November 17, 2022, AGH University of Science and Technology, Krakow

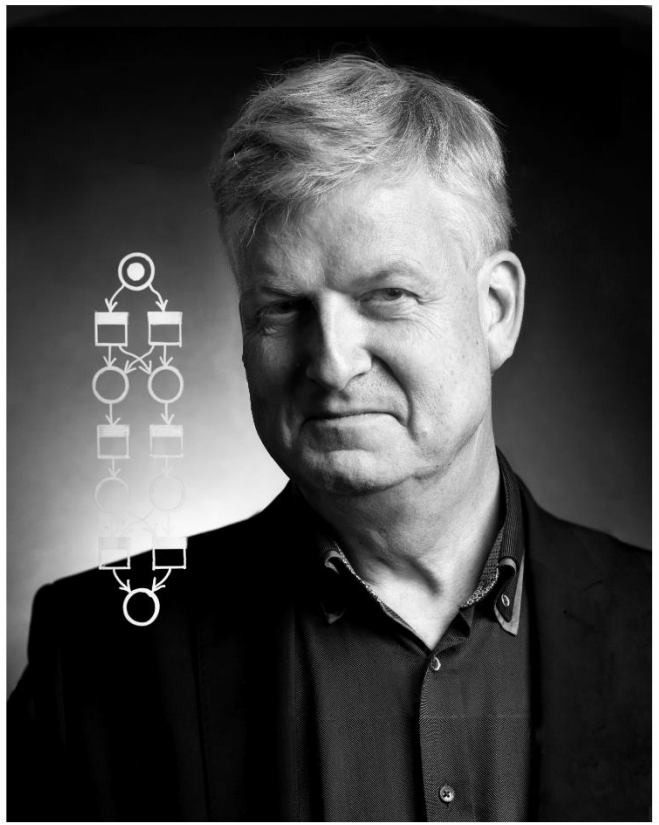
Autonomous Process Execution Management

Powered by Process Mining

prof.dr.ir. Wil van der Aalst
www.vdaalst.com @wvdaalst | www.pads.rwth-aachen.de | www.celonis.com

About Wil

- AvH professor @RWTH
- Chair of the PADS group @ RWTH, before 30 years at TU/e.
- Chief scientist @ Celonis.
- Board of Governors Tilburg University & Scientific Advisor Fraunhofer FIT.
- “Godfather of Process Mining”
- Founder of conference series like BPM and ICPM, and the IEEE TFPM.

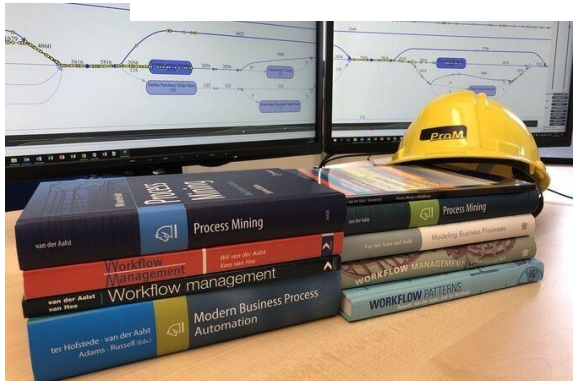


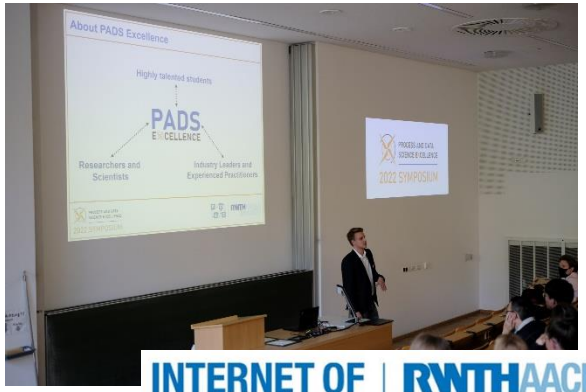
Chair of Process and Data Science

About PADS

- 30+ researchers (excluding HiWis).
- Leading group in process mining.
- Leading role in AI Center, Internet of Production, and around 15 projects.
- Courses in process and data science.

Center for Artificial Intelligence | RWTH AACHEN UNIVERSITY



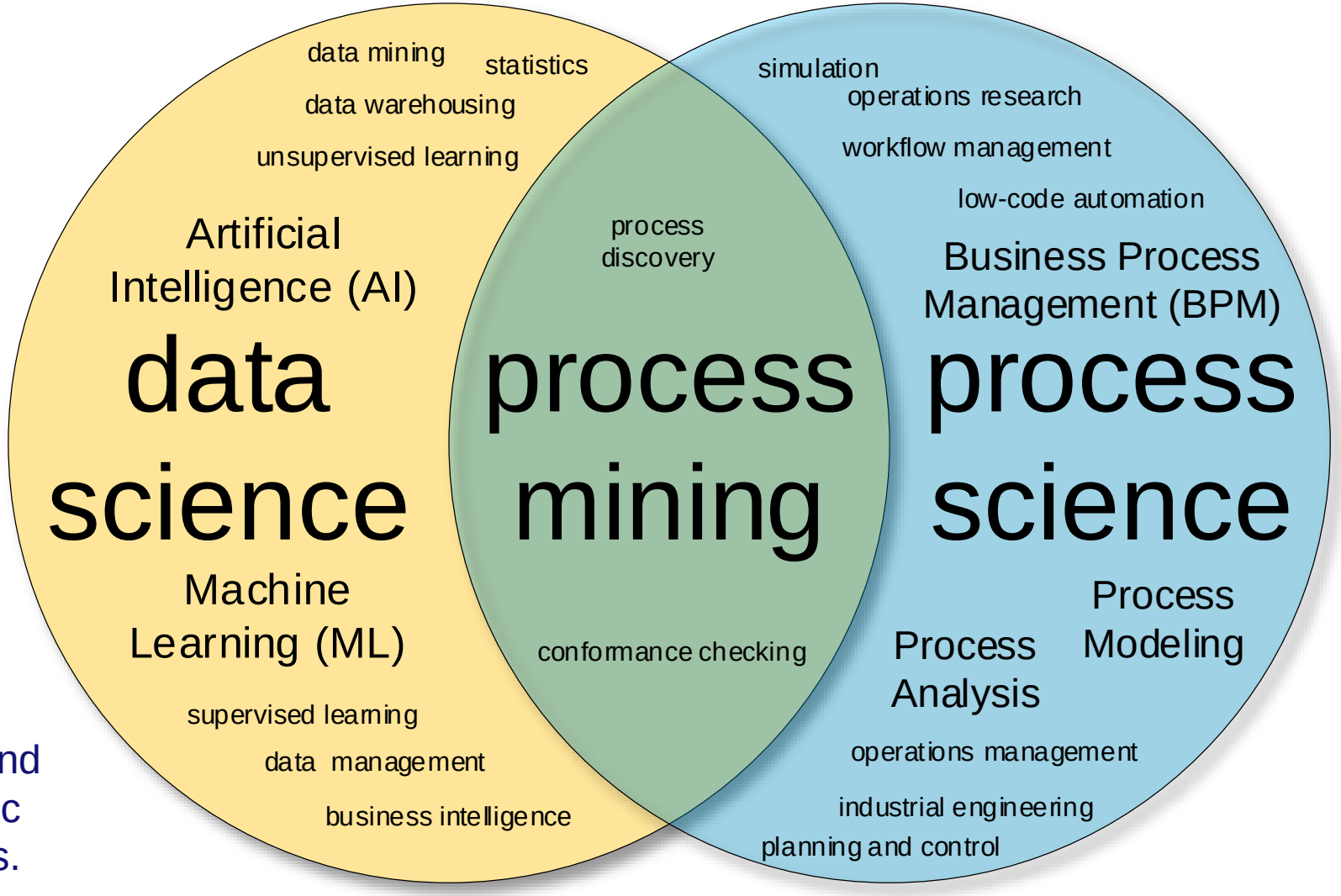


INTERNET OF PRODUCTION | RWTH AACHEN UNIVERSITY

celonis ACADEMIC CENTER OF EXCELLENCE

P D A S Chair of Process and Data Science

Process Mining as the glue between data and processes

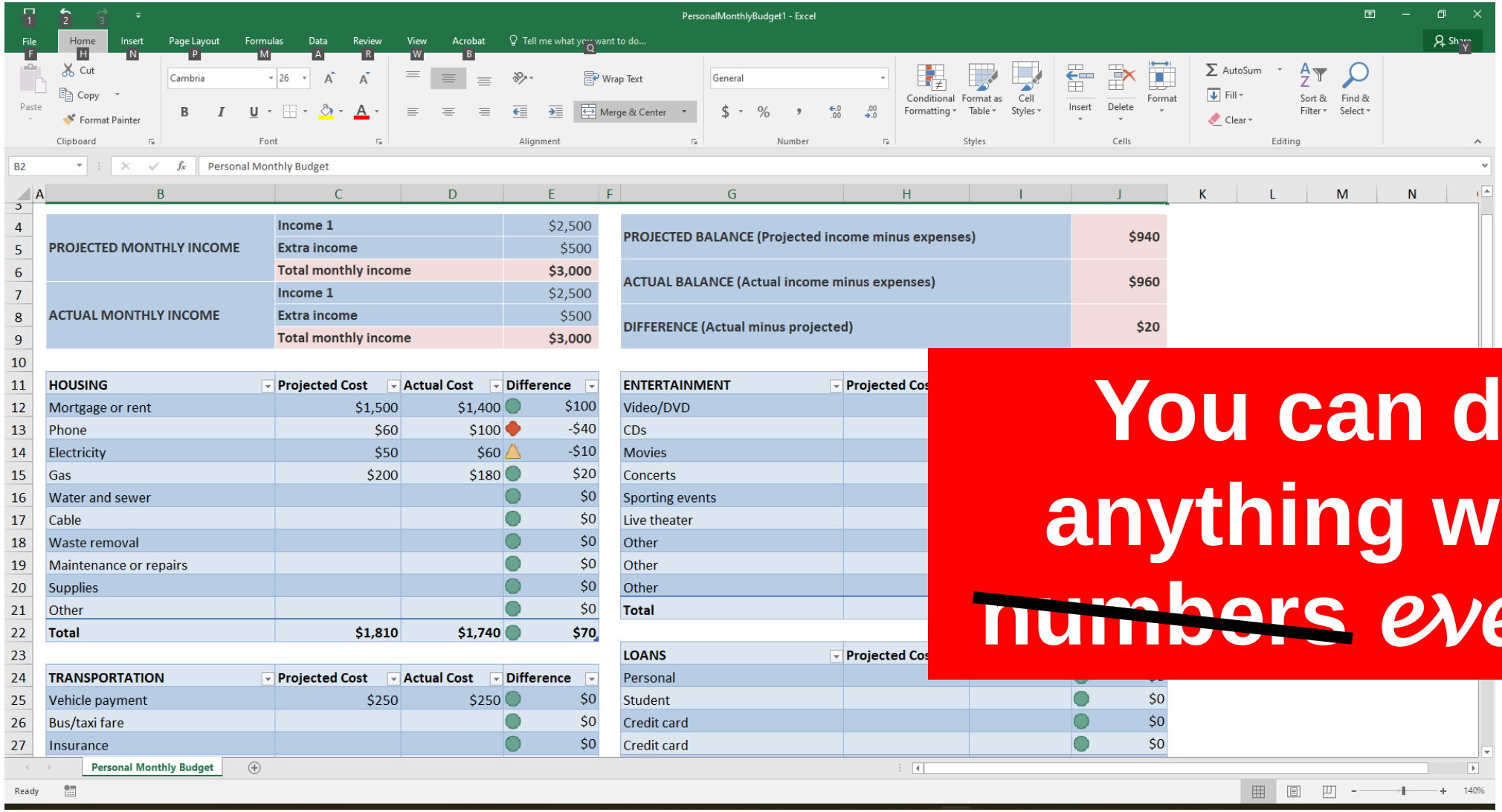


Traditionally, not data-driven and a focus on modeling (languages) and automation.

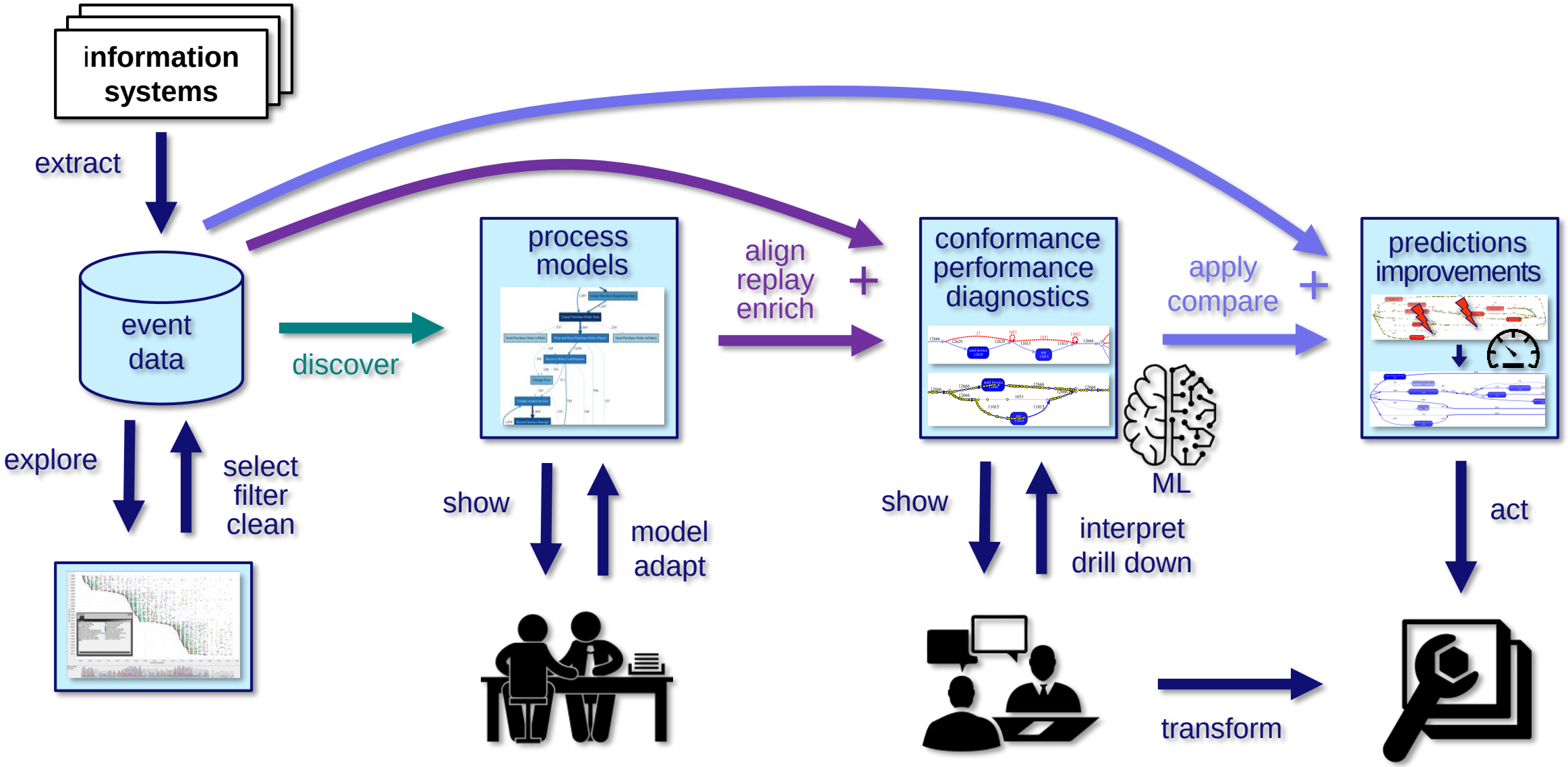
Traditionally, not process-centric and a focus on specific tasks or decisions.

