	...	...	...	...
4	place order	...	...	...	...	...	...
4	pay	...	...	...	...	...	...
4	send invoice	...	...	...	...	...	...
4	prepare delivery	...	...	...	...	...	...
4	make delivery	...	...	...	...	...	...
4	confirm payment	...	...	...	...	...	...
5	place order	...	...	...	...	...	...
5	pay	...	...	...	...	...	...
5	send invoice	...	...	...	...	...	...
5	prepare delivery	...	...	...	...	...	...
5	confirm payment	...	...	...	...	...	...
5	make delivery	...	...	...	...	...	...



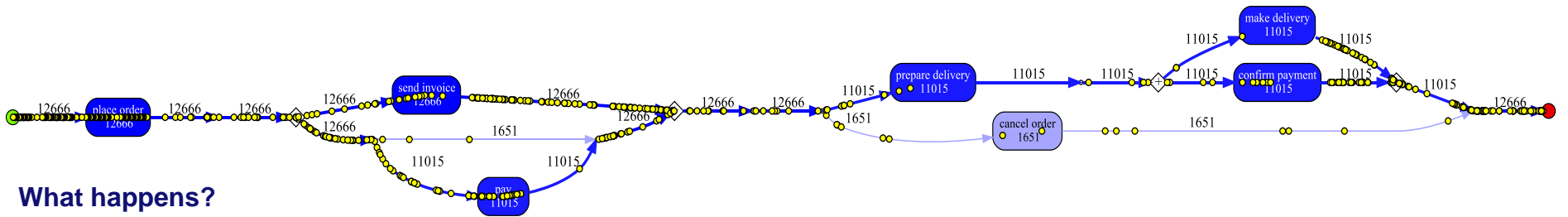
Using the whole event log



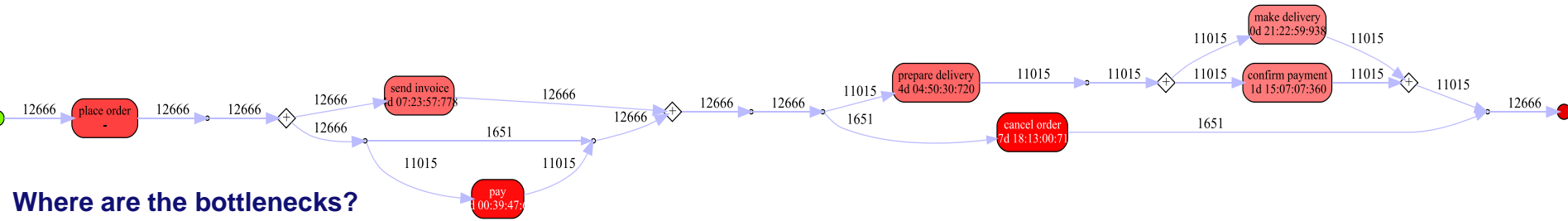
No modeling needed!



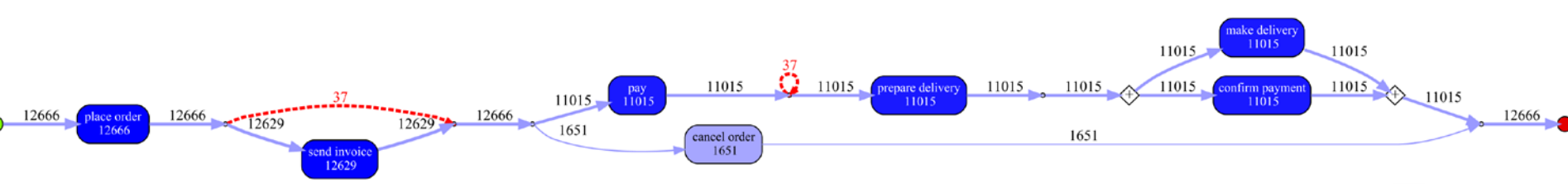
Performance and Compliance



What happens?



Where are the bottlenecks?

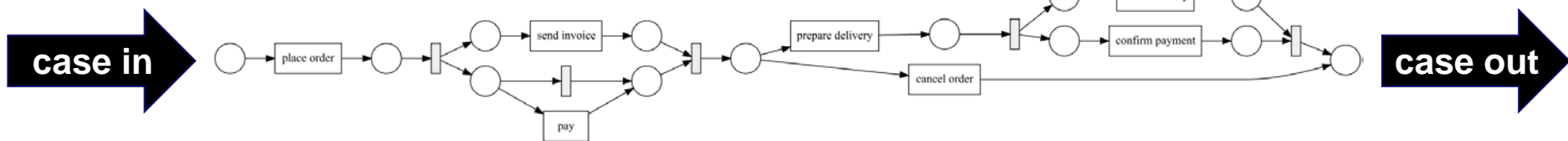
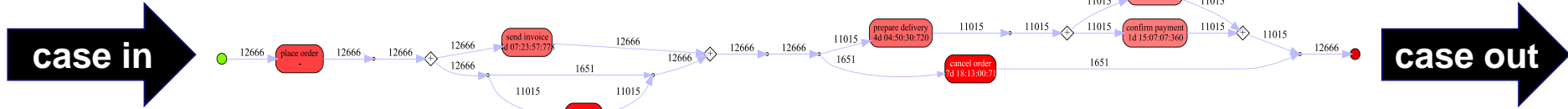
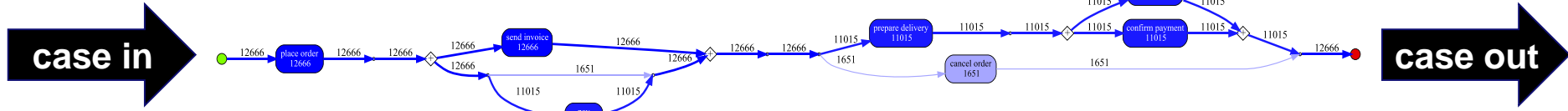


Where do we deviate from the happy path?

Commercial tools also support many of these ideas developed around 15-20 years ago!



Traditional Process Models Assume a Single Case Notion!



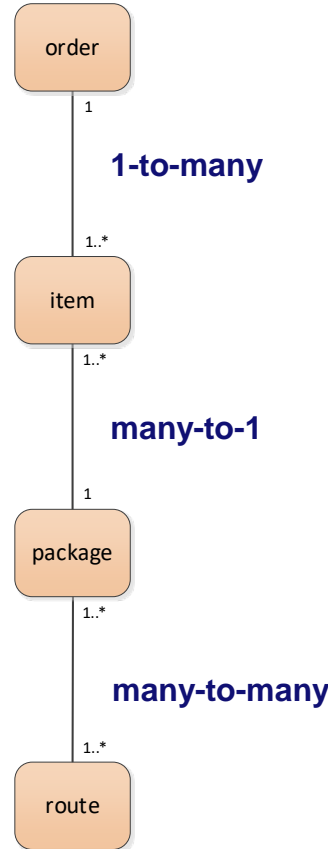
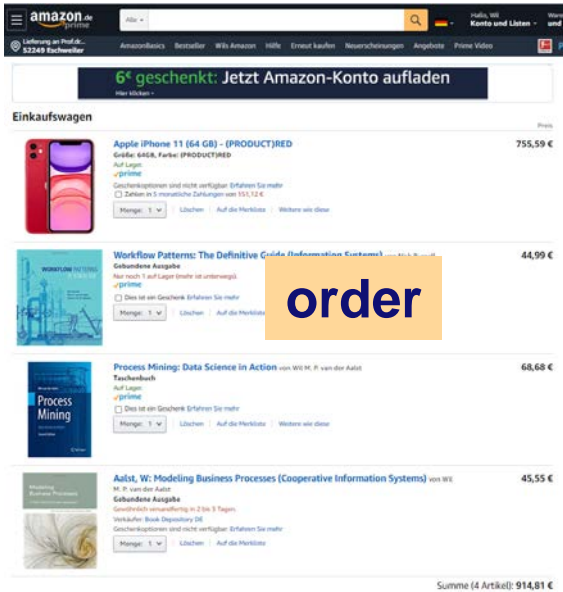
Navigation icons: Close (X), Case (ID icon), Mail, Clock, People, and Search (*).

Also BPMN, UML ADs, EPCs, etc.

Object-Centric Process Mining

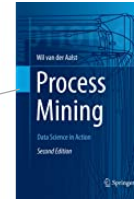
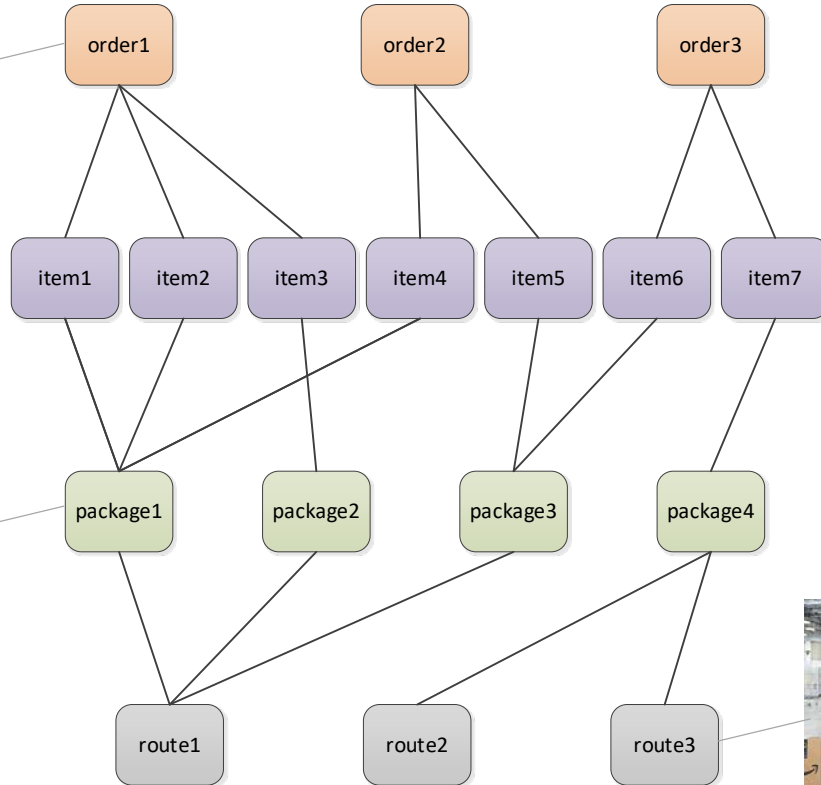
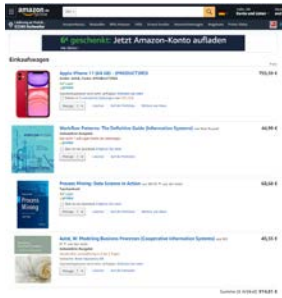
“event data and processes are not flat”