Chair of Process and Data Science

Generic as a spreadsheet



Chair of Process and Data Science



Chair of Process and Data Science

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
...	...	....	...	....	...	...	...
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 64 GB	858,00 €	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	85,00 €	1	NL-7828AM-11a
6204	make delivery	Kaylee	2018/02/13 16:51:54.000	SAMSUNG Core Prime G361	85,00 €	1	NL-7828AM-11a
6265	confirm payment	Lily	2018/02/13 16:55:55.000	SAMSUNG Galaxy S4	329,00 €	1	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

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

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
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

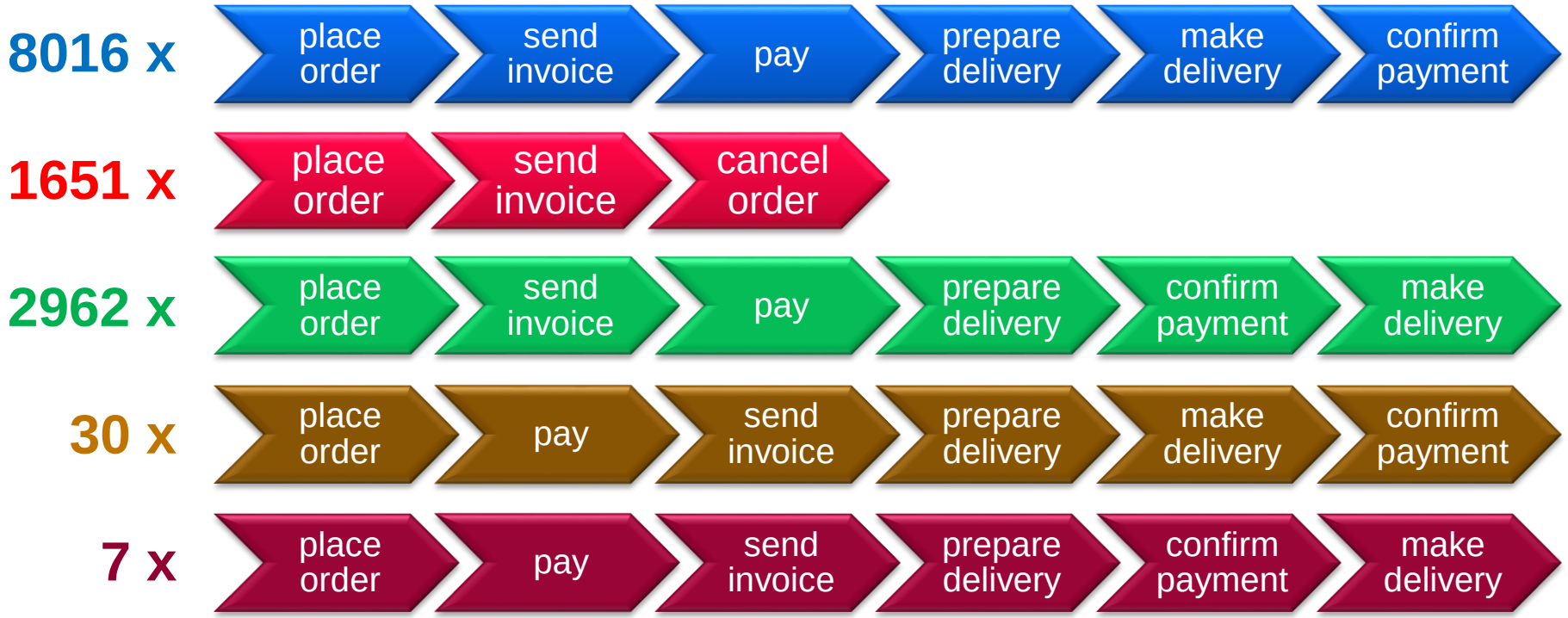
Order 6352

Chair of Process and Data Science

Let’s look at the whole event log again

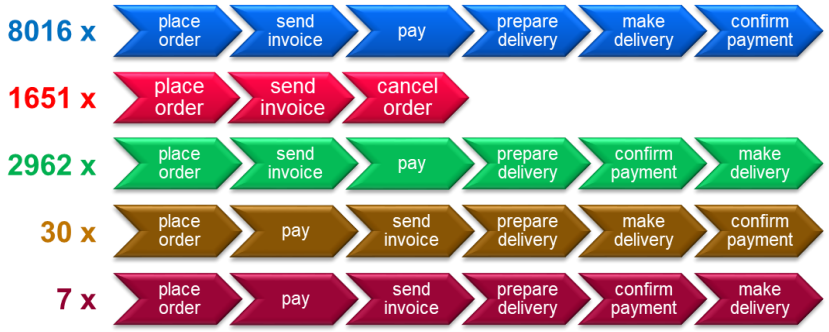
71,043 events
12,666 cases
7 activities

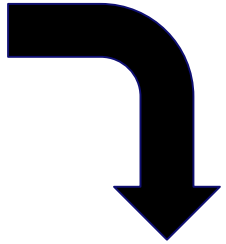
Case ID	Activity	Resource	Timestamp	product	prod-price	quantity	address
6350	place order	Aiden	2018/02/13 14:29:45.000	APPLE iPhone 6 16 GB	639,00 €	5	NL-7751DG-21
6283	pay	Lily	2018/02/13 14:39:25.000	SAMSUNG Galaxy S6 32 GB	543.99	3	NL-7828AM-11a
6253	prepare delivery	Sophia	2018/02/13 15:01:33.000	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-9521IG-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-30
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-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
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-7941IT-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-7907IZ-42
6353	place order	Sophia	2018/02/13 20:16:20.000	APPLE iPhone 5s 16 GB	449,00 €	4	NL-7751AR-19

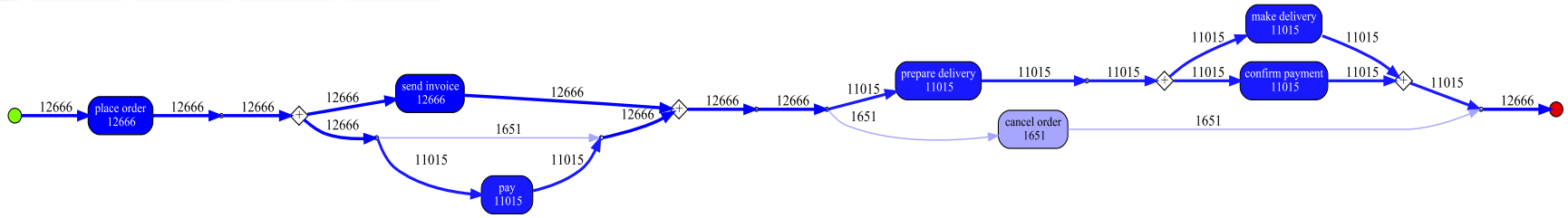


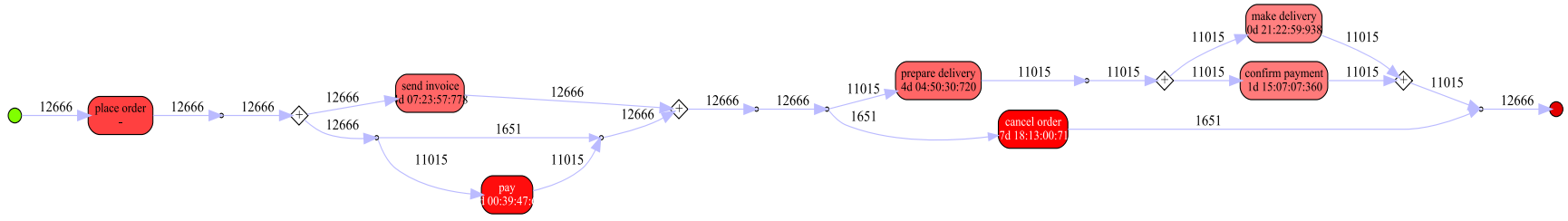
Chair of Process and Data Science

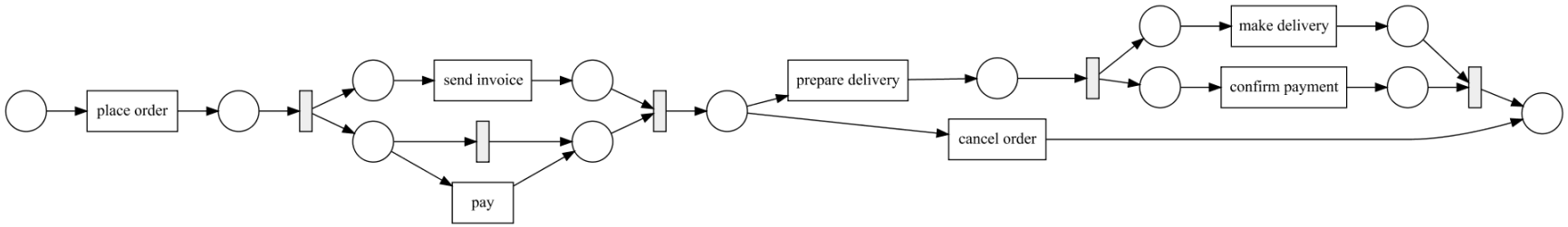
Using the whole event log





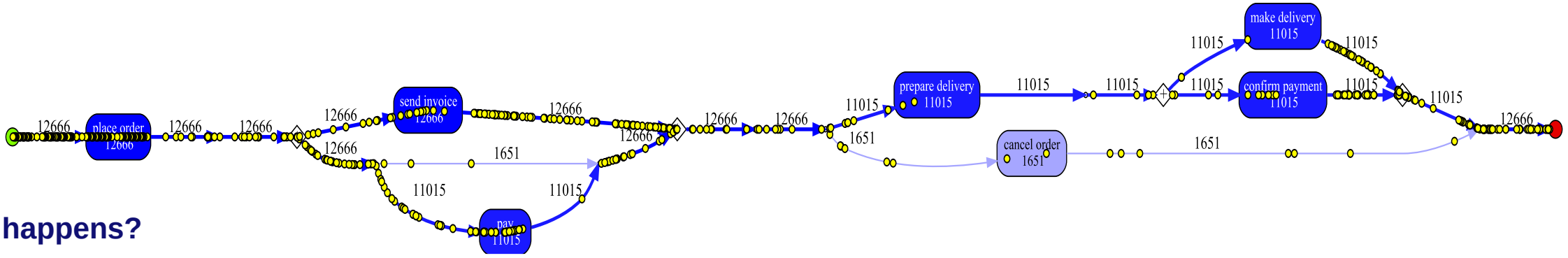




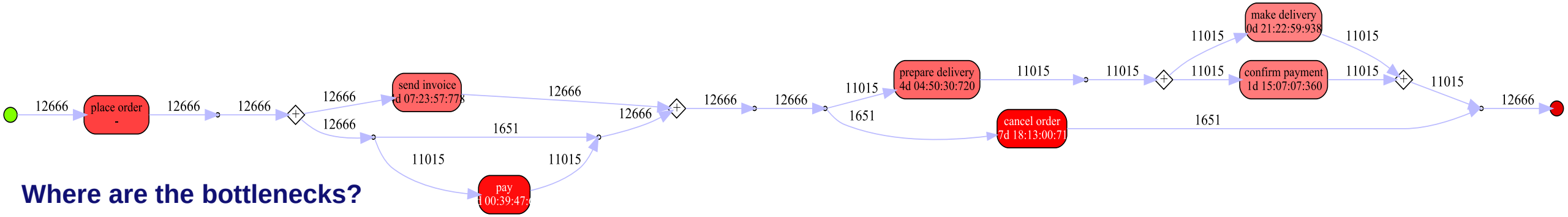


Chair of Process and Data Science

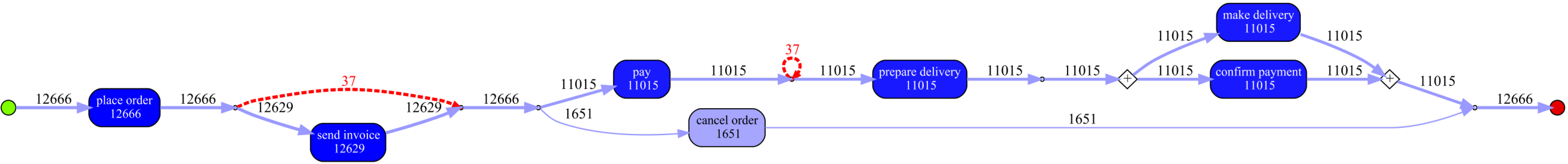
Performance and Compliance



What happens?



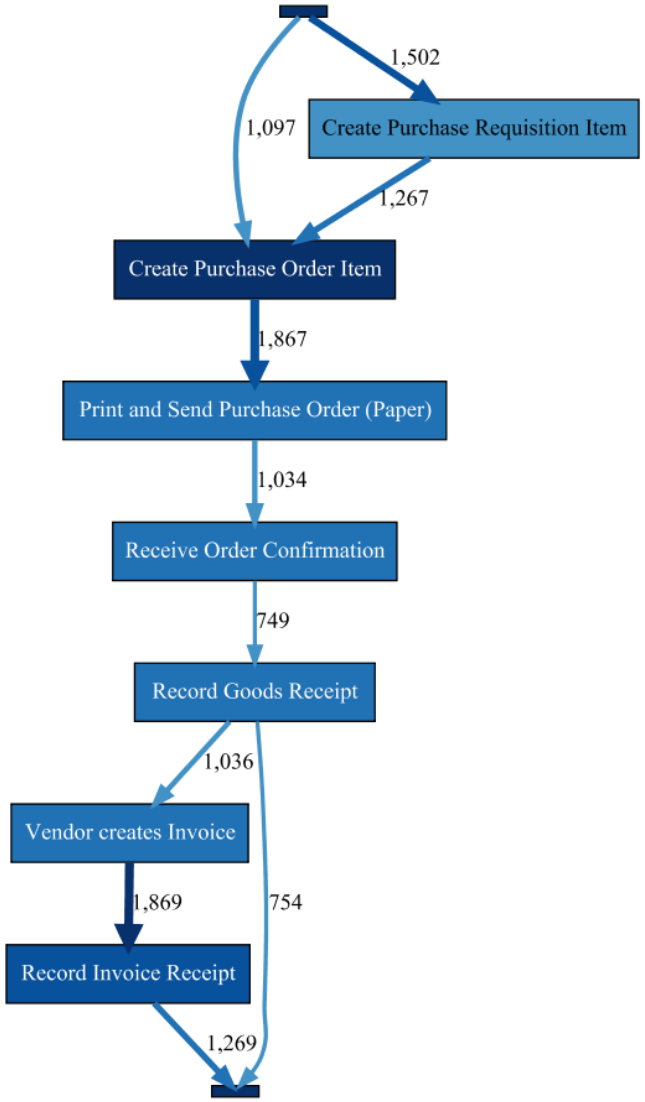
Where are the bottlenecks?

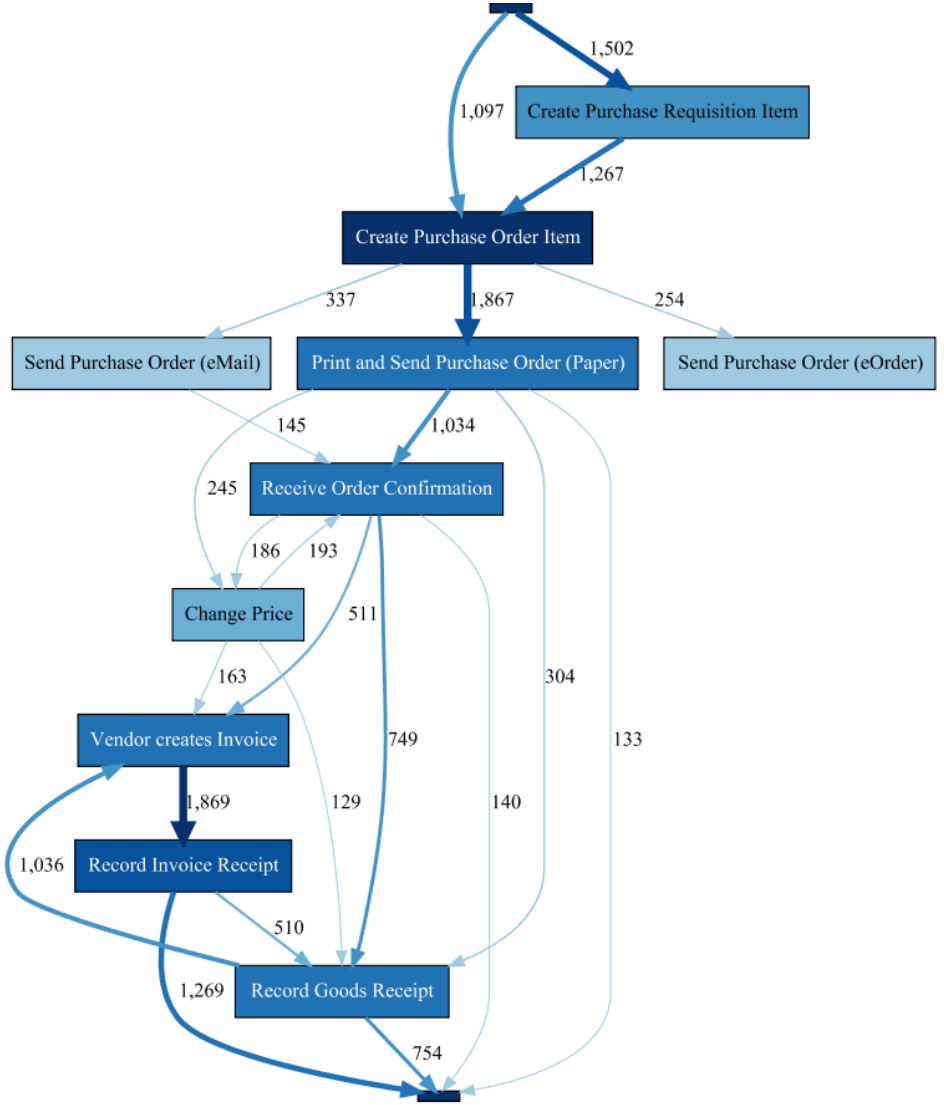


Where do we deviate from the happy path?