Example illustrating object-centric PM

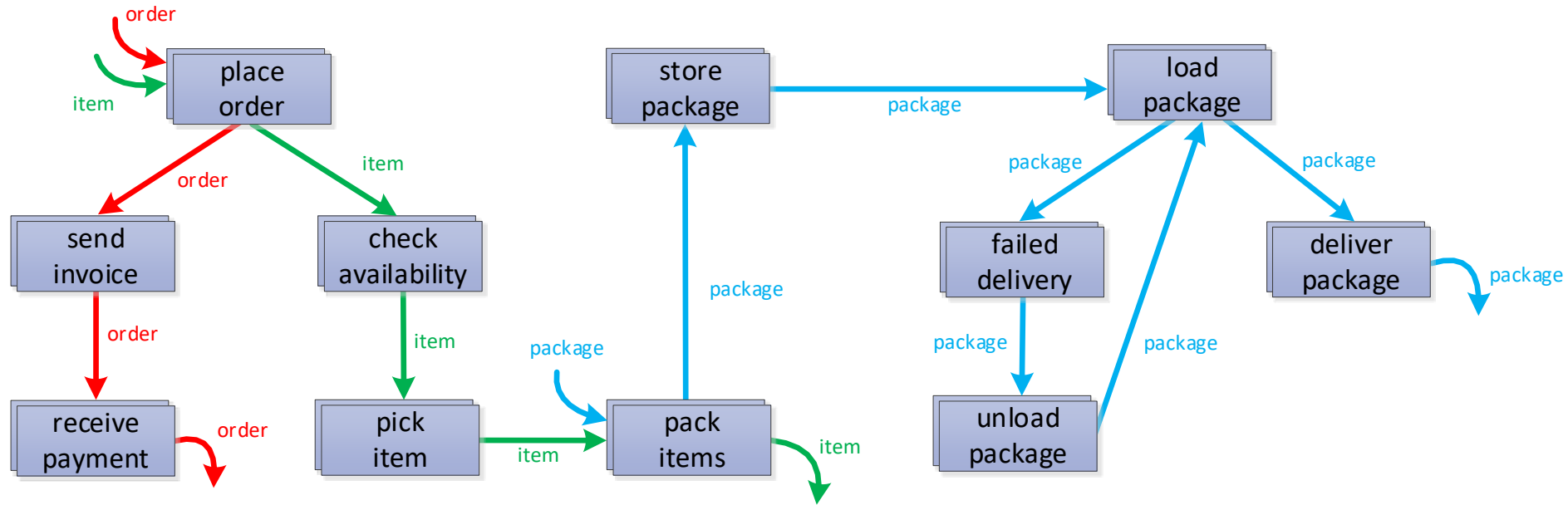


Example illustrating object-centric PM

(No activities, just describing the relationships among objects)



Goal: One model showing multiple object types



See Wil van der Aalst: Object-Centric Process Mining: Dealing with Divergence and Convergence in Event Data. SEFM 2019, 3-25 https://doi.org/10.1007/978-3-030-30446-1_1

a "place order" event may refer to multiple items

the following assumption

a "failed delivery" event refers to one package, one or more items, one or more orders, etc.

a "pick item" event refers to one item

let's simplify to focus on the essence

objects

activity	time	order	items	packages	customers	price	weight
pick item	2019-12-26 12:04:46	991224	{884803}	{}	{Wil van der Aalst}	529.0	0.21
reorder item	2019-12-26 12:37:26	991271	{885002}	{}	{Mohammadreza Fani Sani}	129.0	0.495
place order	2019-12-26 12:44:23	991283	{885038,885039}	{}	{Luis Santos}	2700.0	1.733
pick item	2019-12-26 14:01:16	991266	{884983}	{}	{Marco Pegoraro}	2200.0	1.25
create package	2019-12-26 14:01:16	991265	{884975,884974,884978,884971,884970,884973}	{660798}	{Seran Uysal}	3506.97	2.12
send package	2019-12-26 14:16:11	991265	{884975,884974,884978,884971,884970,884973}	{660798}	{Seran Uysal}	3506.97	2.12
pick item	2019-12-26 14:16:48	991279	{885027}	{}	{Claudia Graf}	799.0	0.166
confirm order	2019-12-26 14:26:01	991283	{885038,885039}	{}	{Luis Santos}	2700.0	1.733
reorder item	2019-12-26 14:32:43	991271	{884912}	{}	{Tobias Brockhoff}	39.99	0.0
confirm order	2019-12-26 14:33:23	991283	{885036,885037}	{}	{Lisa Mannel}	134.98	1.16
confirm order	2019-12-26 14:33:23	991283	{885041,885042,885043,885044}	{}	{Junxiong Gao}	2500.0	1.7
confirm order	2019-12-26 14:33:23	991283	{884561,884873,884913,884876,884938,884914,884941}	{660790}	{Christine Dobbert}	4222.98	2.79
confirm order	2019-12-26 14:33:23	991283	{884939,884940,884941,884942,884943}	{}	{Junxiong Gao}	5982.95	3.42
confirm order	2019-12-26 14:33:23	991283	{884922,884923,885004,885005,884901}	{660796}	{Mohammadreza Fani Sani}	699.0	0.72
confirm order	2019-12-26 14:33:23	991283	{884974,884978,884971,884970,884973}	{660798}	{Seran Uysal}	3267.9	1.66
confirm order	2019-12-26 15:40:51	991274	{885008,885009,885010,885011}	{}	{Junxiong Gao}	59.99	0.0
failed delivery	2019-12-26 15:46:21	991128,99125	{884424,884932,884999,885008,885009,885011,884903}	{660797}	{Junxiong Gao}	89.99	0.28
payment reminder	2019-12-26 15:54:44	991169	{884565,884566,884567,884568}	{}	{Gyunann Park}	4087.99	3.011
pick item	2019-12-26 15:55:38	991201	{884717}	{}	{Seran Uysal}	529.0	0.21
pick item	2019-12-26 16:00:38	991251	{884912}	{}	{Tobias Brockhoff}	1500.0	1.133
reorder item	2019-12-26 16:04:42	991265	{884977}	{}	{Seran Uysal}	89.99	0.28
payment reminder	2019-12-26 16:11:39	991164	{884542,884543,884544,884545,884546,884547}	{}	{Junxiong Gao}	4087.99	3.011
pick item	2019-12-26 16:22:04	991241	{884882}	{}	{Lisa Mannel}	529.0	0.21
create package	2019-12-26 16:22:04	991263,99126	{884967,884964,884966}	{660799}	{Luis Santos}	1500.0	1.133

Software Objects

Objects are typed and events may have any number of objects.

activity	time	orders	items	packages
pick item	2019-12-26 12:04:46	{991224}	{884803}	{}
reorder item	2019-12-26 12:37:26	{991271}	{885002}	{}
place order	2019-12-26 12:44:23	{991283}	{885038,885039}	{}
pick item	2019-12-26 14:01:16	{991266}	{884983}	{}
create package	2019-12-26 14:01:16	{991265}	{884975,884974,884978,884971,884970,884973}	{660798}
send package	2019-12-26 14:16:11	{991265}	{884975,884974,884978,884971,884970,884973}	{660798}
pick item	2019-12-26 14:16:48	{991279}	{885027}	{}
confirm order	2019-12-26 14:26:01	{991283}	{885038,885039}	{}
reorder item	2019-12-26 14:32:43	{991251}	{884912}	{}
confirm order	2019-12-26 14:32:44	{991282}	{885036,885037}	{}
pick item	2019-12-26 14:33:28	{991278}	{885024}	{}
place order	2019-12-26 14:48:33	{991284}	{885040,885041,885042,885043,885044}	{}
failed delivery	2019-12-26 15:04:50	{991124,991166}	{884879,884880,884873,884913,884876,884938,884914,884915}	{660790}
pick item	2019-12-26 15:05:00	{991283}	{885025}	{}
confirm order	2019-12-26 15:05:00	{991283}	{884938,884939,884940,884941,884942,884943}	{}
send package	2019-12-26 15:26:49	{991247,991250}	{884902,884922,884923,885004,885005,884901}	{660796}
failed delivery	2019-12-26 15:36:16	{991265}	{884975,884974,884978,884971,884970,884973}	{660798}
confirm order	2019-12-26 15:40:51	{991274}	{885008,885009,885010,885011}	{}
failed delivery	2019-12-26 15:46:21	{991128,991250}	{884424,884932,884999,885008,885009,885011,884903}	{660797}
payment reminder	2019-12-26 15:54:44	{991169}	{884565,884566,884567,884568}	{}
pick item	2019-12-26 15:55:38	{991201}	{884717}	{}

activity

timestamp

orders

items

packages

three types of objects



products

column is used



	activity	time	orders	items	packages
254	create package	2019-05-27 15:04:52	{990023,990015}	{880058,880059,880040}	{660003}
255	pick item	2019-05-27 15:04:22	{990039}	{880154}	{}
256	pick item	2019-05-27 15:04:51	{990033}	{880121}	{}
257	confirm order	2019-05-27 15:14:58	{990036}	{880131,880132,880133,880134}	{}
258	pick item	2019-05-27 15:17:22	{990038}	{880147}	{}
259	create package	2019-05-27 15:17:22	{990007}	{880023,880025,880024,880022}	{660010}
260	reorder item	2019-05-27 15:43:45	{990038}	{880146}	{}
261	send package	2019-05-27 15:49:53	{990007}	{880023,880025,880024,880022}	{660010}
262	pick item	2019-05-27 16:07:59	{990005}	{880014}	{}
263	pick item	2019-05-27 16:08:21	{990030}	{880107}	{}
264	place order	2019-05-27 16:12:18	{990046}	{880173,880174,880175,880176}	{}
265	pick item	2019-05-27 16:14:56	{990013}	{880047}	{}
266	item out of stock	2019-05-27 16:17:26	{990041}	{880051}	{}
267	pick item	2019-05-27 16:18:58	{990033}	{880044}	{}
268	create package	2019-05-27 16:18:58	{990018,990039}	{880006,880070,880069,880067,880154,880071}	{660011}
269	send package	2019-05-27 16:24:47	{990016,990014,990031}	{880050,880051,880050,880056,880059,880049,880058,880057,880117,880...	{660007}
270	pick item	2019-05-27 16:45:33	{990030}	{8800113}	{}
271	reorder item	2019-05-27 16:50:50	{990043}	{880168}	{}
272	pick item	2019-05-27 16:51:02	{990021}	{880080}	{}
273	pay order	2019-05-27 16:56:23	{990023}	{880089,880090}	{}
274	item out of stock	2019-05-27 17:10:55	{990037}	{880143}	{}
275	pay order	2019-05-27 17:14:22	{990034}	{880125,880126,880127,880128}	{}
276	confirm order	2019-05-27 17:14:43	{990039}	{880150,880151,880152,880153,880154,880155,880156}	{}
277	item out of stock	2019-05-27 17:19:33	{990039}	{880155}	{}
278	confirm order	2019-05-27 17:21:37	{990043}	{880165,880166,880167,880168,880169}	{}
279	pick item	2019-05-27 17:21:57	{990029}	{880105}	{}
280	send package	2019-05-27 17:32:16	{990009,990015,990024}	{880032,880053,880055,880031,880092,880091,880030}	{660005}
281	pick item	2019-05-27 17:40:09	{990037}	{880139}	{}
282	place order	2019-05-27 17:44:23	{990047}	{880177,880178,880179,880180}	{}
283	reorder item	2019-05-27 17:58:16	{990032}	{880118}	{}

Disco
by Fluxicon

Cancel

File encoding: UTF-8

 Use quotes

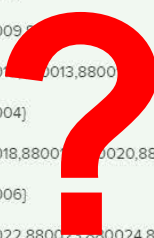
Map activity table columns

For Process Mining to function, we need to find out which columns contain the necessary data.



1/5 Select Case ID column
Click on the column that contains your case IDs. Case ID is usually a numeric value that is unique and identifies each case in your process.

activity	time	orders	items	packages	customers	products
place order	2019-05-20 09:07:47	{990001}	{880001,880002,880003,880004}	0	{Christina Rensinghof}	{iPad mini,iPhone 11,Kindle Paperwhite}
pick item	2019-05-20 09:40:14	{990001}	{880002}	0	{Christina Rensinghof}	{iPhone 11}
place order	2019-05-20 10:35:21	{990002}	{880006,880007,880008}	0	{Christine Dobbert}	{iPad,iPad Pro,Echo Show 5}
confirm order	2019-05-20 10:41:07	{990002}	{880006,880007,880008}	0	{Christine Dobbert}	{iPad,iPad Pro,Echo Show 5}
place order	2019-05-20 12:30:30	{990003}	{880009}	0	{Mohammadreza Fani Sani}	{iPhone 8,Echo Show 5}
place order	2019-05-20 14:20:47	{990004}	{880011}	0	{Majid Rafiei}	{iPad}
confirm order	2019-05-20 14:50:51	{990003}	{880009}	0	{Mohammadreza Fani Sani}	{iPhone 8,Echo Show 5}
place order	2019-05-20 16:01:22	{990005}	{880010,880013,880014,880015}	0	{Gyunam Park}	{iPad Pro,Kindle,iPhone 11}
pick item	2019-05-20 16:35:33	{990001}	{880004}	0	{Christina Rensinghof}	{Fire Stick}
place order	2019-05-20 17:22:31	{990006}	{880018,880019,880020,880021}	0	{Marco Pegoraro}	{Echo Show 8,iPhone X,Kindle Paperwhite}
pick item	2019-05-20 18:30:53	{990002}	{880006}	0	{Christine Dobbert}	{iPad}
place order	2019-05-20 19:04:49	{990007}	{880022,880023,880024,880025}	0	{Anahita Farhang Ghahfarokhi}	{Kindle,Echo Studio,Echo Show 5}
confirm order	2019-05-20 19:59:41	{990005}	{880012,880013,880014,880015}	0	{Gyunam Park}	{iPad Pro,Kindle,iPhone 11}



Select Case ID



Select File

2

Map columns

3

Upload file

4

Data Analysis



Map event_log-all.csv



Open New



ABBY® Timeline

To upload data you must first map the fields (columns) of your data file.

- Map **required fields** (Timeline ID, Timestamp and Event Name) by dragging the corresponding label to the desired column
- Map **optional fields** (columns) that you want to use for filtering your timelines by dragging the New Attribute label to the desired column.
- Once you have completed your mapping press the 'Confirm and start upload button'.

More...

Label all as attributes

Timeline ID

Event category

Event number

New attribute

Event name

Timestamp

orders

items

packages

customers

products

PRICE

activity

time

orders

items

packages

customers

products

price

Sani}

place order	2019-05-20 16:01:22	{990005}	{880012,880013,880014,880015,880016,880017}	{}	{Gyunam Park}	{iPad Pro,Kindle,iPhone X,Echo,iPhone 11 Pro,Kindle Paperwhite}	3260.98
pick item	2019-05-20 16:35:33	{990001}	{880004}	{}	{Christina Rensinghof}	{Fire Stick}	39.99
place order	2019-05-20 17:22:31	{990006}	{880018,880019,880020,880021}	{}	{Marco Pegoraro}	{Echo Show 8,iPhone X,MacBook Air,MacBook Air}	5233.99
pick item	2019-05-20 18:30:53	{990002}	{880006}	{}	{Christine Dobbert}	{iPad}	495.0
place order	2019-05-20 19:04:49	{990007}	{880022,880023,880024,880025}	{}	{Anahita Farhang Ghahfarokhi}	{Kindle,Echo Studio,Echo Dot,Echo Studio}	514.96
confirm order	2019-05-20 19:59:41	{990005}	{880012,880013,880014,880015,880016,880017}	{}	{Gyunam Park}	{iPad Pro,Kindle,iPhone X,Echo,iPhone 11 Pro,Kindle Paperwhite}	3260.98



ⓘ Please make sure that Timeline ID is mapped

🔗 Help

Cancel

Confirm and start upload

Configure CSV Parser Settings

CSV Parser: Settings

Charset

Configure the character encoding that is used by the CSV file

windows-1252

Separator Character

Configure the character that is used by the CSV file to separate two fields

Semicolon (;)

Quote Character

Configure the character that is used by the CSV file that is used to quote values if they contain the separator character or a newline

DOUBLE QUOTE (")

activity	time	orders	items	packages	customers	products	price	weight
place order	2019-05-2...	{990001}	{880001,8...	{}	{Christina ...	{iPad mini,L...	2220.99	1.307
pick item	2019-05-2...	{990001}	{880002}	{}	{Christina ...	{iPhone 11}	799.0	0.166
place order	2019-05-2...	{990002}	{880006,8...	{}	{Christine ...	{iPad,iPad ...	1688.99	1.846
confirm or...	2019-05-2...	{990002}	{880006,8...	{}	{Christine ...	{iPad,iPad ...	1688.99	1.846
place order	2019-05-2...	{990003}	{880009,8...	{}	{Mohamm...	{iPhone 8,...	623.99	1.09
place order	2019-05-2...	{990004}	{880011}	{}	{Majid Rafi...	{iPad}	500.0	0.483
confirm or...	2019-05-2...	{990003}	{880009,8...	{}	{Mohamm...	{iPhone 8,...	623.99	1.09
place order	2019-05-2...	{990005}	{880012,8...	{}	{Gyunam P...	{iPad Pro,...	3260.98	2.601
pick item	2019-05-2...	{990001}	{880004}	{}	{Christina ...	{Fire Stick}	39.99	0.2
place order	2019-05-2...	{990006}	{880018,8...	{}	{Marco Pe...	{Echo Sho...	5233.99	3.652
pick item	2019-05-2...	{990002}	{880006}	{}	{Christine ...	{iPad}	495.0	0.483
place order	2019-05-2...	{990007}	{880022,8...	{}	{Anahita F...	{Kindle,Ec...	514.96	3.823
confirm or...	2019-05-2...	{990005}	{880012,8...	{}	{Gyunam P...	{iPad Pro,...	3260.98	2.601
place order	2019-05-2...	{990008}	{880026,8...	{}	{Gyunam P...	{Echo Dot,...	2824.97	4.11
place order	2019-05-2...	{990009}	{880030,8...	{}	{Lisa Mann...	{iPad Air,E...	1079.99	2.0
pick item	2019-05-2...	{990005}	{880015}	{}	{Gyunam P...	{Echo}	99.99	0.78
confirm or...	2019-05-2...	{990006}	{880018,8...	{}	{Marco Pe...	{Echo Sho...	5233.99	3.652
pick item	2019-05-2...	{990008}	{880028}	{}	{Gyunam P...	{Echo Stud...	199.99	1.48
item out of ...	2019-05-2...	{990005}	{880014}	{}	{Gyunam P...	{iPhone X}	699.0	0.172
item out of ...	2019-05-2...	{990005}	{880016}	{}	{Gyunam P...	{iPhone 11...	1149.0	0.188
pick item	2019-05-2...	{990006}	{880018}	{}	{Marco Pe...	{iPhone X}	699.0	0.172