Chair of Process and Data Science

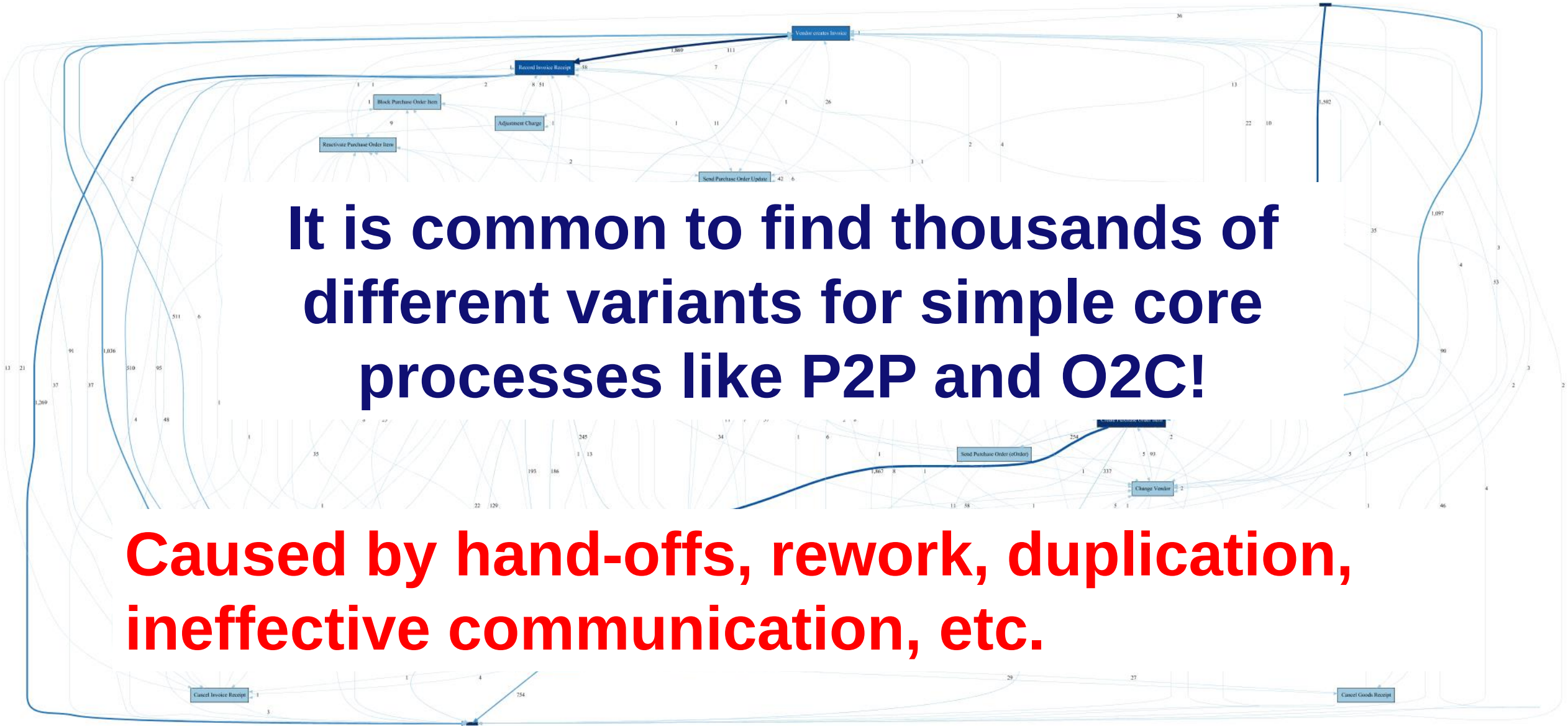
Reality is not so simple





Chair of Process and Data Science

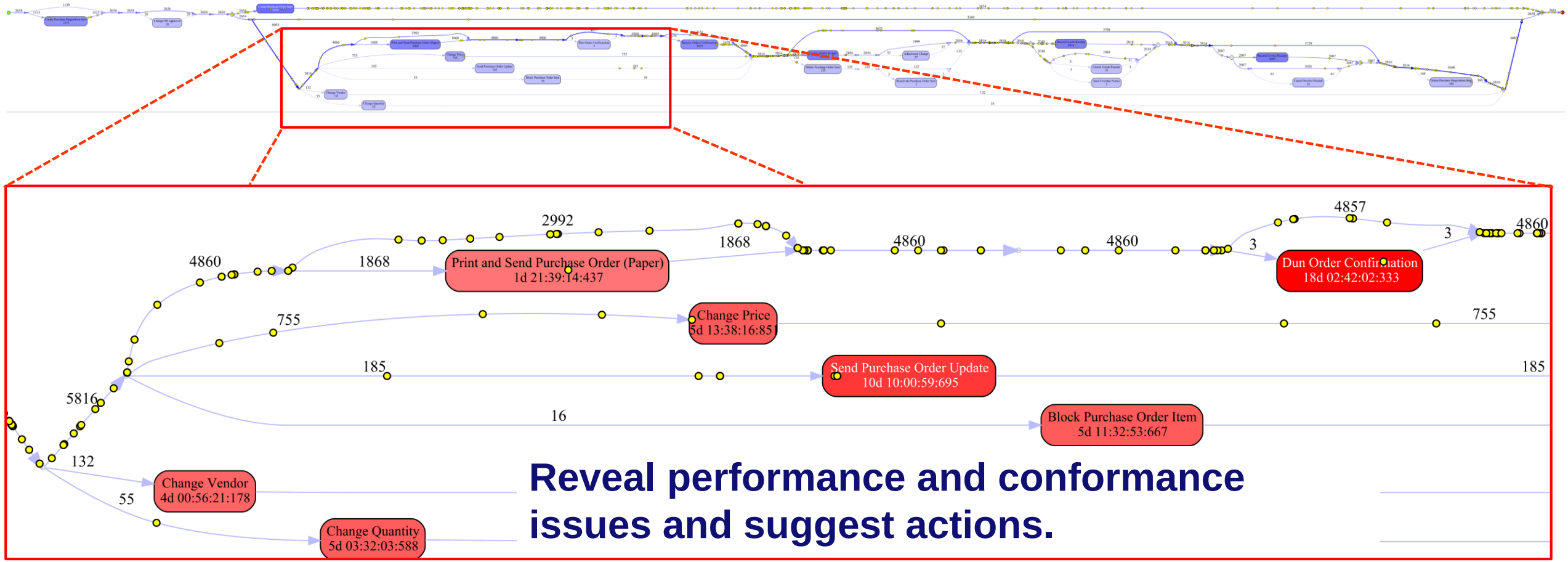
Reality is not so simple



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.

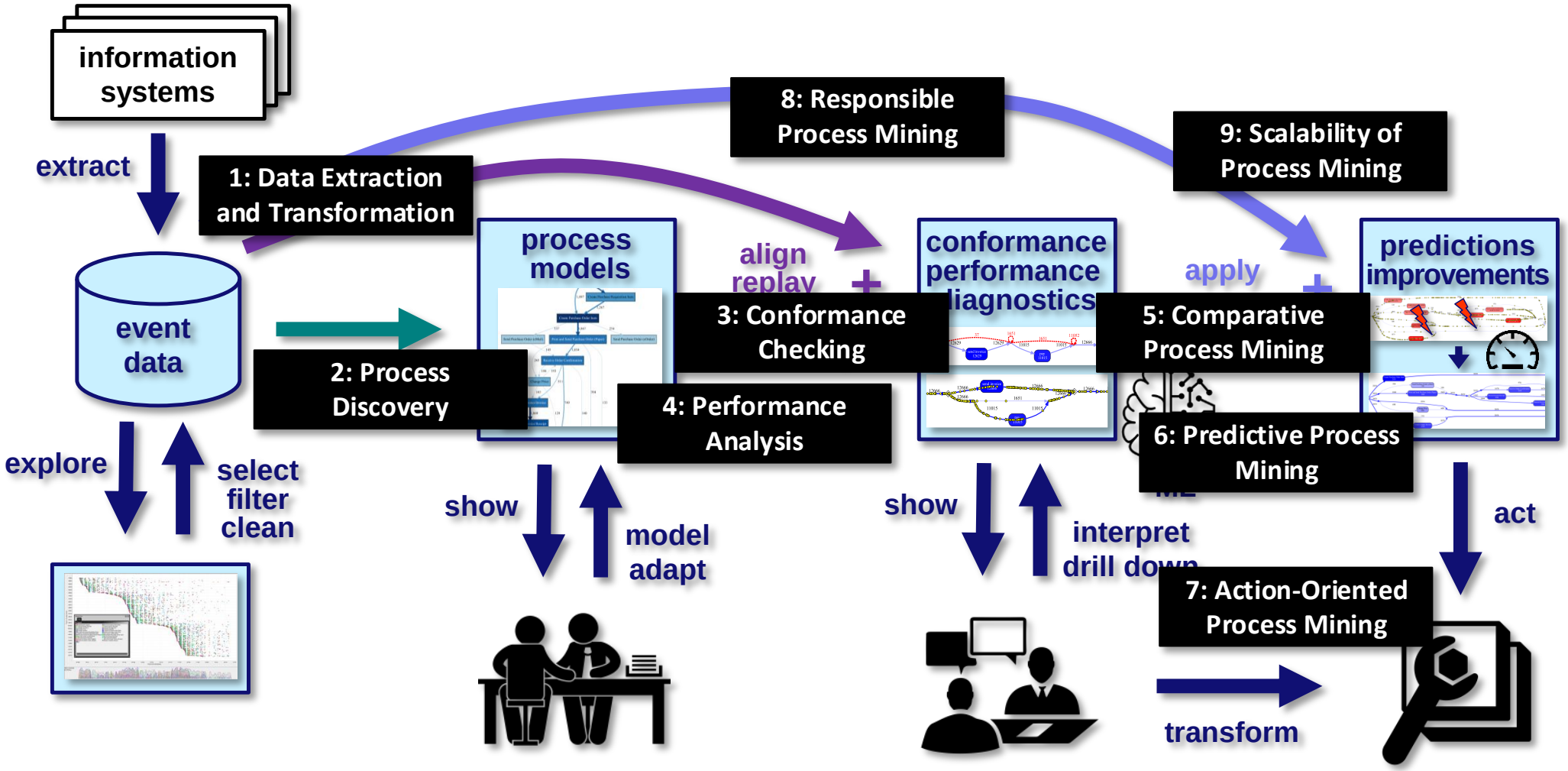
Process mining helps organizations to address compliance and performance problems



Reveal performance and conformance issues and suggest actions.

Chair of Process and Data Science

High-Level Research Questions



Chair of Process and Data Science

Chair of Process and Data Science

RWTH AACHEN UNIVERSITY

Highly concurrent - many objects

Max Verstappen, pit stop 1.86 seconds, Russian GP 2020 (note that Red Bull uses Celonis).

Objects: 1 driver, 1 car, 4+4 tires, 15+ pit crew members, 1 race, etc.

Remember: a classical event = case + activity + timestamp + …

Traditional process mining is like following one object, e.g., one tire.

Convergence problem:

- Assume we have a high-level event "pitstop" involving 20+ objects.
- Taking tires as a case perspective, each pitstop occurs 8 times.

Divergence problem:

- Assume we consider low-level events like "remove tire (rt)" and "mount tire (mt)" and driver as a case notion.
- We may see … rt-rt-mt-rt-mt-rt-mt-mt …
- Causalities get lost.

Object-Centric Process Mining (OCPM)

	activity	time	applicants	applications	offers	vacancies	recruiters	managers
2492	check references	2019-07-15 10:06:54	{}	{Application[770294]}	{}	{}	{Jana Kershaw,Simon Keane}	{}
2493	assign recruiter	2019-07-15 10:10:54	{}	{Application[770482]}	{}	{}	{Ed Kershaw,Ed Geisler,Simon Geisler}	{}
2494	assign recruiter	2019-07-15 10:22:34	{}	{Application[770483]}	{}	{}	{Jana Meister,Ed Meister,Ed Geisler}	{}
2495	send rejection	2019-07-15 10:24:35	{Jorge Neumann}	{Application[770256]}	{}	{}	{Jana Hense}	{}
2496	invite for interview	2019-07-15 10:31:02	{Andre Lemmens}	{Application[770241]}	{}	{Vacancy[550039] - Programmer}	{Simon Geisler,Simon Meister}	{}
2497	assign recruiter	2019-07-15 10:46:54	{}	{Application[770485]}	{}	{}	{Simon Geisler,Dionne Geisler,Simon Hense}	{}
2498	submit application	2019-07-15 11:04:06	{Dave Brown}	{Application[770489]}	{}	{Vacancy[550048] - Programmer}	{}	{}
2499	send rejection	2019-07-15 11:06:01	{Mary Li}	{Application[770297]}	{}	{}	{Ed Kershaw}	{}
2500	assign vacancy	2019-07-15 11:07:32	{}	{Application[770444]}	{}	{Vacancy[550048] - Programmer}	{}	{}
2501	assign recruiter	2019-07-15 11:12:18	{}	{Application[770417]}	{}	{}	{Dionne Keane,Jana Keane,Ed Kershaw}	{}
2502	check references	2019-07-15 11:37:25	{}	{Application[770390]}	{}	{}	{Dionne Keane,Simon Hense}	{}
2503	conduct interview	2019-07-15 11:41:15	{Johan Wagner}	{Application[770291]}	{}	{Vacancy[550013] - Manager}	{Jana Hense}	{Alexander Rinke}
2504	assign recruiter	2019-07-15 11:42:04	{}	{Application[770473]}	{}	{}	{Ed Geisler,Dionne Kershaw,Ed Meister}	{}
2505	submit application	2019-07-15 11:48:25	{Pete Jones}	{Application[770490]}	{}	{}	{}	{}
2506	assign vacancy	2019-07-15 12:00:50	{}	{Application[770328]}	{}	{Vacancy[550051] - Programmer}	{}	{}
2507	send rejection	2019-07-15 12:01:44	{Pete Park}	{Application[770319]}	{}	{}	{Jana Geisler}	{}
2508	invite for interview	2019-07-15 12:04:17	{Angela Wagner}	{Application[770223]}	{}	{Vacancy[550034] - Programmer}	{Jana Hense,Dionne Geisler}	{}
2509	send rejection	2019-07-15 12:10:01	{Lisa Jansen}	{Application[770141]}	{}	{}	{Dionne Geisler}	{}
2510	offer accepted and hired	2019-07-15 12:17:05	{Detlef Pietersen}	{Application[770120]}	{Offer[[990016]]}	{Vacancy[550011] - Programmer}	{Ed Keane}	{}
2511	send rejection	2019-07-15 12:21:53	{Johan Taylor}	{Application[770336]}	{}	{}	{Dionne Meister}	{}
2512	assign recruiter	2019-07-15 12:24:27	{}	{Application[770274]}	{}	{}	{Dionne Keane,Simon Kershaw,Ed Hense}	{}
2513	condu							
2514	subm							
2515	check							
2516	first s							
2517	assign							
2518	send rejection	2019-07-1						
2519	assign recruiter	2019-07-1						
2520	submit application	2019-07-1						
2521	first screening	2019-07-1						
2522	invite for interview	2019-07-1						
2523	assign vacancy	2019-07-1						

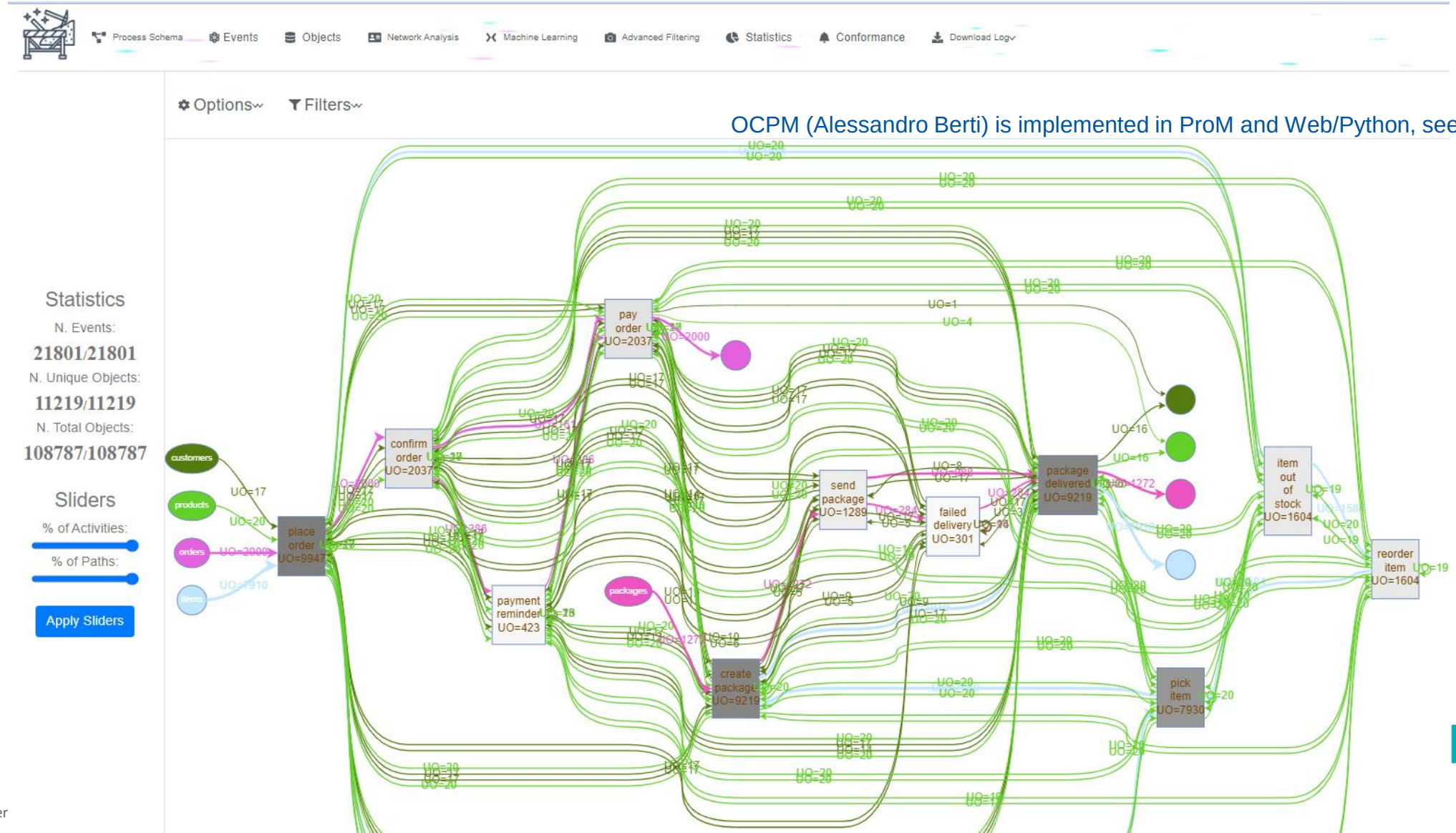
event = activity + timestamp + objects (of different types) + …