Cancel

Previous

Next

Configure Conversion from CSV to XES

Mapping to Standard XES Attributes

[Show Expert Configuration](#)

Case Column (Optional)

Groups events into traces, and is mapped to 'concept:name' of the trace. Select one or more columns, re-order by drag & drop.

activity

activity
time
orders
items
packages
customers
products
price

Event Column (Optional)

Mapped to 'concept:name' of the event. Select one or more columns, re-order by drag & drop.

activity

Selected event columns:
activity

Start Time (Optional)

Mapped to 'time.timestamp' of a separate start event.

time

Could not auto-detect the used date format. Please provide a

Completion Time (Optional)

Mapped to 'time.timestamp'

time

yyyy-M-d H:mm:ss

Cancel

Previous

Next



Need to flatten the event data when using a conventional process mining technique

- **Pick** an object type as the **case** notion.
- **Replicate** each event for each object of the corresponding type.

activity	time	orders	items	packages
...
place order	2019-12-26	{991283}	{885038,885039}	{}
...

one event if order is used as a case notion

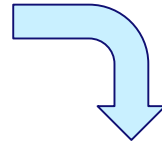
two events if item is used as a case notion

no event if package is used as a case notion



Order as a case notion

activity	time	orders	items	packages
...
place order	2020-6-20	{99001}	{88001, 88002}	{}
pick item	2020-6-22	{99001}	{88001}	{}
pick item	2020-6-23	{99001}	{88002}	{}
...
send package	2020-6-25	{99001, 99002}	{88002, 88003, 88004}	{66001}
...

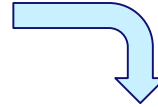


activity	time	orders	items	packages
...
place order	2020-6-20	99001	{88001, 88002}	{}
pick item	2020-6-22	99001	{88001}	{}
pick item	2020-6-23	99001	{88002}	{}
...
send package	2020-6-25	99001	{88002, 88003, 88004}	{66001}
send package	2020-6-25	99002	{88002, 88003, 88004}	{66001}
...

Events may be duplicated

Item as a case notion

activity	time	orders	items	packages
...
place order	2020-6-20	{99001}	{88001, 88002}	{}
pick item	2020-6-22	{99001}	{88001}	{}
pick item	2020-6-23	{99001}	{88002}	{}
...
send package	2020-6-25	{99001, 99002}	{88002, 88003, 88004}	{66001}
...

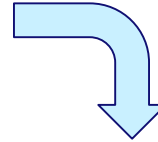


activity	time	orders	items	packages
...
place order	2020-6-20	{99001}	88001	{}
place order	2020-6-20	{99001}	88002	{}
pick item	2020-6-22	{99001}	88001	{}
pick item	2020-6-23	{99001}	88002	{}
...
send package	2020-6-25	{99001, 99002}	88002	{66001}
send package	2020-6-25	{99001, 99002}	88003	{66001}
send package	2020-6-25	{99001, 99002}	88004	{66001}
...

Events may be duplicated

Package as a case notion

activity	time	orders	items	packages
...
place order	2020-6-20	{99001}	{88001, 88002}	{}
pick item	2020-6-22	{99001}	{88001}	{}
pick item	2020-6-23	{99001}	{88002}	{}
...
send package	2020-6-25	{99001, 99002}	{88002, 88003, 88004}	{66001}
...



activity	time	orders	items	packages
...
send package	2020-6-25	99002	{88002, 88003, 88004}	66001
...

Events may disappear

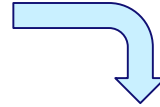
Possible problems

- **Deficiency:** Events in the original event log that have no corresponding events in the flattened event log may **unintentionally disappear** from the data set.
- **Convergence:** Events referring to multiple objects of the selected type are replicated, possibly leading to **unintentional duplication**.
- **Divergence:** Events referring to **different objects** of a type not selected as the case notion are considered to be **causally related**.

Convergence

Events referring to multiple objects of the selected type are replicated, possibly leading to unintentional duplication

activity	time	orders	items	packages
...
place order	2020-6-20	{99001}	{88001, 88002}	{}
pick item	2020-6-22	{99001}	{88001}	{}
pick item	2020-6-23	{99001}	{88002}	{}
...
send package	2020-6-25	{99001, 99002}	{88002, 88003, 88004}	{66001}
...



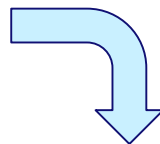
activity	time	orders	items	packages
...
place order	2020-6-20	{99001}	88001	{}
place order	2020-6-20	{99001}	88002	{}
pick item	2020-6-22	{99001}	88001	{}
pick item	2020-6-23	{99001}	88002	{}
...
send package	2020-6-25	{99001, 99002}	88002	{66001}
send package	2020-6-25	{99001, 99002}	88003	{66001}
send package	2020-6-25	{99001, 99002}	88004	{66001}

How to compute costs, times, frequencies, etc. when events are replicated?

Divergence

Events referring to different objects of a type not selected as the case notion are considered to be causally related

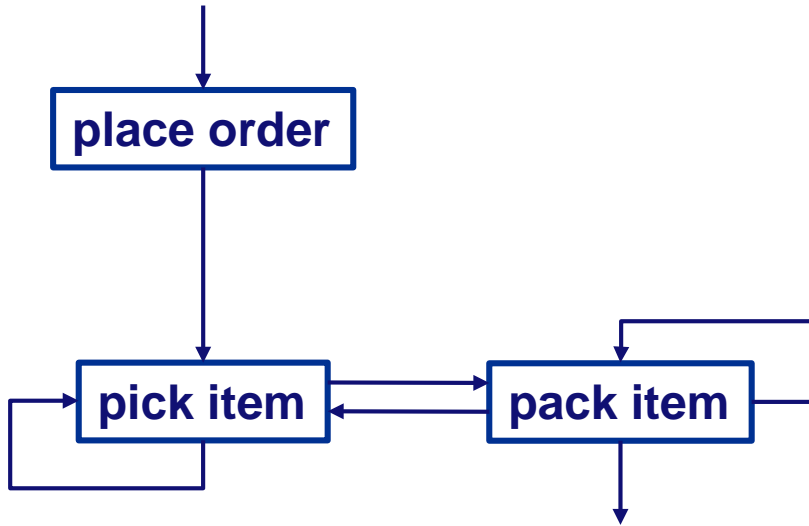
activity	time	orders	items	packages
...
place order	2020-6-20	{99001}	{88001, 88002, 88003}	{ }
pick item	2020-6-22	{99001}	{88001}	{ }
pick item	2020-6-23	{99001}	{88002}	{ }
pack item	2020-6-22	{99001}	{88002}	{ }
pack item	2020-6-23	{99001}	{88001}	{ }
pick item	2020-6-22	{99001}	{88003}	{ }
pack item	2020-6-23	{99001}	{88003}	{ }
...



activity	time	orders	items	packages
...
place order	2020-6-20	99001	{88001, 88002, 88003}	{ }
pick item	2020-6-22	99001	{88001}	{ }
pick item	2020-6-23	99001	{88002}	{ }
pack item	2020-6-22	99001	{88002}	{ }
pack item	2020-6-23	99001	{88001}	{ }
pick item	2020-6-22	99001	{88003}	{ }
pack item	2020-6-23	99001	{88003}	{ }
...

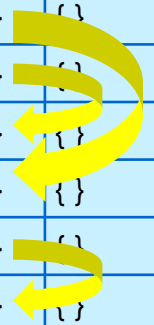
Divergence

Events referring to different objects of a type not selected as the case notion are considered to be causally related



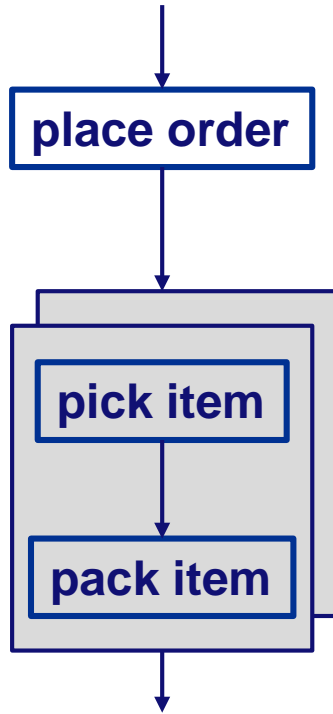
Things happen in a fixed order but this is not visible!

activity	time	orders	items	packages
...
place order	2020-6-20	99001	{88001, 88002, 88003}	{}
pick item	2020-6-22	99001	{88001}	{}
pick item	2020-6-23	99001	{88002}	{}
pack item	2020-6-22	99001	{88002}	{}
pack item	2020-6-23	99001	{88001}	{}
pick item	2020-6-22	99001	{88003}	{}
pack item	2020-6-23	99001	{88003}	{}
...



Divergence

Events referring to different objects of a type not selected as the case notion are considered to be causally related



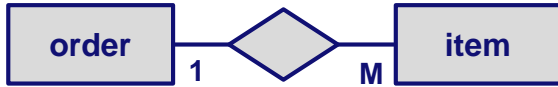
activity	time	orders	items	packages
...
place order	2020-6-20	99001	{88001, 88002, 88003}	{ }
pick item	2020-6-22	99001	{88001}	{ }
pick item	2020-6-23	99001	{88002}	{ }
pack item	2020-6-22	99001	{88002}	{ }
pack item	2020-6-23	99001	{88001}	{ }
pick item	2020-6-22	99001	{88003}	{ }
pack item	2020-6-23	99001	{88003}	{ }
...

Concurrency and causality!

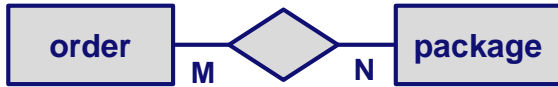
Relevance? See any d

(Chen notation, Crow's foot notation, UML class diagrams)

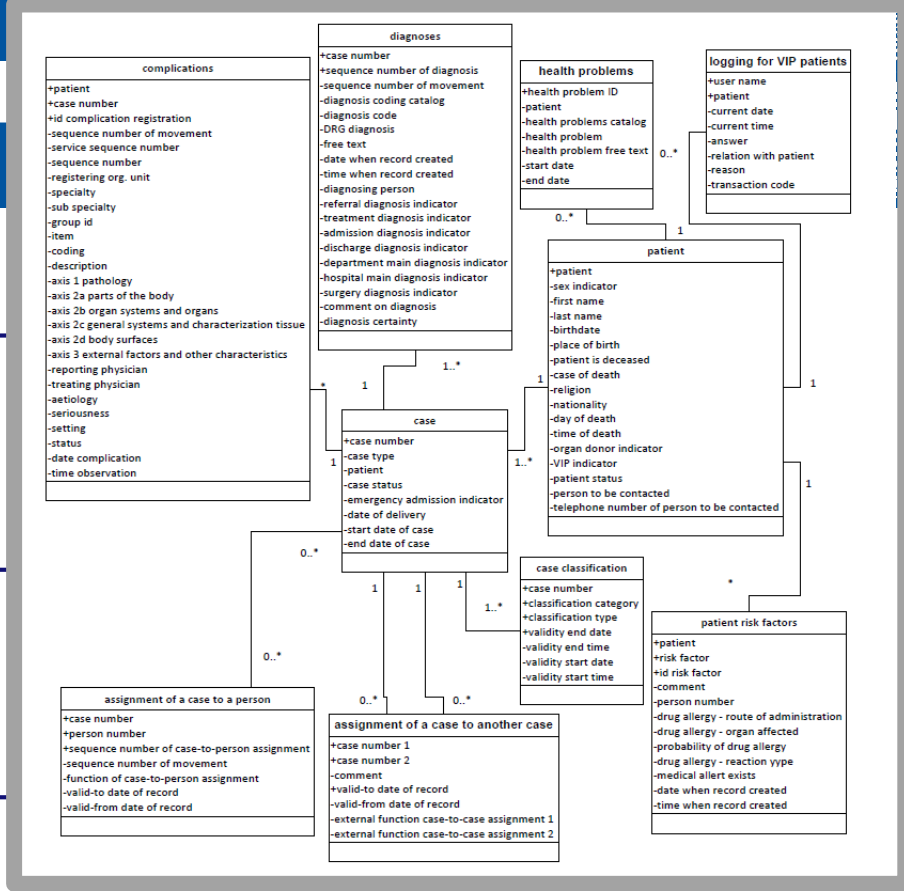
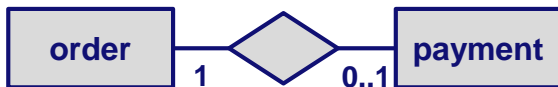
one-to-many



many-to-many



one-to-one



Very few relations are one-to-one!

Hence, a single case notion is not enough!

How to deal with this?



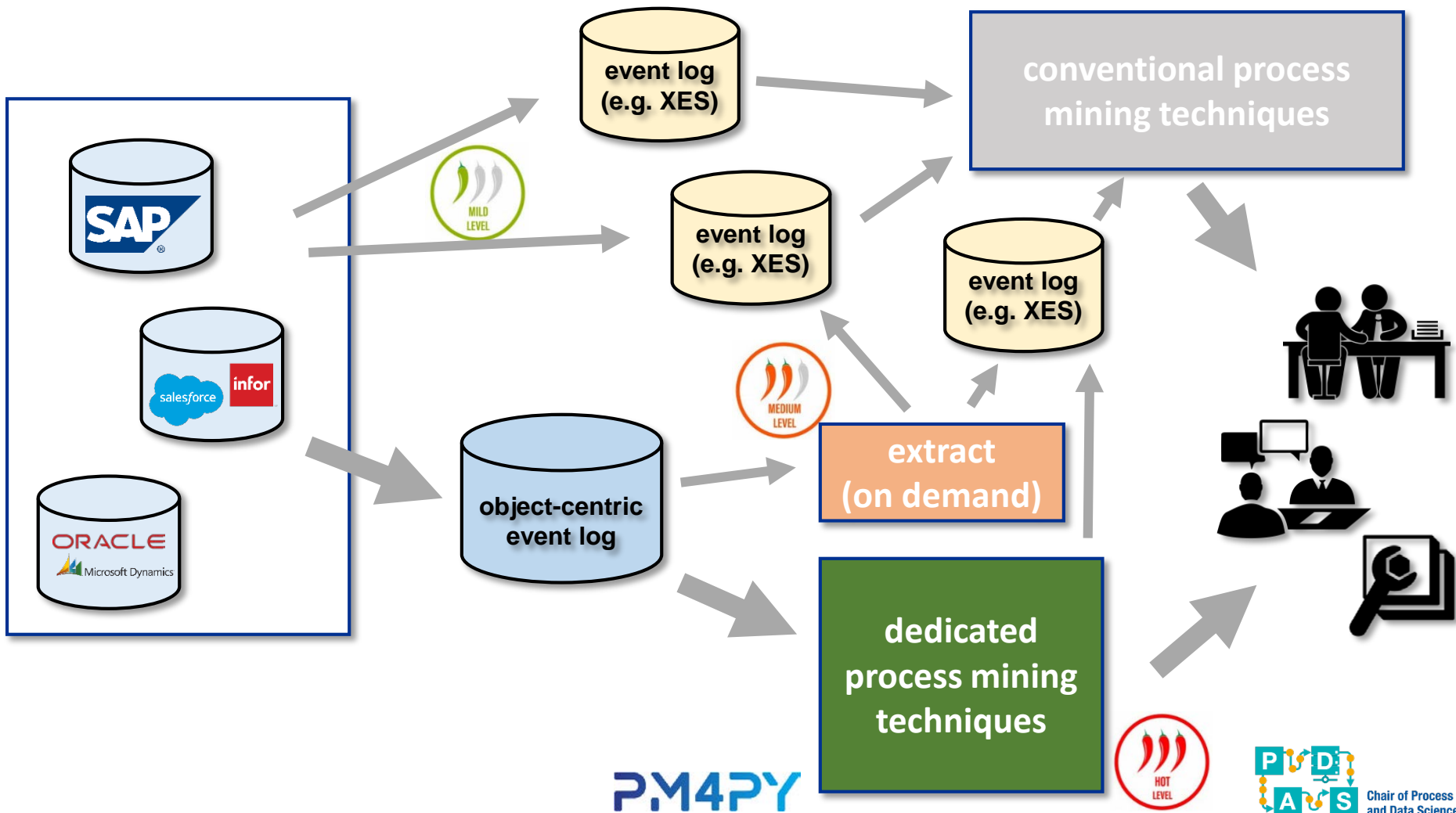
Directly extracting one or more conventional event logs (e.g. XES) realizing that there are may be convergence and divergence problems.



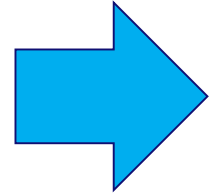
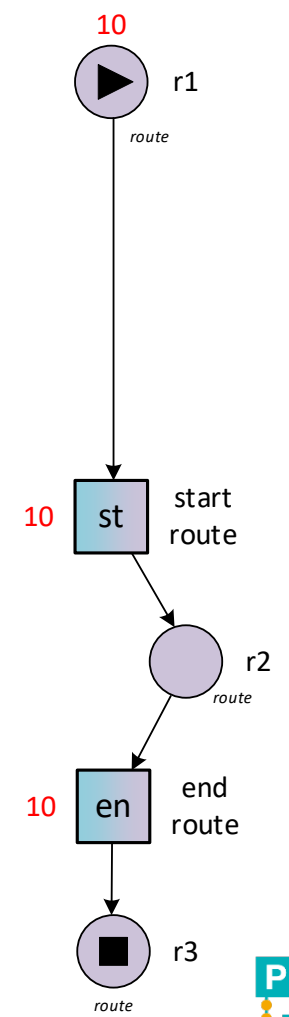
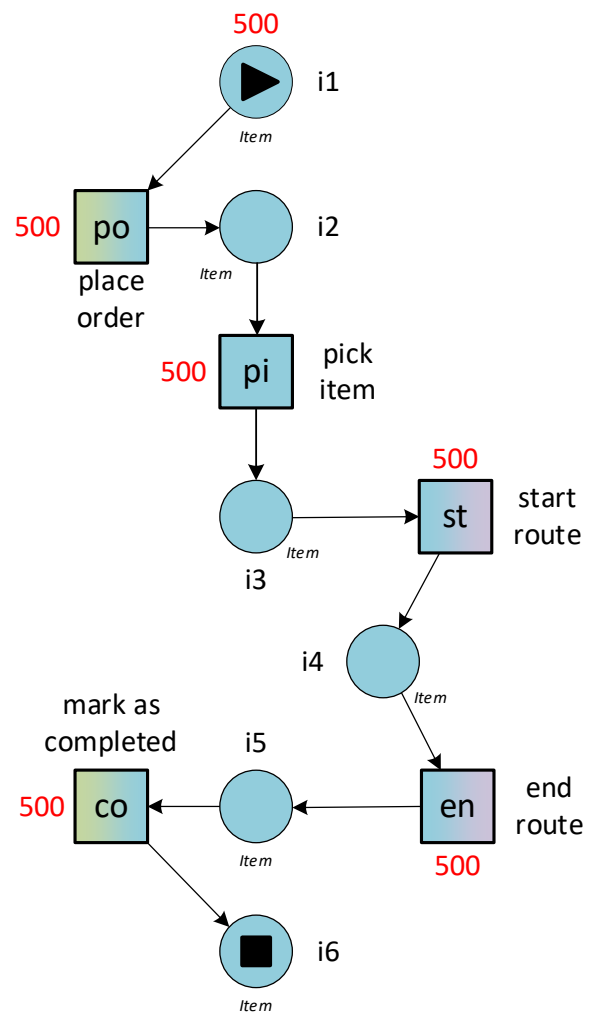
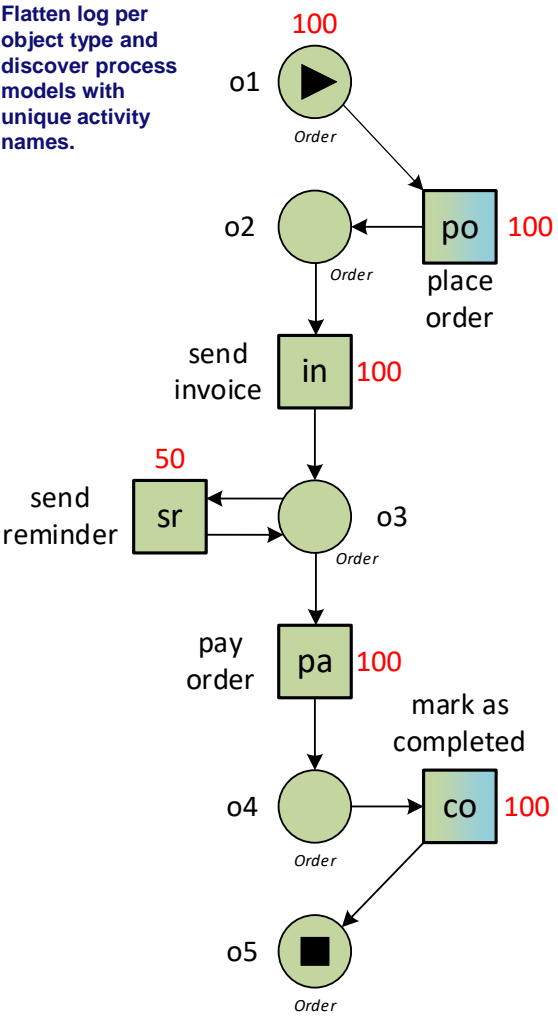
Extracting one object-centric event log and creating conventional event logs (e.g. XES) on demand.