643	place order	2019-06-01 15:50:48	{990081}	{880329,880330,880331,880332}	{}	{Wil van der Aalst}	{iPad mini,Echo Show 5,Kindle,Echo}	723.97	2.423
644	place order	2019-06-02 16:35:30	{990082}	{880333,880334,880335}	{}	{Anahita Farhang Ghahfarokhi}	{Kindle,Fire Stick 4K,iPhone 11 Pro}	1323.98	0.951
645	place order	2019-06-03 08:44:59	{990083}	{880336,880337}	{}	{Seran Uysal}	{iPad Air,Echo Plus}	630.99	1.72
646	package delivered	2019-06-03 08:50:06	{}	{880190,880219,880195,880220,880192,880242,880221,880265,880272,880241,880197,880267,8	{660027}	{Mahnaz Qafari}	{Echo Show 5,Kindle Paperwhite,iPhone 8,Fire Stick 4K,Fire Stick,MacBook Pro,Fire Stick 4K,i	6373.94	5.713
647	pay order	2019-06-03 09:40:39	{990074}	{}	{}	{Tobias Brockhoff}	{Kindle,Echo,iPad,Kindle Paperwhite}	808.98	2.241
648	confirm order	2019-06-03 09:51:39	{990083}	{}	{}	{Seran Uysal}	{iPad Air,Echo Plus}	630.99	1.72
649	pick item	2019-06-03 10:08:21	{}	{880325}	{}	{}	{Kindle}	79.99	0.483
650	create package	2019-06-03 10:08:21	{}	{880245,880244}	{660031}	{Luis Santos}	{iPhone X,iPhone 11}	1498.0	0.338
651	reorder item	2019-06-03 10:14:55	{}	{880285}	{}	{}	{iPad mini}	449.0	0.28
652	pick item	2019-06-03 10:15:37	{}	{880294}	{}	{}	{iPhone X}	699.0	0.172
653	pick item	2019-06-03 10:19:07	{}	{880321}	{}	{}	{iPhone 11 Pro}	1149.0	0.188
654	create package	2019-06-03 10:19:07	{}	{880132,880187,880147}	{660032}	{Seran Uysal}	{Echo Show 5,iPhone 11 Pro,iPad}	1733.99	1.551
655	pick item	2019-06-03 10:27:22	{}	{880319}	{}	{}	{Echo Plus}	149.99	1.28
656	pay order	2019-06-03 10:32:50	{990054}	{}	{}	{Christine Dobbert}	{Echo Studio,Kindle Paperwhite,Echo Studio}	533.98	3.455
657	reorder item	2019-06-03 10:50:41	{}	{880090}	{}	{}	{iPhone 11}	799.0	0.166
658	place order	2019-06-03 10:57:16	{990084}	{880338,880339,880340}	{}	{Mohammadreza Fani Sani}	{Kindle Paperwhite,iPad Air,Echo Dot}	639.99	1.315
659	pick item	2019-06-03 11:03:04	{}	{880289}	{}	{}	{iPad mini}	449.0	0.28
660	pick item	2019-06-03 11:11:23	{}	{880254}	{}	{}	{iPad Air}	476.0	0.44
661	create package	2019-06-03 11:11:23	{}	{880234,880238,880076,880205,880210,880233,880235,880236,880298,880237}	{660033}	{Claudia Graf}	{Fire Stick 4K,Echo Plus,iPad,iPhone X,Echo Show 5,MacBook Pro,iPad mini,Echo Plus,iPhone	6300.96	6.423
662	pick item	2019-06-03 11:24:44	{}	{880337}	{}	{}	{Echo Plus}	149.99	1.28
663	pay order	2019-06-03 11:30:13	{990059}	{}	{}	{Tobias Brockhoff}	{Echo Dot,iPhone 8,iPhone 11,Kindle Paperwhite}	1491.99	1.251
664	confirm order	2019-06-03 11:32:14	{990078}	{}	{}	{Mahsa Bafrani}	{Echo Plus,iPad Pro,iPhone 11 Pro,Echo Show 8}	2532.98	2.931
665	send package	2019-06-03 11:33:10	{}	{}	{660030}	{Christina Rensinghof}	{}	10155.94	11.479
666	pick item	2019-06-03 11:34:04	{}	{880316}	{}	{}	{Echo Studio}	199.99	1.48
667	pick item	2019-06-03 11:35:07	{}	{880328}	{}	{}	{iPad Air}	476.0	0.44
668	confirm order	2019-06-03 11:45:40	{990079}	{}	{}	{Christina Rensinghof}	{Kindle Paperwhite,Kindle}	213.99	0.978

Chair of Process and Data Science

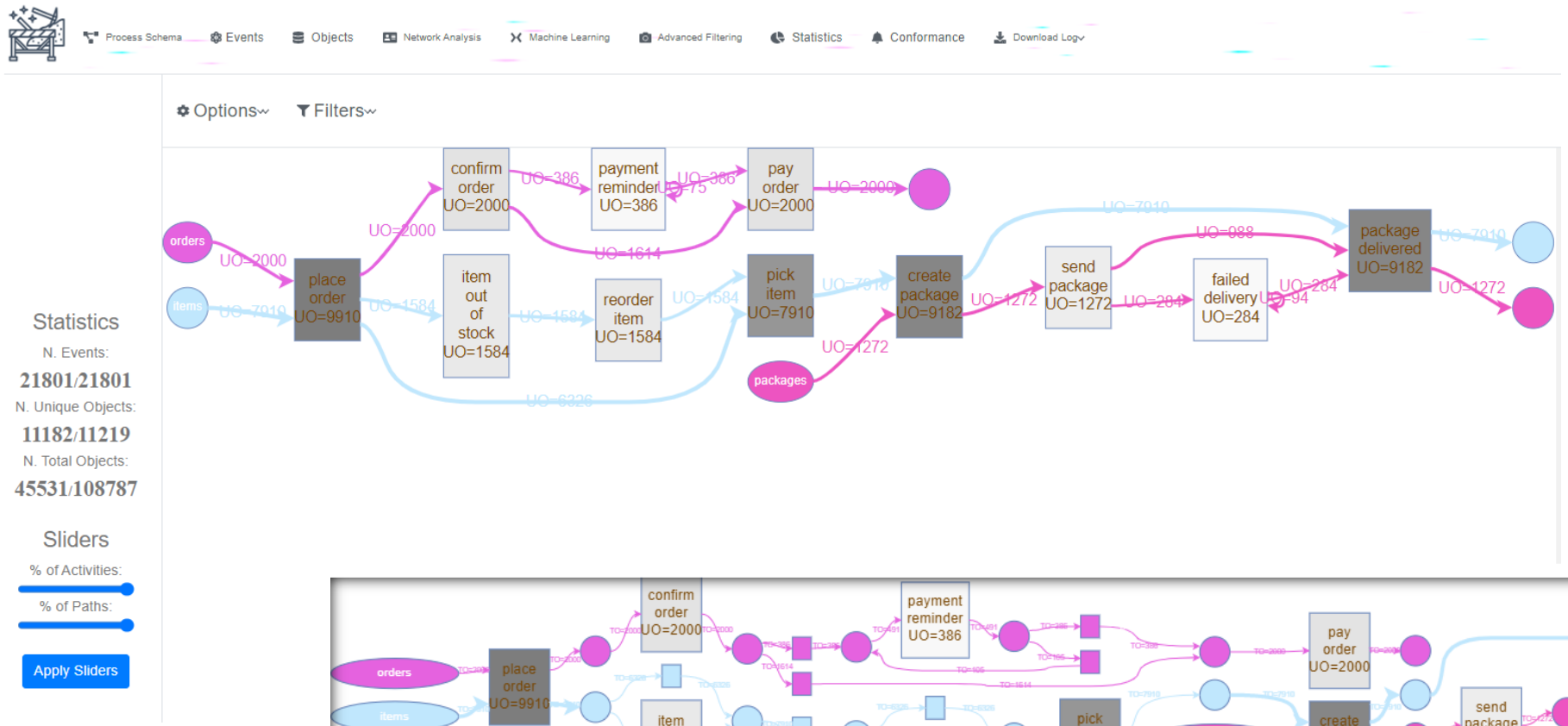
Five Object Types (packages, items, orders, customers, and products)

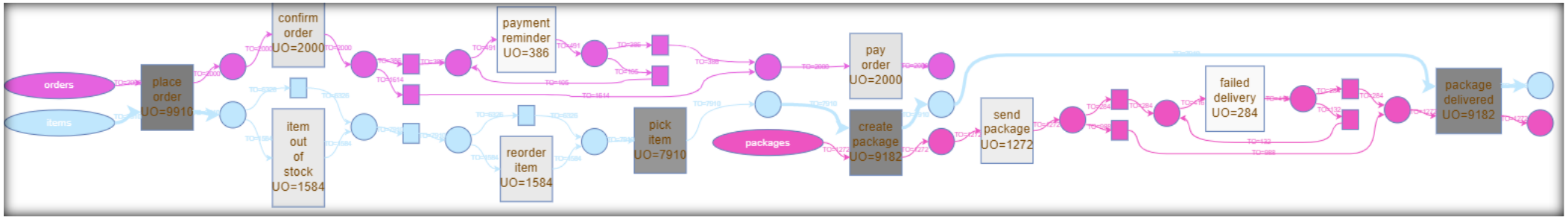
OCPM (Alessandro Berti) is implemented in ProM and Web/Python, see www.ocpm.info



Chair of Process and Data Science

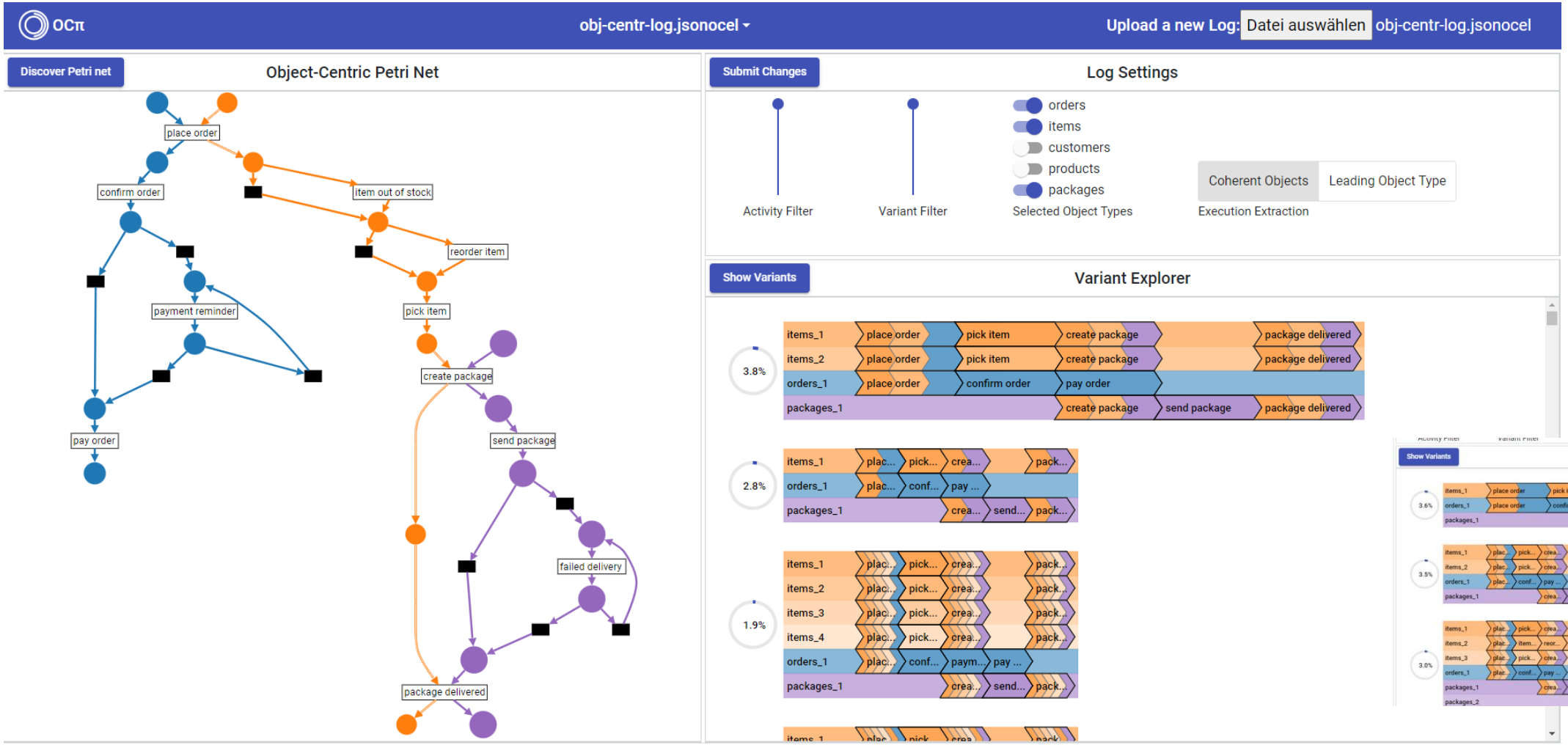
Three Object Types (packages, items, and orders)





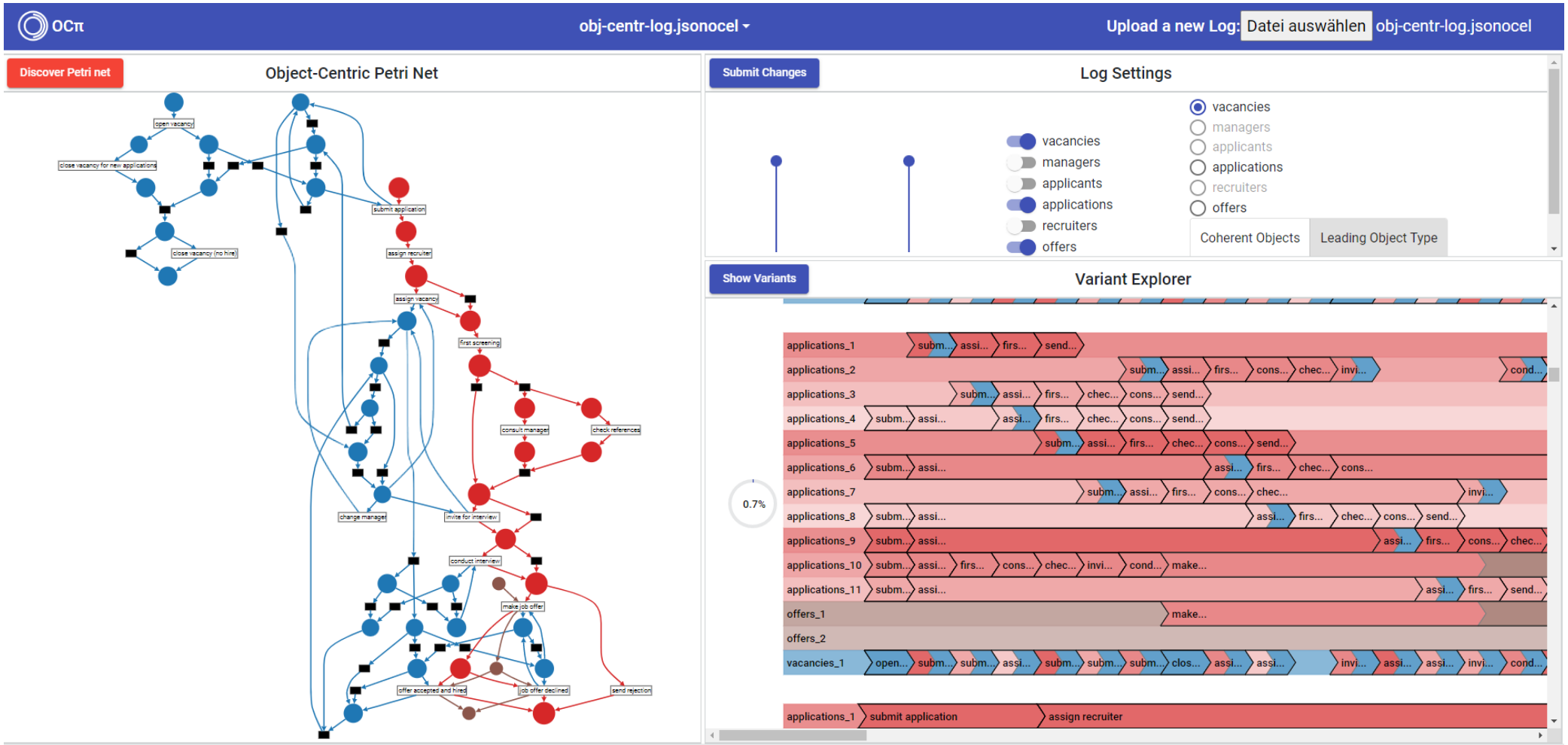
Chair of Process and Data Science

Exploring variants using OCπ (developed Jan Niklas Adams)



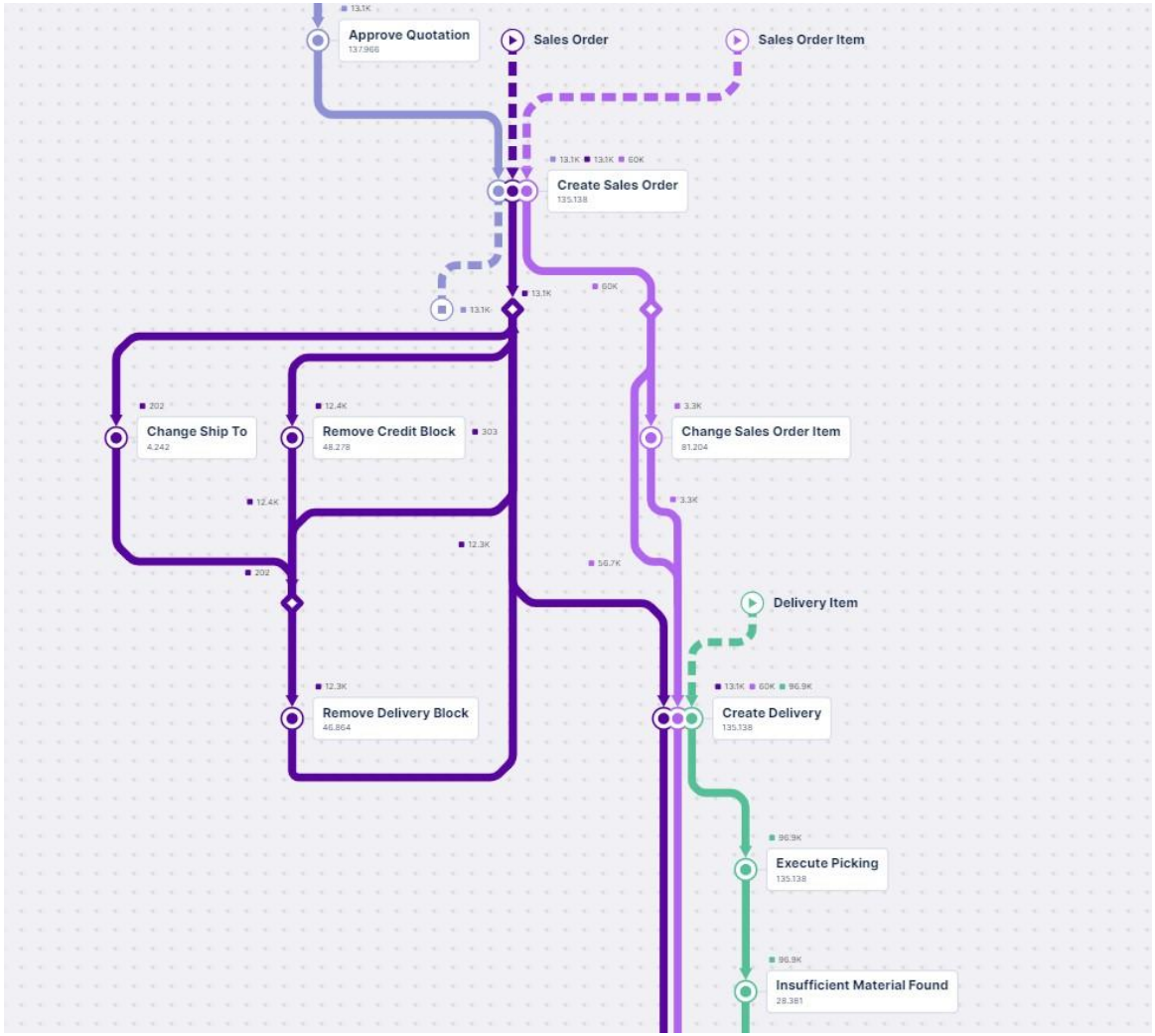
Chair of Process and Data Science

Another example (handling applications)



Chair of Process and Data Science

Celonis Process Sphere



Chair of Process and Data Science

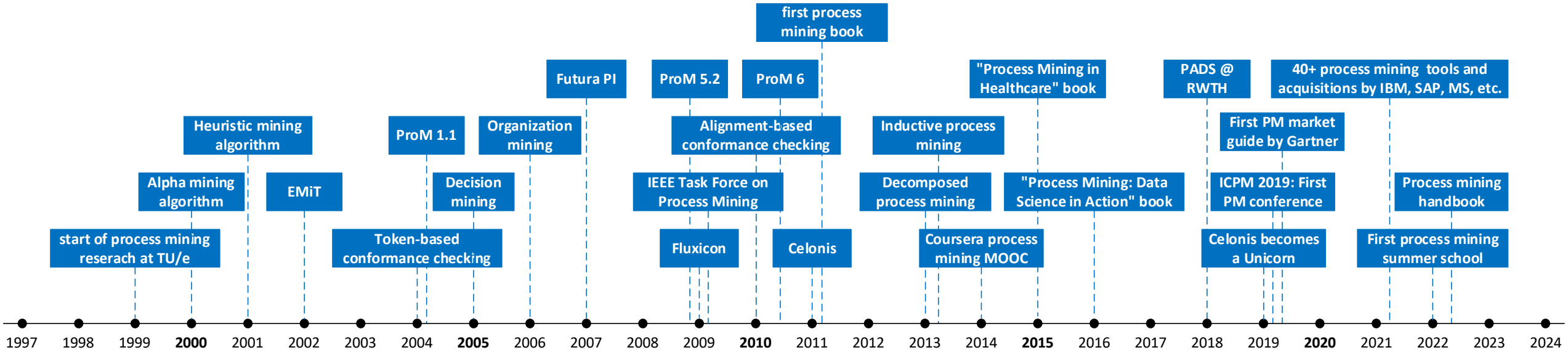
Process discovery is not a solved problem!

- **Challenges:**
  - Only example observations, typically covering a negligible fraction of possible process executions.
  - No negative observations.
  - Infrequent behavior.
- **Dimensions:**
  - Concurrency and loops
  - Skip activities
  - Duplicate activities
  - Long term-dependencies
  - Multiple object types
  - Etc.

Chair of Process and Data Science

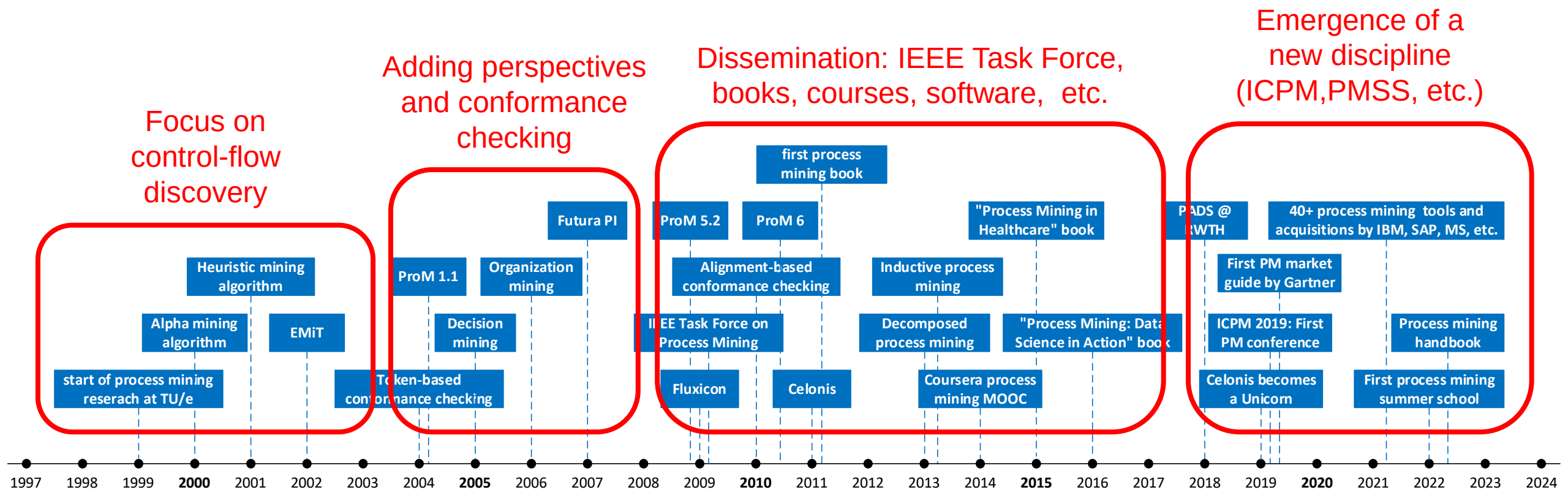
RWTH AACHEN UNIVERSITY

Timeline of Process Mining



Chair of Process and Data Science

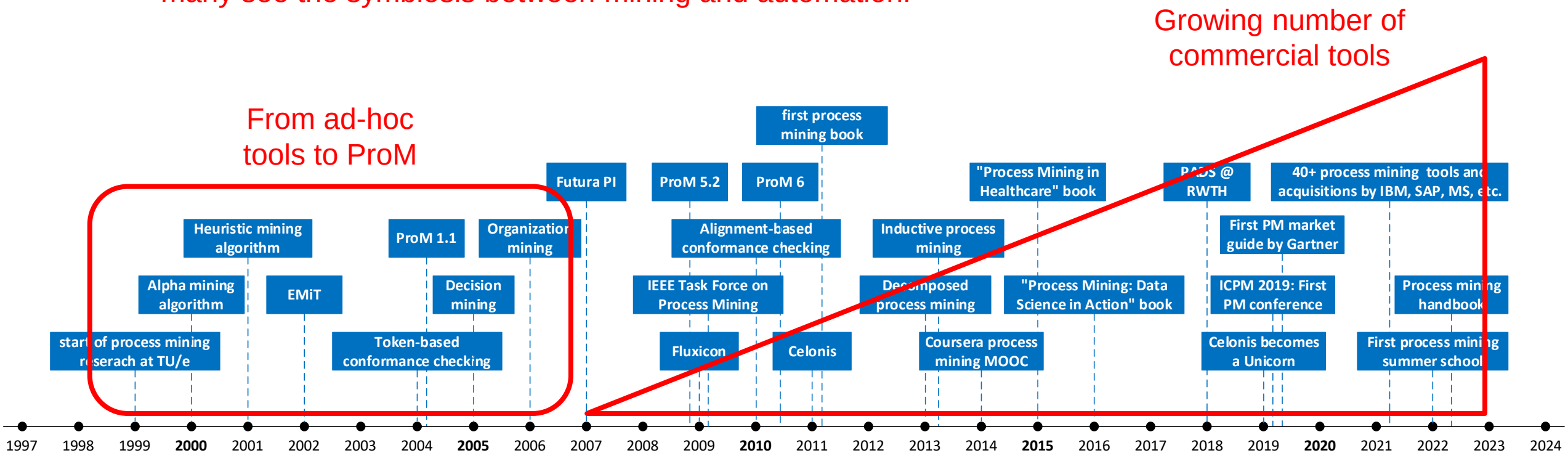
Timeline of Process Mining



Chair of Process and Data Science

Timeline of Process Mining

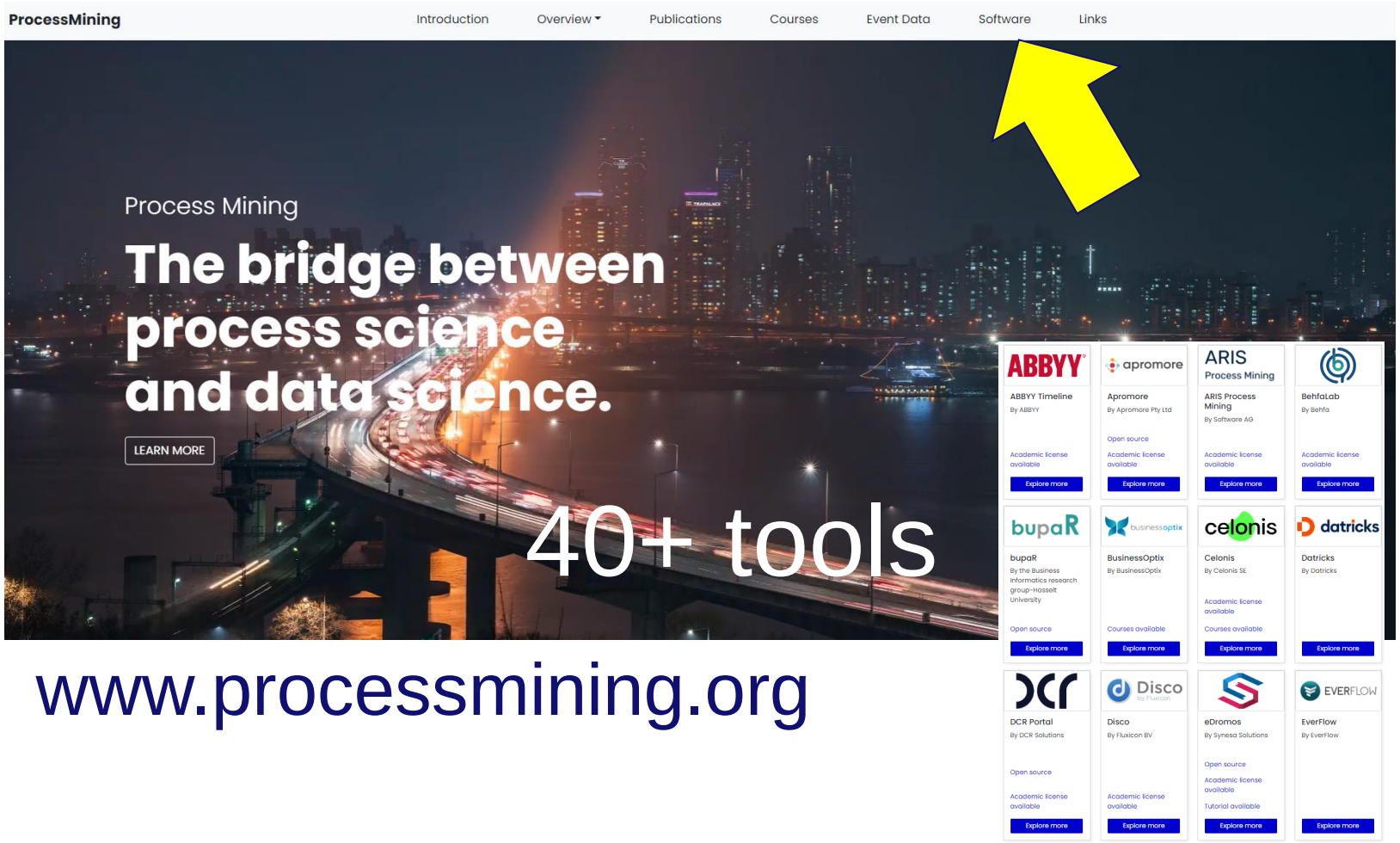
The large software vendors are trying to catch up, and today many see the symbiosis between mining and automation.



Chair of Process and Data Science

Many process mining tools are available

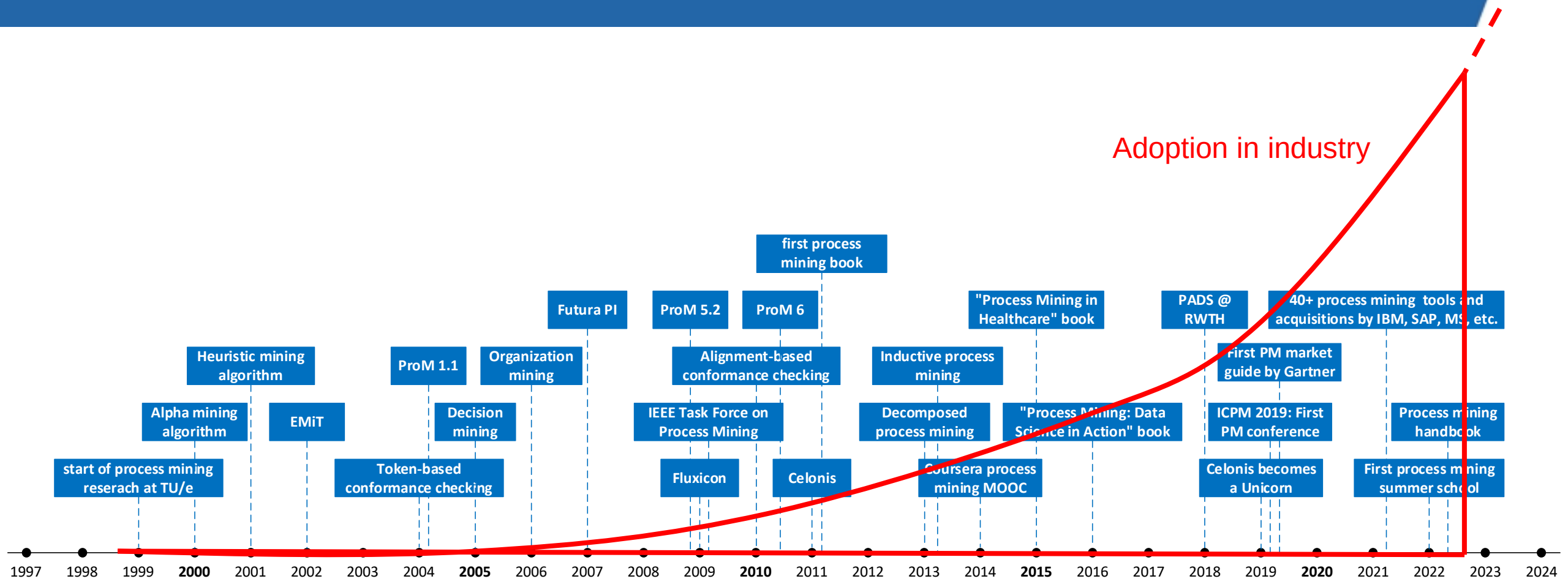
Vendor	Tool	Website	Acad. ver.
Abbyy	ABBYY Timeline	www.abbyy.com	No
Appian (Lana Labs)	LANA Process Mining	lanalabs.com	No
Apromore	Apromore Enterprise Edition	apromore.org	Yes
bupaR	bupaR	bupar.net	Yes
businessOptix	businessOptix	businessoptix.com	Yes
Celonis	Celonis EMS	celonis.com	Yes
Datricks	Datricks	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

Timeline of Process Mining



Chair of Process and Data Science

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.)!