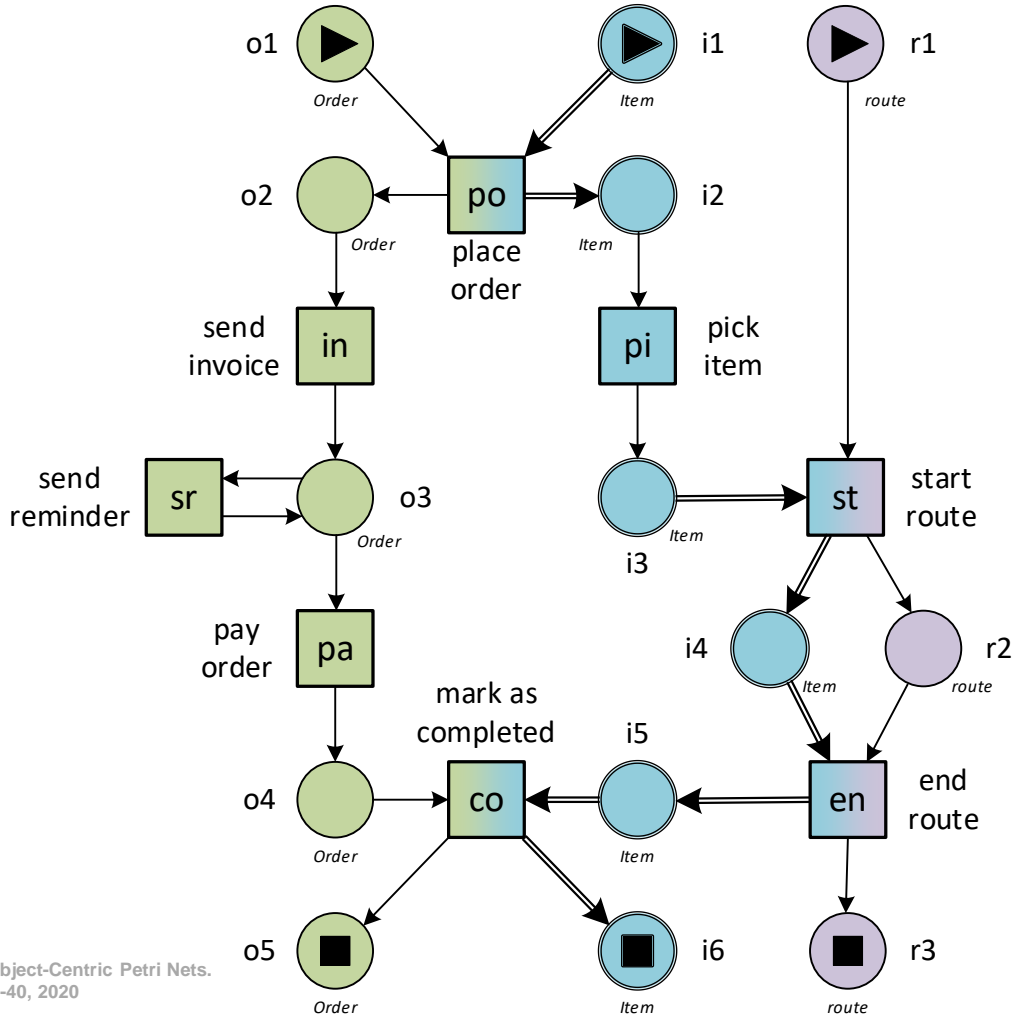
Extracting one object-centric event log and using process mining techniques directly working on object-centric event logs.



Flatten log per object type and discover process models with unique activity names.



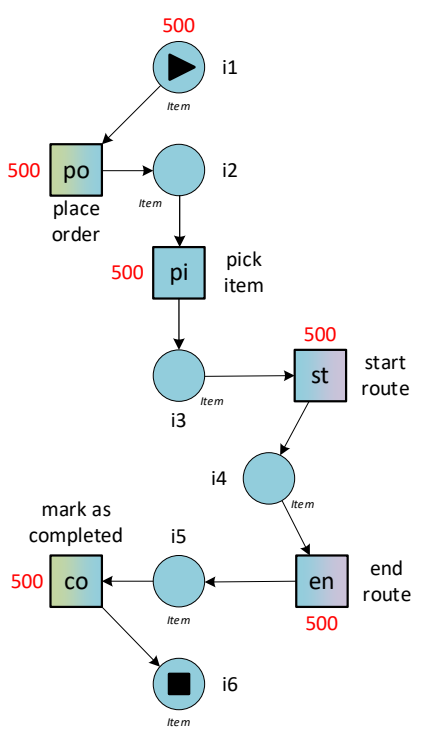
Merge the different models using the original frequencies.



W.M.P. van der Aalst and A. Berti. Discovering Object-Centric Petri Nets. Fundamenta Informaticae, vol. 175, no. 1-4, pp. 1-40, 2020

© Wil van der Aalst (use only with permission & acknowledgements)

Example for the object type item.

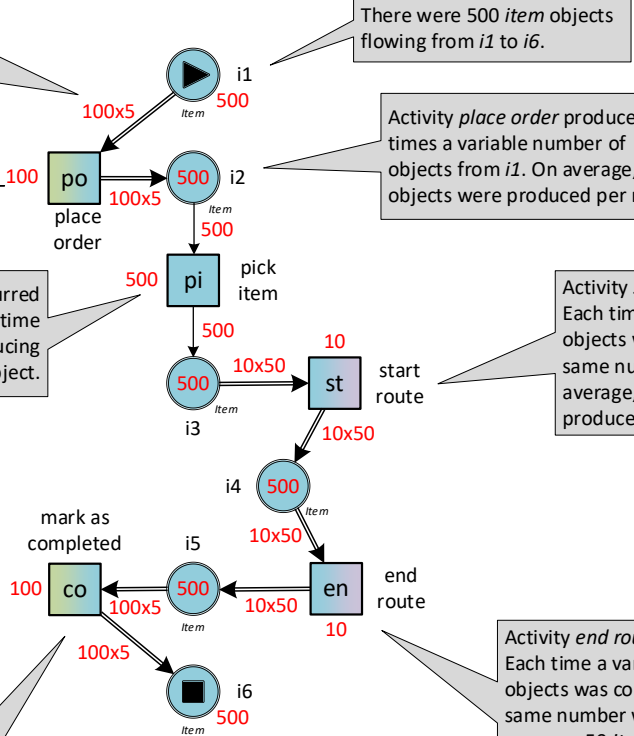


Activity *place order* consumed 100 times a variable number of *item* objects from *i1*. On average, 5 *item* objects were consumed per round.

Activity *place order* occurred 100 times.

Activity *pick item* occurred 500 times each time consuming and producing precisely one *item* object.

Activity *mark as completed* occurred 100 times. Each time a variable number of *item* objects was consumed from *i5* and the same number was produced for *i6*. On average, 5 *item* objects were produced/consumed per round.



There were 500 *item* objects flowing from *i1* to *i6*.

Activity *place order* produced 100 times a variable number of *item* objects from *i1*. On average, 5 *item* objects were produced per round.

Activity *start route* occurred 10 times. Each time a variable number of *item* objects was consumed from *i3* and the same number was produced for *i4*. On average, 50 *item* objects were produced/consumed per round.

Activity *end route* occurred 10 times. Each time a variable number of *item* objects was consumed from *i4* and the same number was produced for *i5*. On average, 50 *item* objects were produced/consumed per round.