You can do anything with ~~numbers~~ *events*

Chair of Process and Data Science

Example: some of Celonis's 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

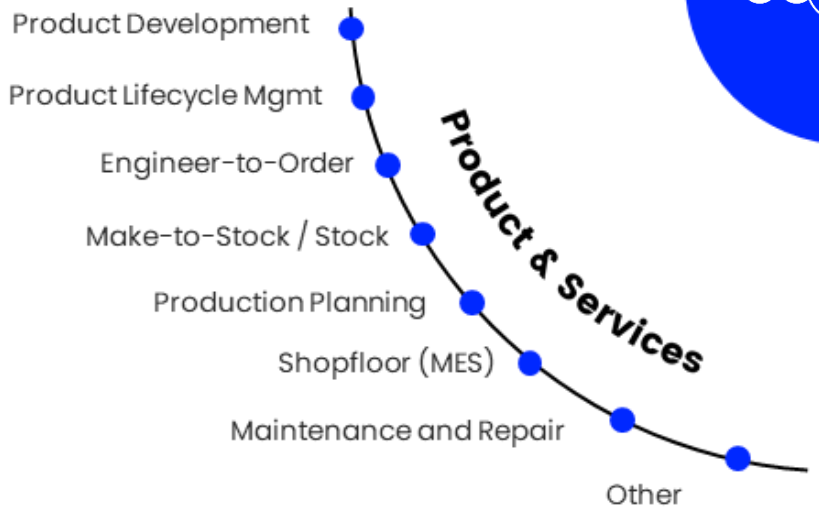
Thousands of large organizations are using Celonis (approx. 50% of Fortune 500) and in some of these there are thousands of active users (e.g., Siemens, BMW, etc.)

For any process in the organization!

DIO
Inventory Turnover
Material / Labor Availability
Out-of-Stock Rate
% Managed Spend
Spend/Revenue
Supplier Metrics
Lead Times

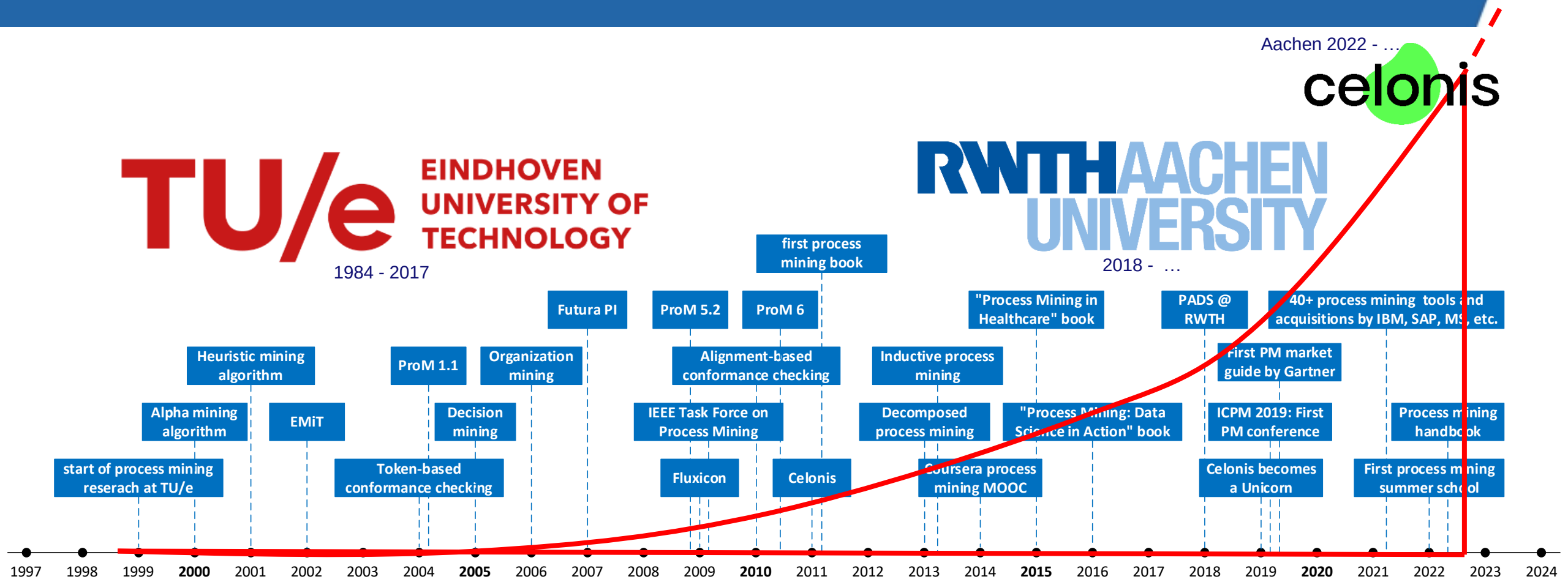
OTIF Ratio
Order Cycle Time
Conversion Rate
Automation
Customer Satisfaction
Resolution Times
 # Replies per Request
Resolution Rates

Warranty Costs
R&D Productivity
R&D Expenses
Time-to-Commercialize
Throughput
Machine Downtime
On-Time Production
ESG Rating



Working Capital
Operating Cash Flow
AP/AR Turnover
DPO & DSO
Employee Satisfaction
Resolution Time
Multi-Hop Incidents
Compliance

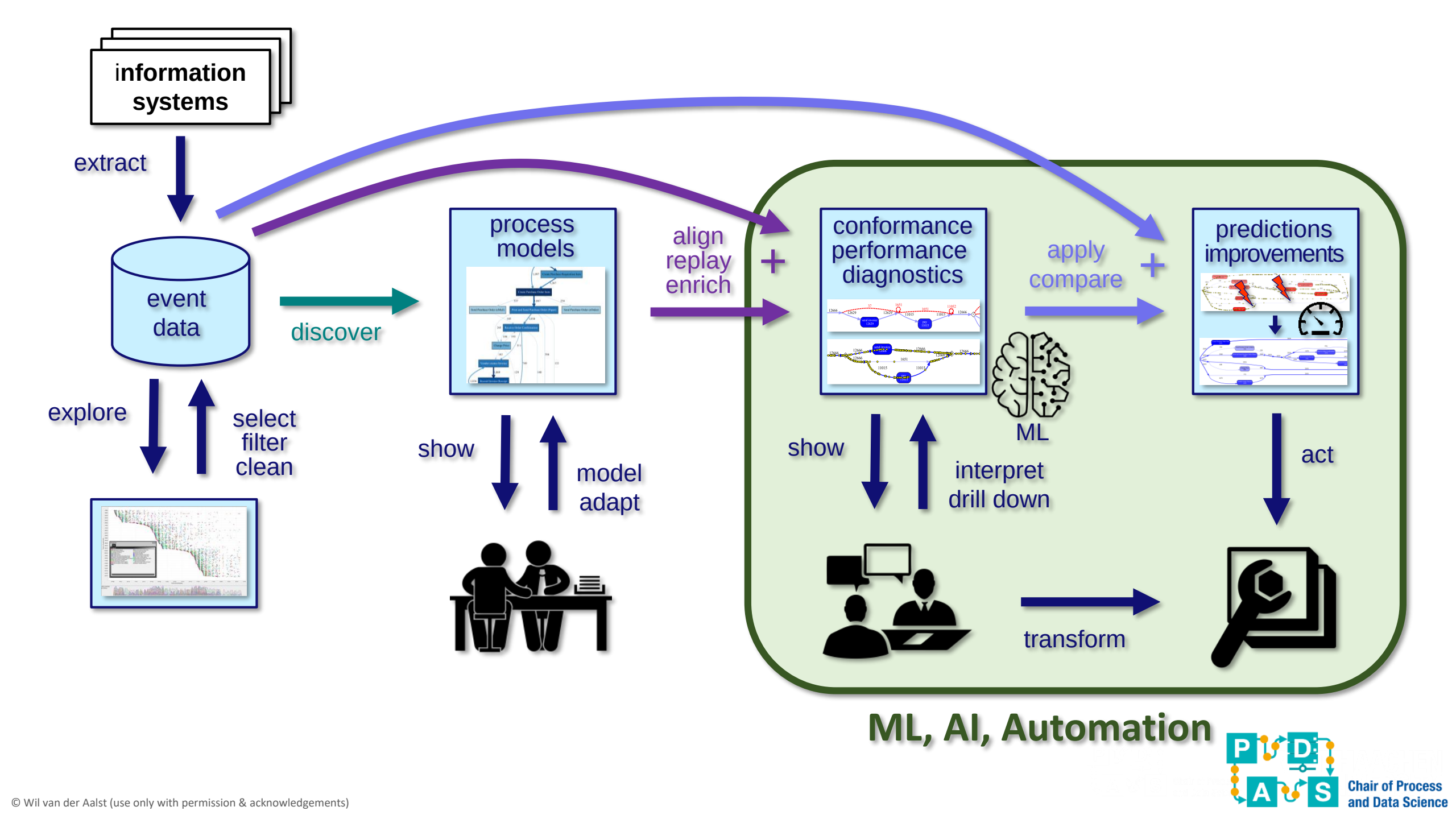
My personal journey



Chair of Process and Data Science

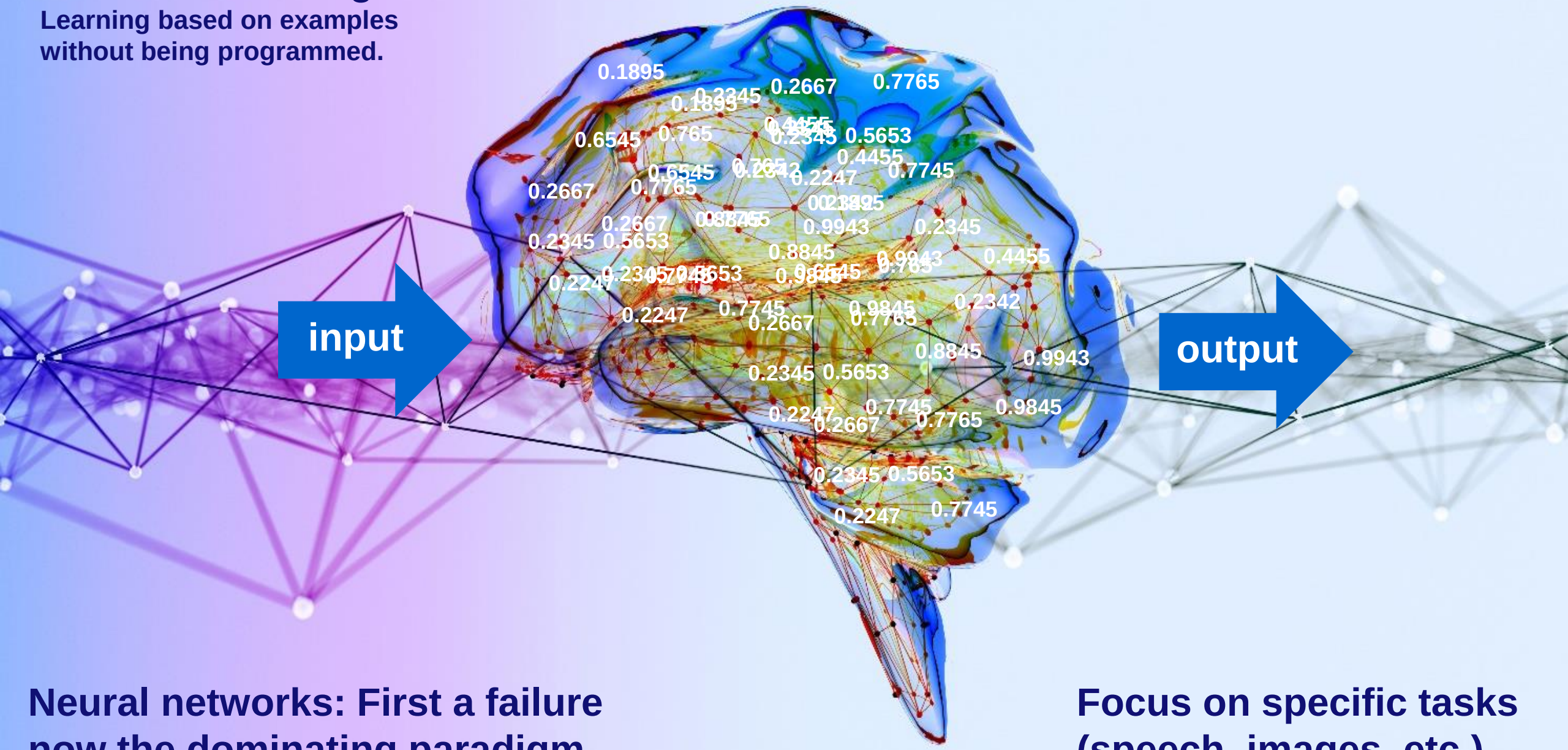
Chair of Process and Data Science

RWTH AACHEN UNIVERSITY



Machine Learning =

Learning based on examples without being programmed.



Neural networks: First a failure now the dominating paradigm

Focus on specific tasks (speech, images, etc.).

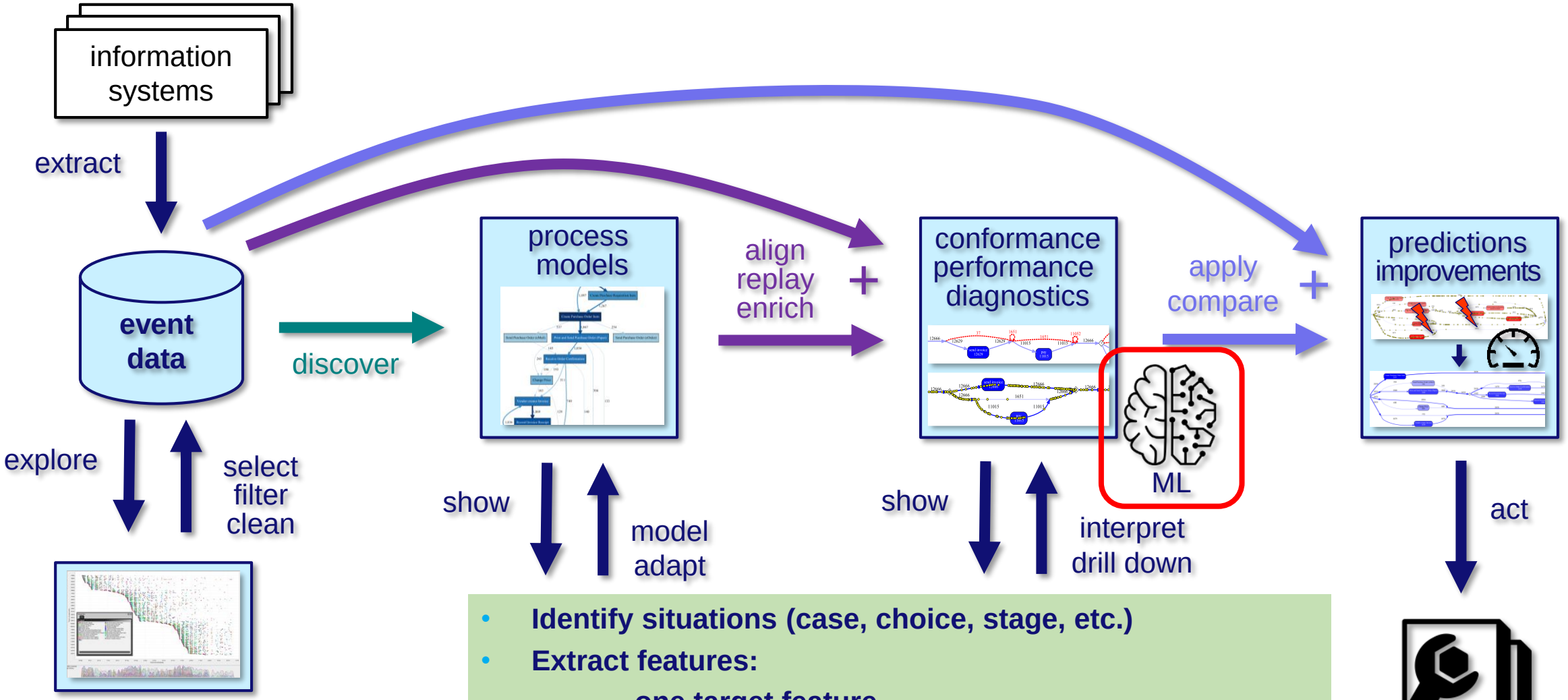
How about managing and improving operational processes?

We are interested in improving end-to-end performance and compliance (not a single task)!

We need process models that are understandable!

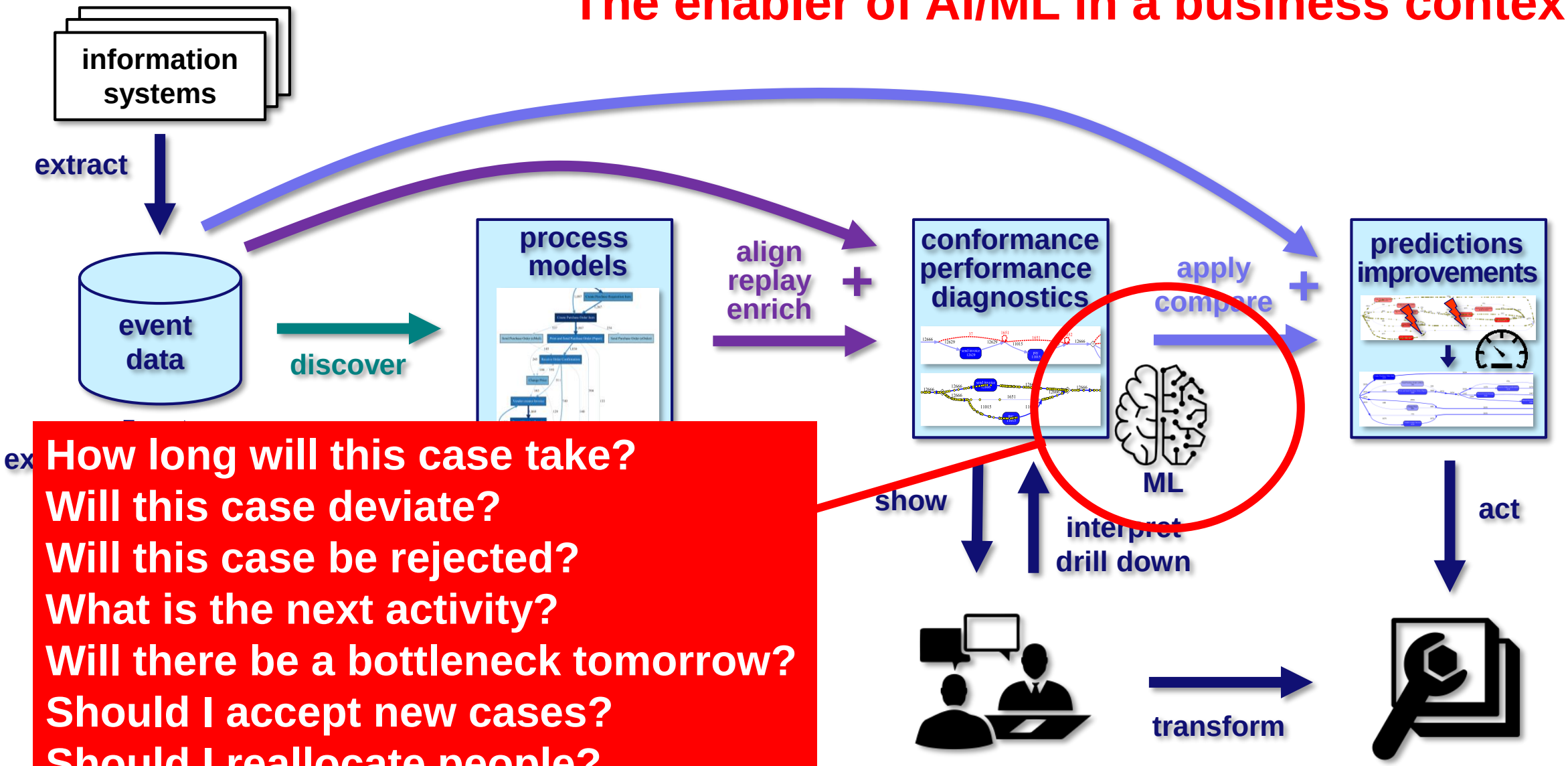
We do not have labeled data, we have SAP, Salesforce, Oracle, Microsoft, Infor, etc. (holding thousands of tables)!

Link to ML



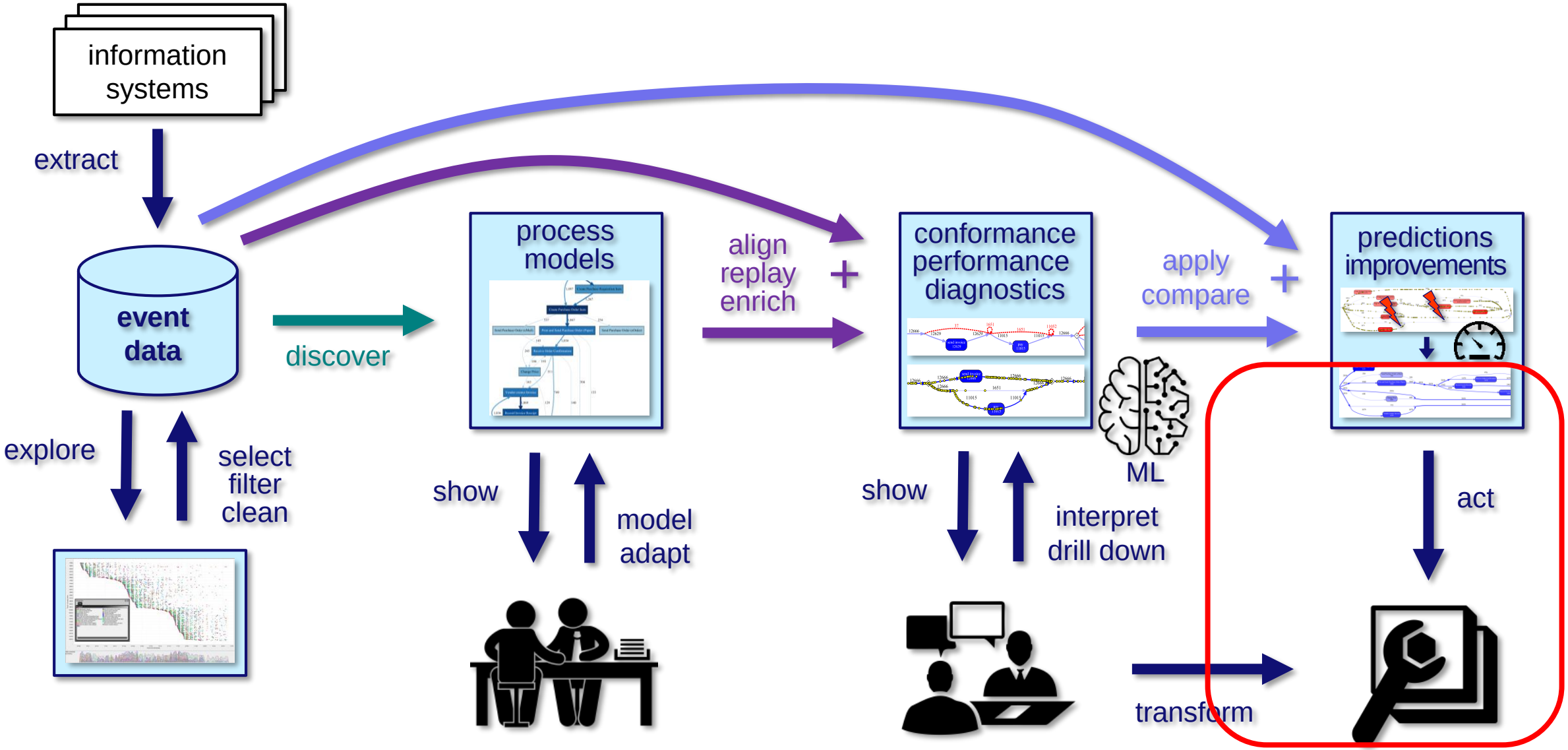
- **Identify situations (case, choice, stage, etc.)**
- **Extract features:**
  - **one target feature**
  - **one or more input features**
- **Build a model explaining the target feature in terms of the input features.**

The enabler of AI/ML in a business context!

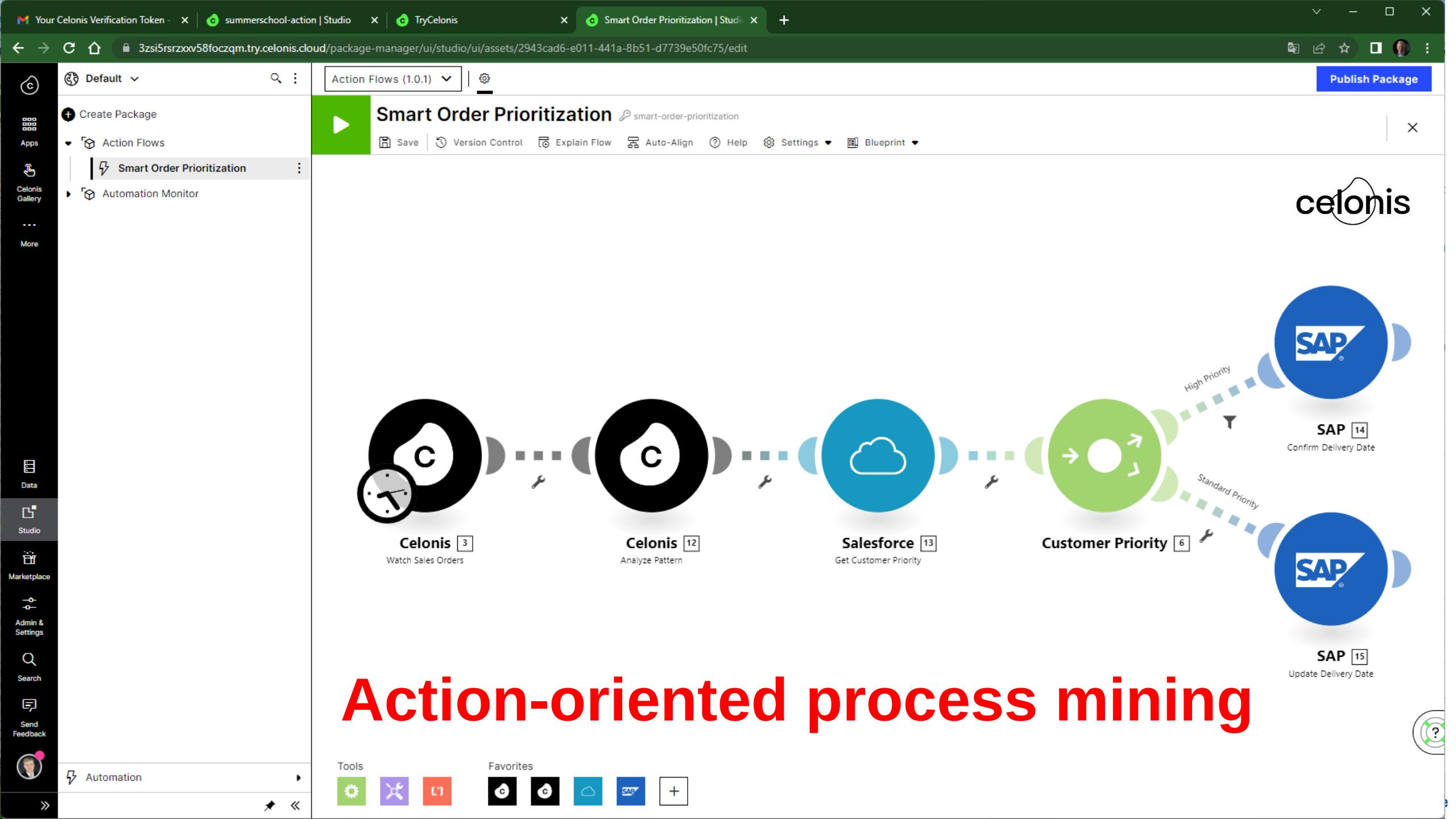


Chair of Process and Data Science

Link to Automation

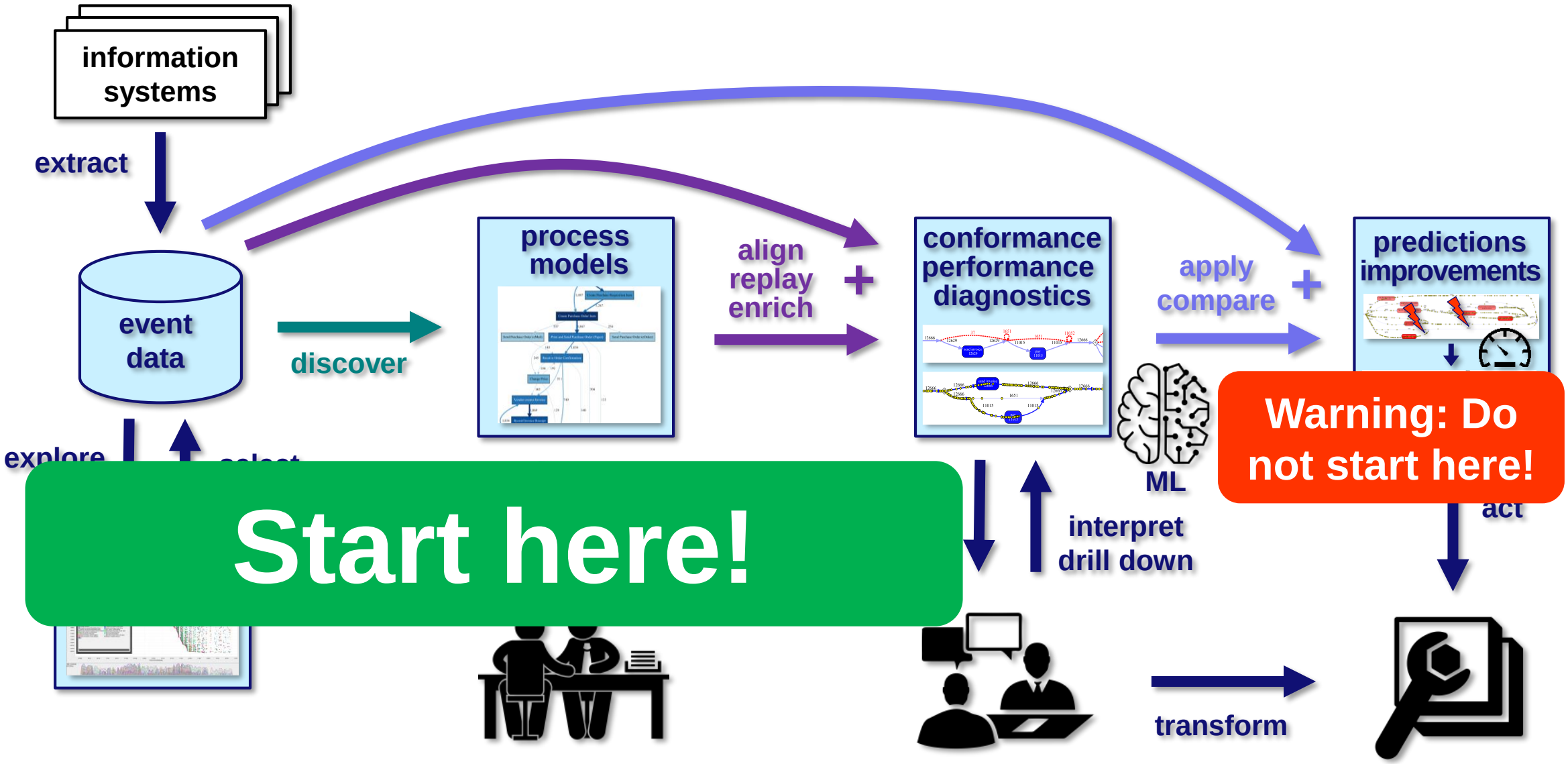


Chair of Process and Data Science


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
Create Package
Action Flows
Smart Order Prioritization
Automation Monitor
Action Flows (1.0.1)
Publish Package
Smart Order Prioritization
smart-order-prioritization
Save
Version Control
Explain Flow
Auto-Align
Help
Settings
Blueprint
celonis
Apps
Celonis Gallery
More
Data
Studio
Marketplace
Admin & Settings
Search
Send Feedback
Automation
High Priority
Standard Priority
Celonis 3
Watch Sales Orders
Celonis 12
Analyze Pattern
Salesforce 13
Get Customer Priority
Customer Priority 6
SAP 14
Confirm Delivery Date
SAP 15
Update Delivery Date
Action-oriented process mining
Tools
Favorites

About Automation

- It is very naïve to replace existing software with something “fresh” (cf. # applications and # tables).
- Process mining helps to see the main problems and can trigger actions/workflows.
- Focus on the “pain points” and not on the whole to ensure a good ROI.
- Low-code automation (e.g., Make/Integromat) and Robotic Process Automation (RPA) help to interface with existing systems.