Step: 8

Time: 0

Options

History

Declarations

Standard priorities

Standard declarations

Types and Defs

- colset Order = int with 99001..99100;

- colset Item = int with 88001..88500;

- colset Route = int with 66001..66010;

- colset Orders = list Order;

- colset Items = list Item;

- colset Routes = list Route;

- var or:Order;

- var ors:Orders;

- var it:Item;

- var its:Items;

- var rt:Route;

- var rts:Routes;

- fun gen

- fun oi

- fun ri

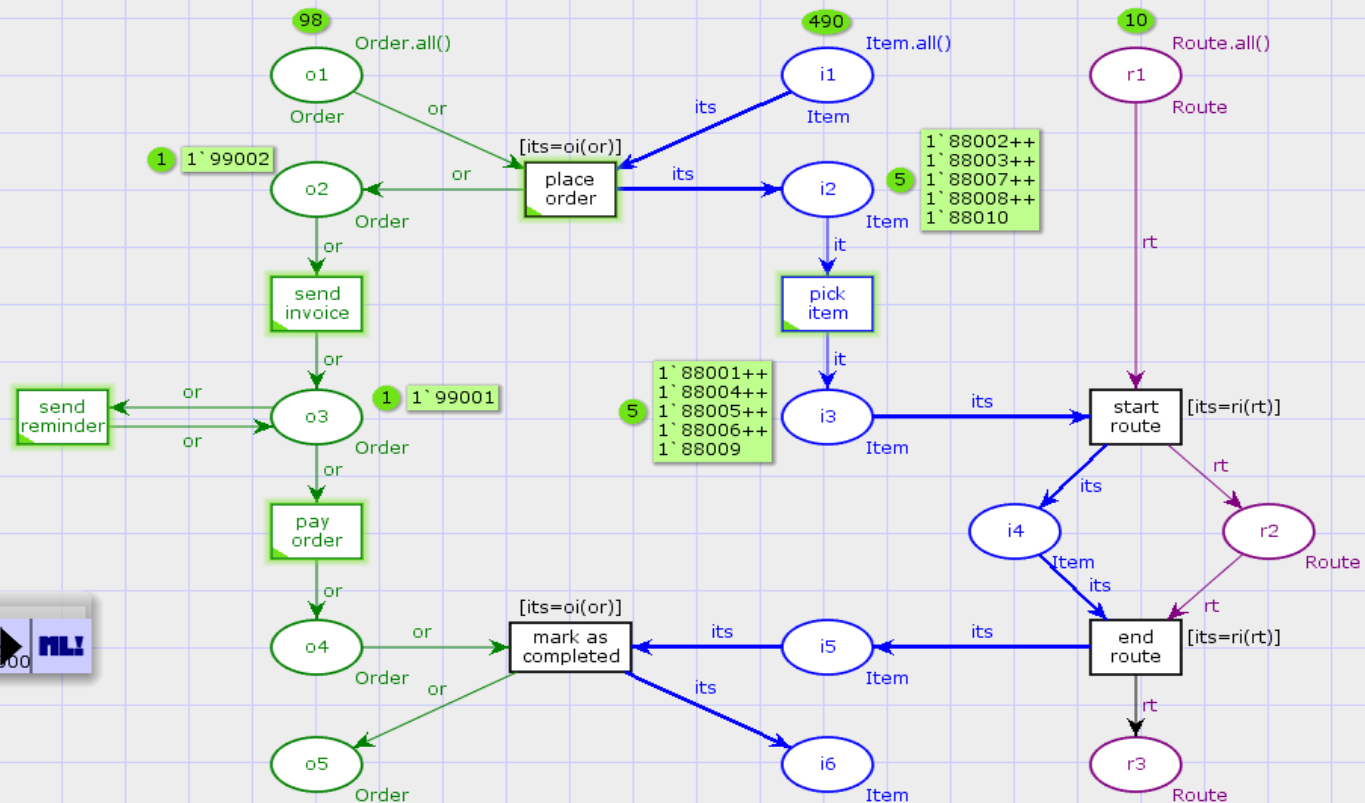
Monitors

object-centric-petri-net

object-centric-petri-net

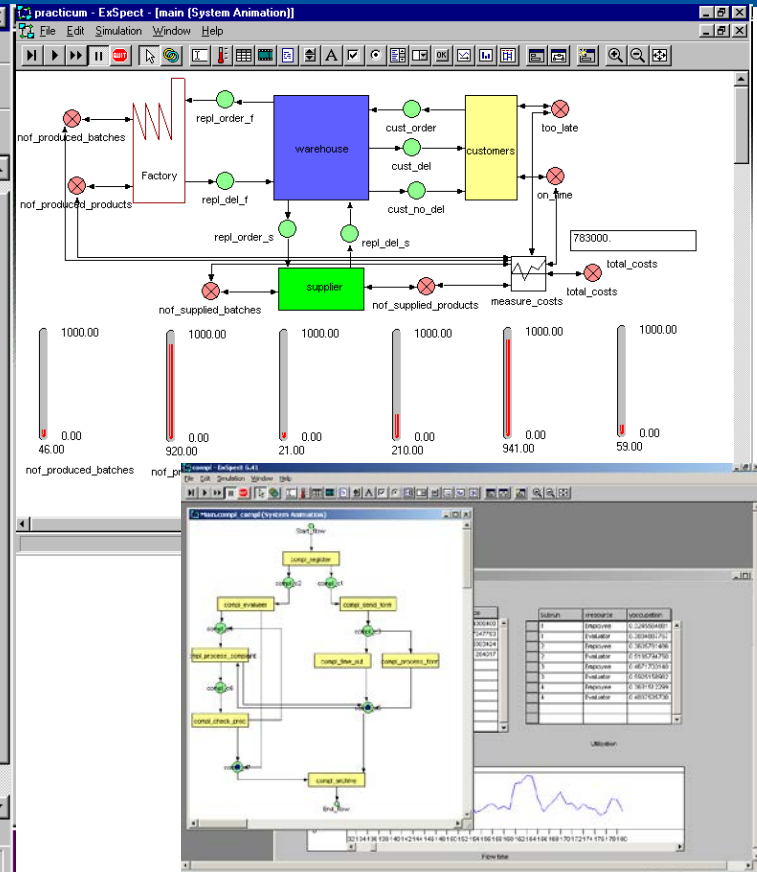
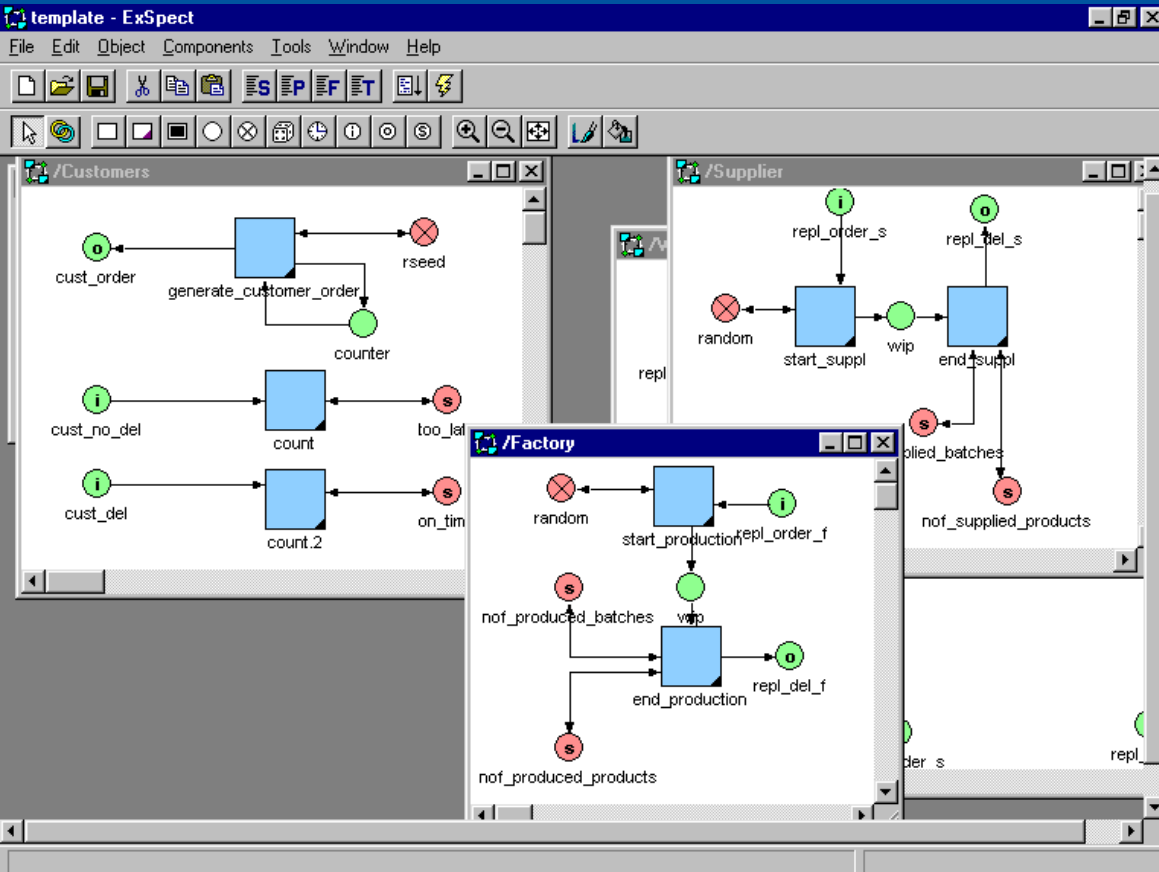
Binder 0

The resulting model can be seen as a Colored Petri Net (CPN).

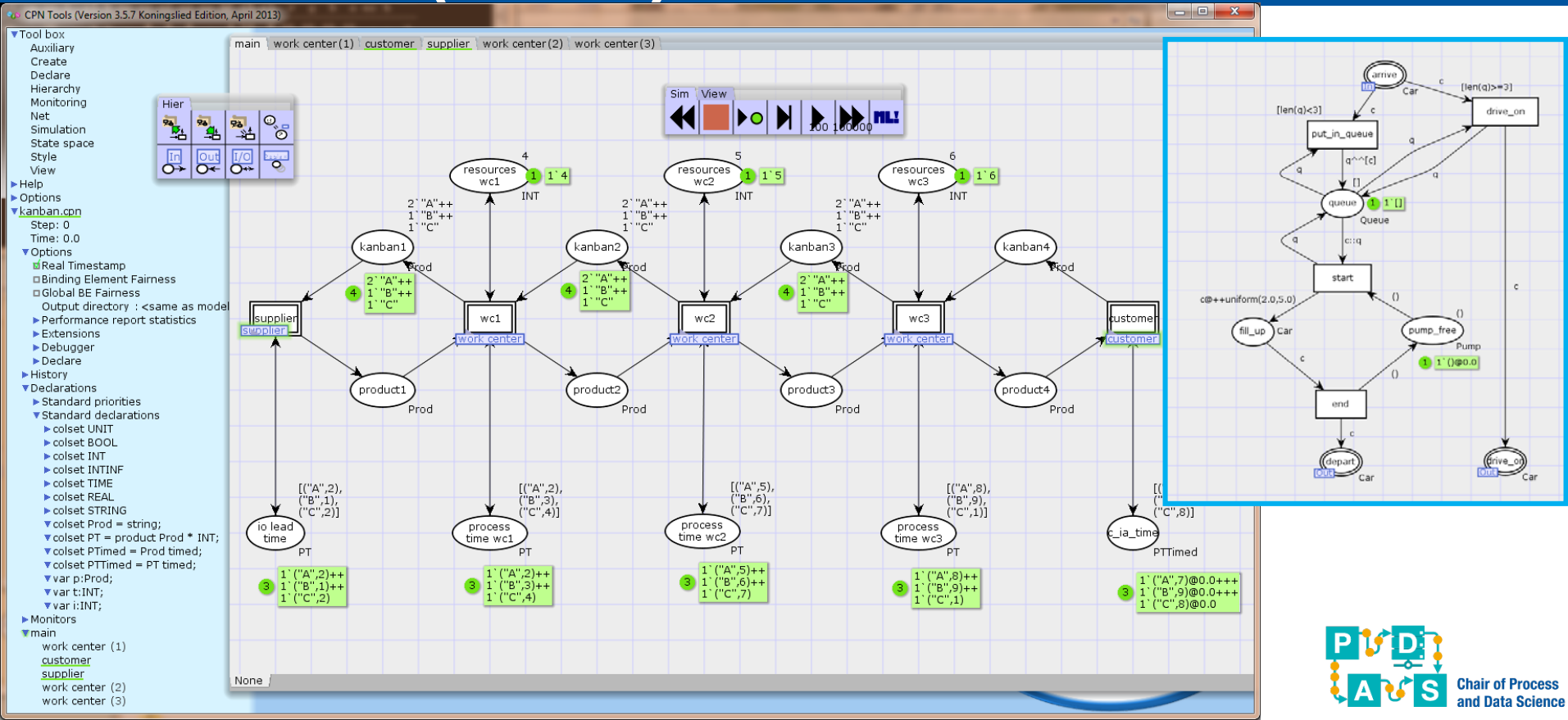


None

Not so new: ExSpecT (1988-2000)



Not so new: Design/CPN (1989-2000) and CPN Tools (2000-)



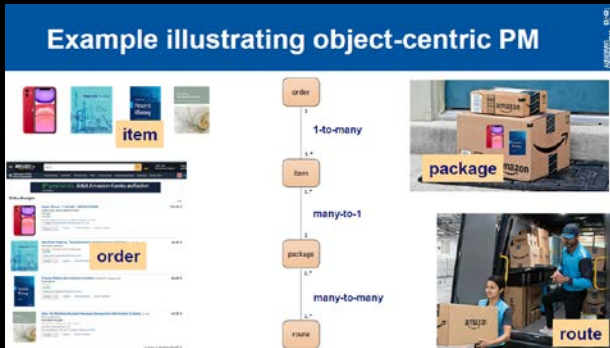
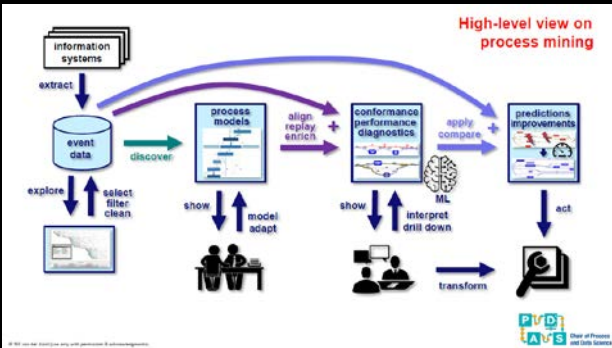
Some pointers

- W.M.P. van der Aalst. **Object-Centric Process Mining: Dealing With Divergence and Convergence in Event Data.** In Software Engineering and Formal Methods (SEFM 2019), LNCS 11724, 3–25. Springer-Verlag, Berlin, 2019.
- W.M.P. van der Aalst and A. Berti. **Discovering Object-Centric Petri Nets.** Fundamenta Informaticae, vol. 175, no. 1-4, pp. 1-40, 2020
- A. Berti and W.M.P. van der Aalst. **Discovering Multiple Viewpoint Models from Relational Databases.** In International Symposium on Data-driven Process Discovery and Analysis, volume 379 of Lecture Notes in Business Information Processing, pages 24–51. Springer-Verlag, Berlin, 2020.

- W.M.P. van der Aalst, A. Artale, M. Montali, and S. Tritini. **Object-Centric Behavioral Constraints: Integrating Data and Declarative Process Modelling.** In Proceedings of the 30th International Workshop on Description Logics (DL 2017), volume 1879 of CEUR Workshop Proceedings. CEUR-WS.org, 2017.
- D. Fahland. **Describing Behavior of Processes with Many-to-Many Interactions.** In S. Donatelli and S. Haar, editors, Applications and Theory of Petri Nets 2019, volume 11522 of Lecture Notes in Computer Science, pages 3–24. Springer-Verlag, Berlin, 2019.
- D. Fahland, M. De Leoni, B. van Dongen, and W.M.P. van der Aalst. **Many-to-Many: Some Observations on Interactions in Artifact Choreographies.** In Proceedings of the 3rd Central-European Workshop on Services and their Composition (ZEUS 2011), pages 9–15. CEUR-WS.org, 2011.
- G. Li, R. Medeiros de Carvalho, and W.M.P. van der Aalst. **Automatic Discovery of Object-Centric Behavioral Constraint Models.** In Business Information Systems (BIS 2017), LNBIP 288, 2017.



Conclusion



the following assumption

a "place order" event may refer to multiple items

a "failed delivery" event refers to one package, one or more items, one or more orders, etc.

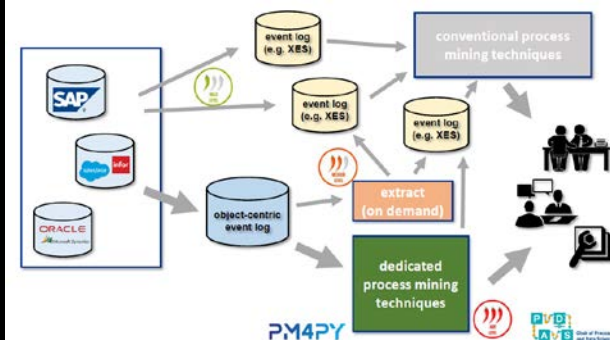
a "pick item" event refers to one item

let's simplify to focus on the essence

objects

Objects are typed and events may have any number of objects.

- ### Possible problems
- Deficiency:** Events in the original event log that have no corresponding events in the flattened event log may **unintentionally disappear** from the data set.
 - Convergence:** Events referring to multiple objects of the selected type are replicated, possibly leading to **unintentional duplication**.
 - Divergence:** Events referring to **different objects** of a type not selected as the case notion are considered to be **causally related**.



Object-Centric Process Mining

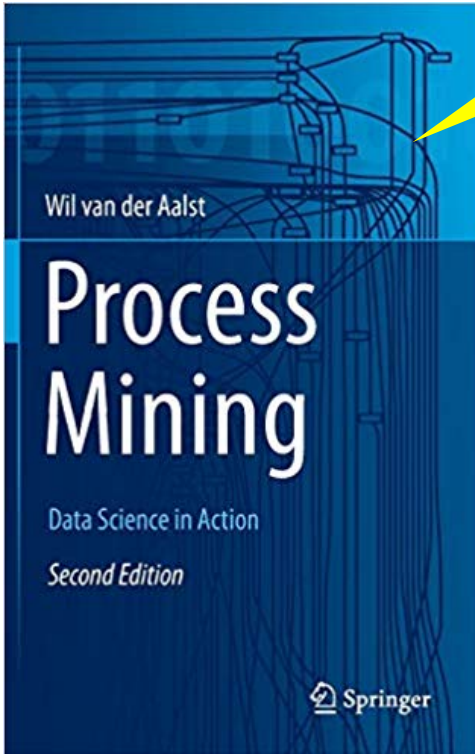
Everything should be made as simple as possible, but not simpler.

package delivered 1256

Value price: 4,620.00

Value weight: 0.27400

Learn more?



“PM Bible”

Over 128.000
participants

coursera

Example Revisited $L_1 = \{(a,b,c,d)^3, (a,c,b,d)^2, (a,c,e,d)\}$

a>b	a→b	b|c	b#e
a>c	a→c	c|b	e#b
a>e	a→e		c#e
b>c	b→d		a#d
b>d			...
c>b			
c>d			
e>d			

start → a → p1 → b → p3 → d → end
 ↓ ↓ ↓
 p2 → c → p4 → e → d

Result produced by the Alpha algorithm

TU/e

<https://www.coursera.org/learn/process-mining>

prof.dr.ir. Wil van der Aalst
RWTH Aachen University
W: vdaalst.com T: @wvdaalst

Fraunhofer

FIT



Chair of Process
and Data Science