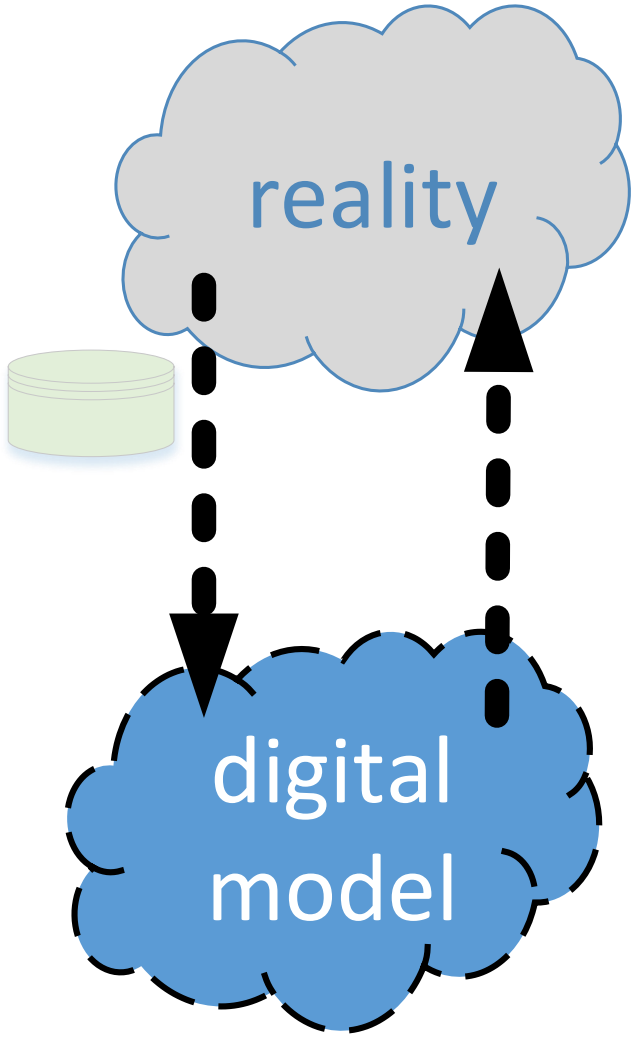


Chair of Process and Data Science

Chair of Process and Data Science

RWTH AACHEN UNIVERSITY

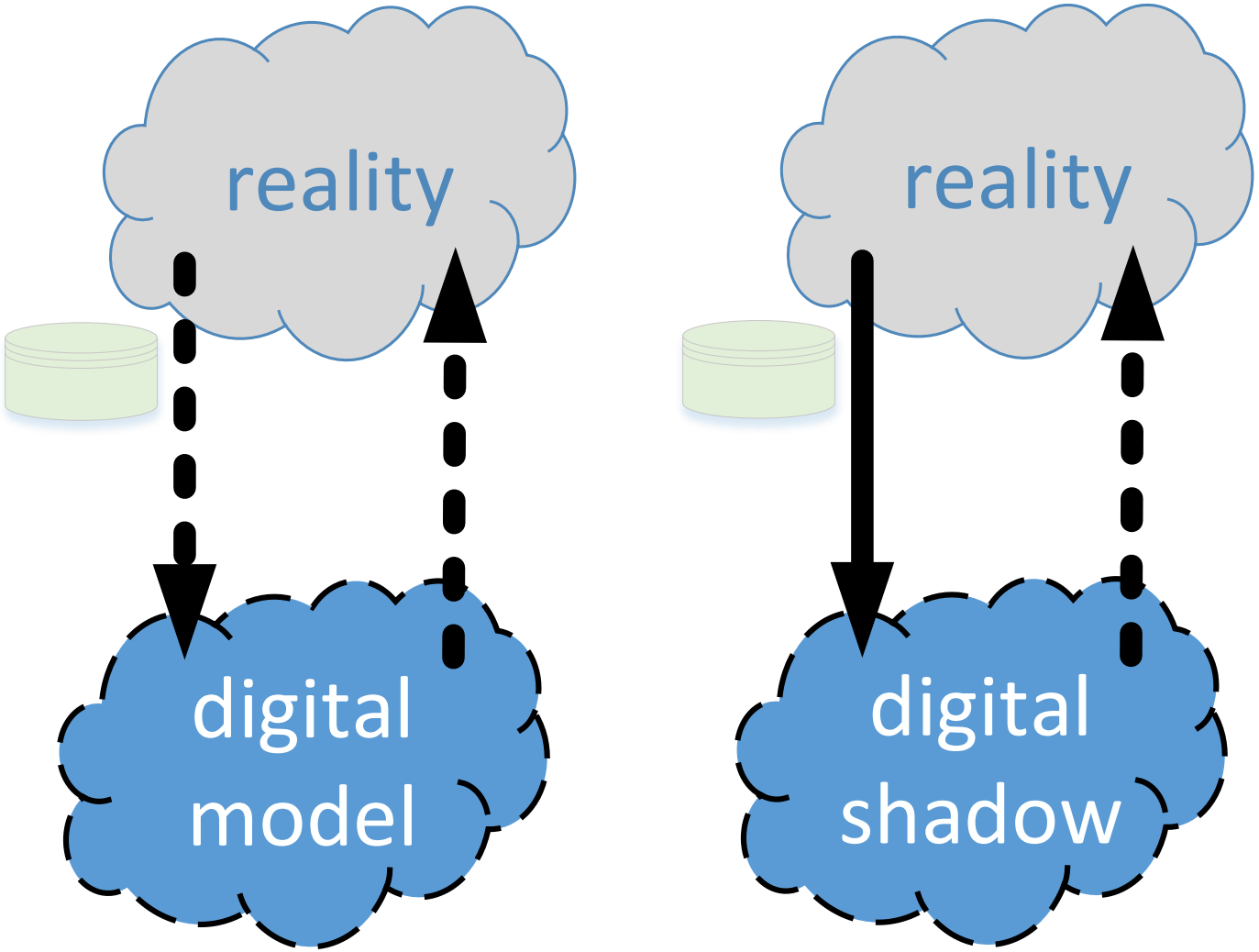
Towards a Digital Twin of an Organization (DTO)



Examples: business process modeling, discrete event simulation, etc.

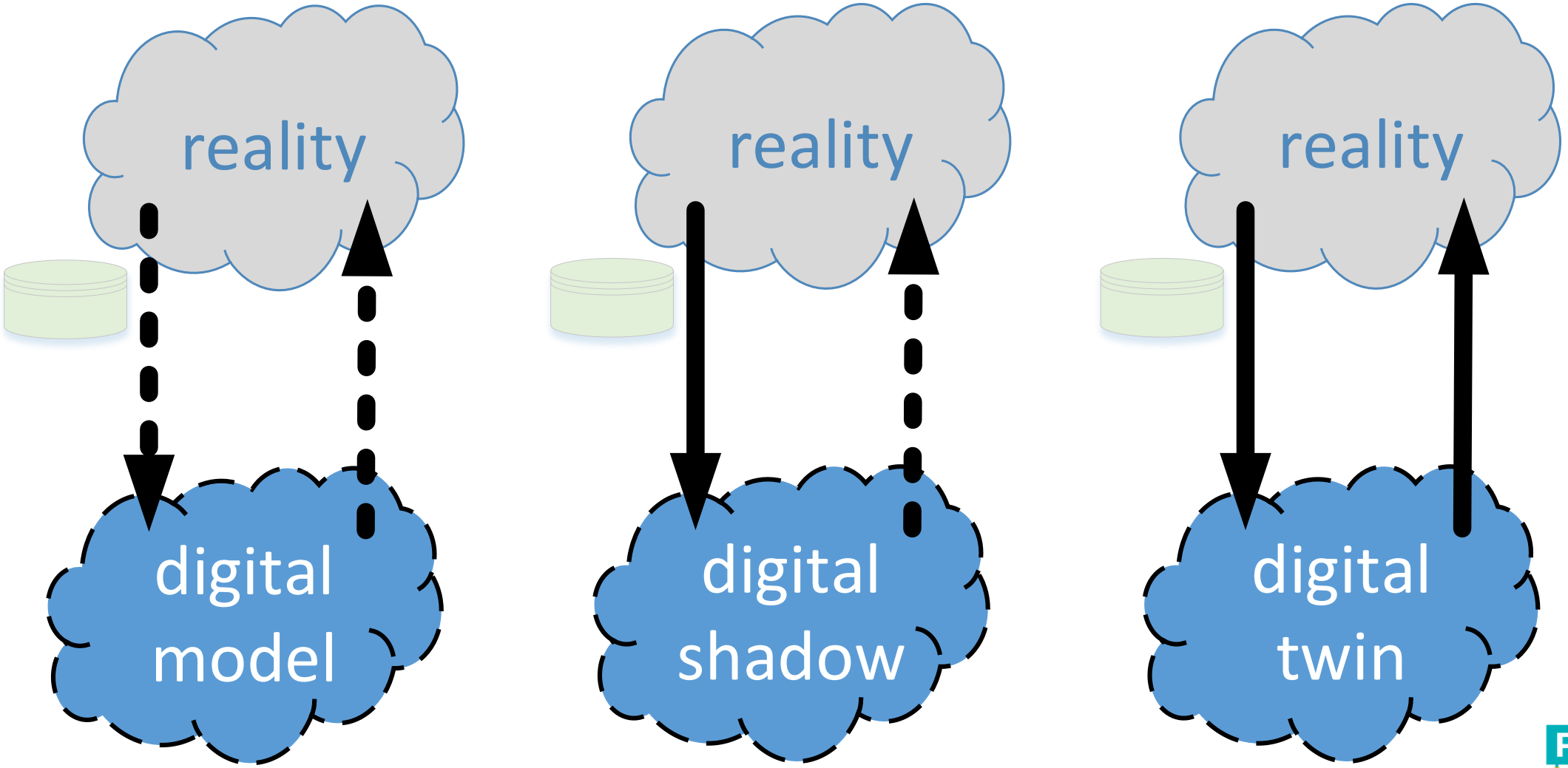
Chair of Process and Data Science

Towards a Digital Twin of an Organization (DTO)



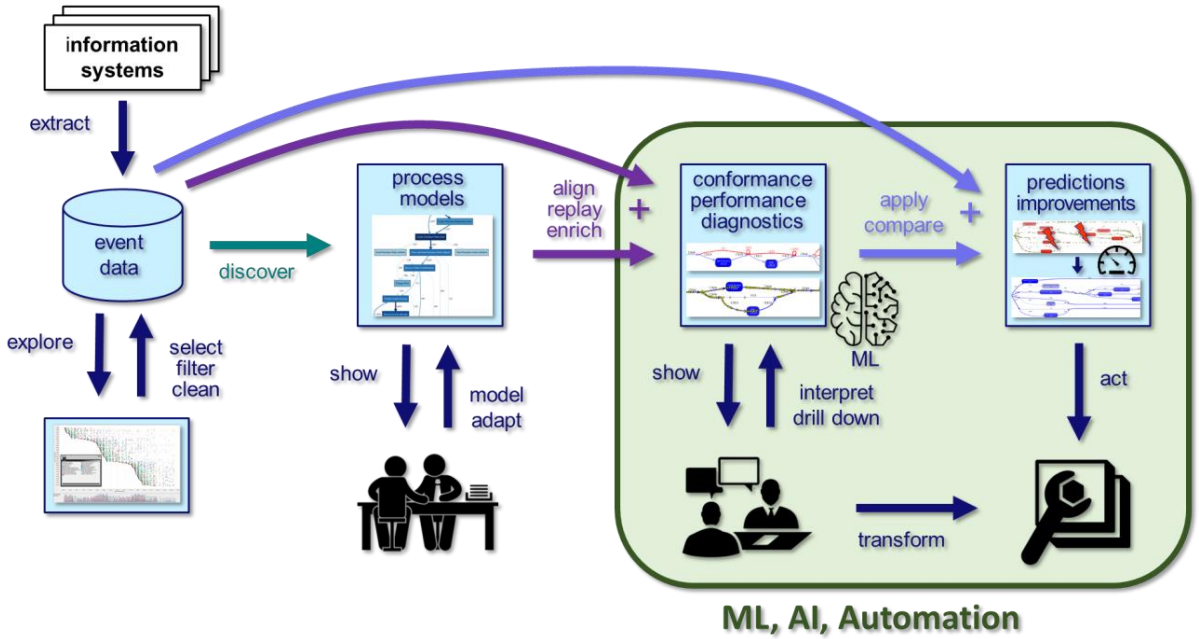
Process mining is a key technology to create a digital shadow. 15 years ago we were already able to automatically create simulation models based on event data only!

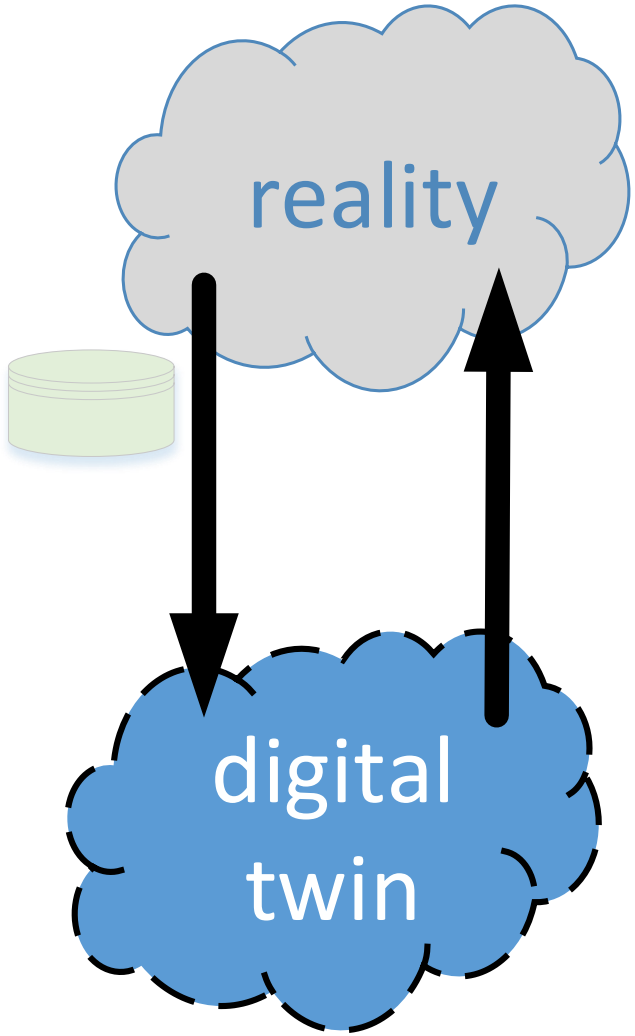
Towards a Digital Twin of an Organization (DTO)



Chair of Process and Data Science

Process mining as the enabler of DTOs





Chair of Process and Data Science

Compare Autonomous Automation to Autonomous Driving …

Mercedes-Benz S-class and EQS: First level 3 internationally certified car on sale since May 2022.

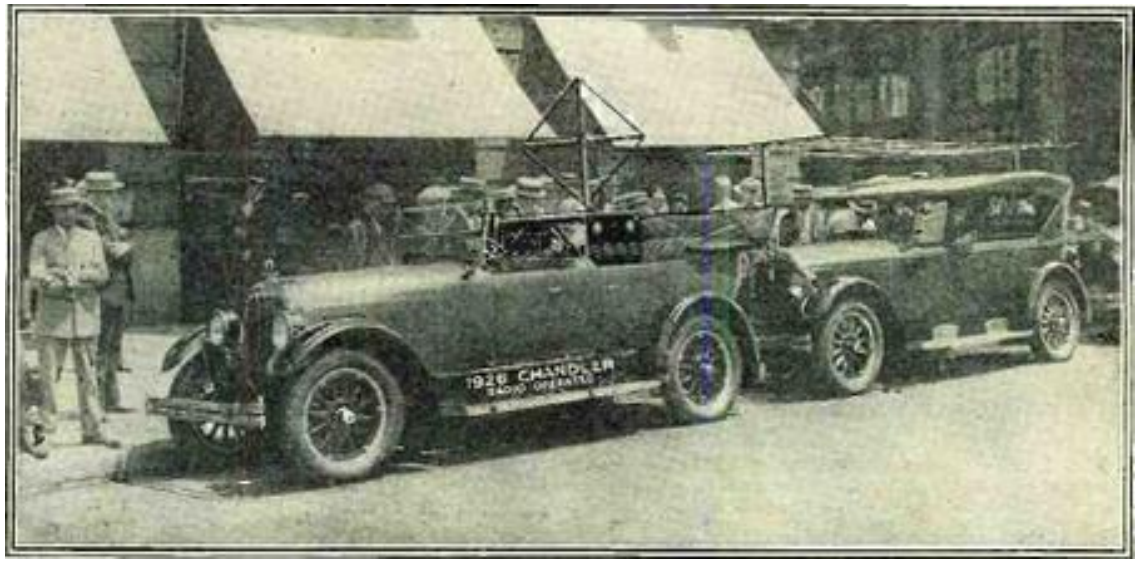
Levels defined by the Society of Automotive Engineers (SAE) https://www.sae.org/

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You are not driving when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/ acceleration support to the driver	These features provide steering AND brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

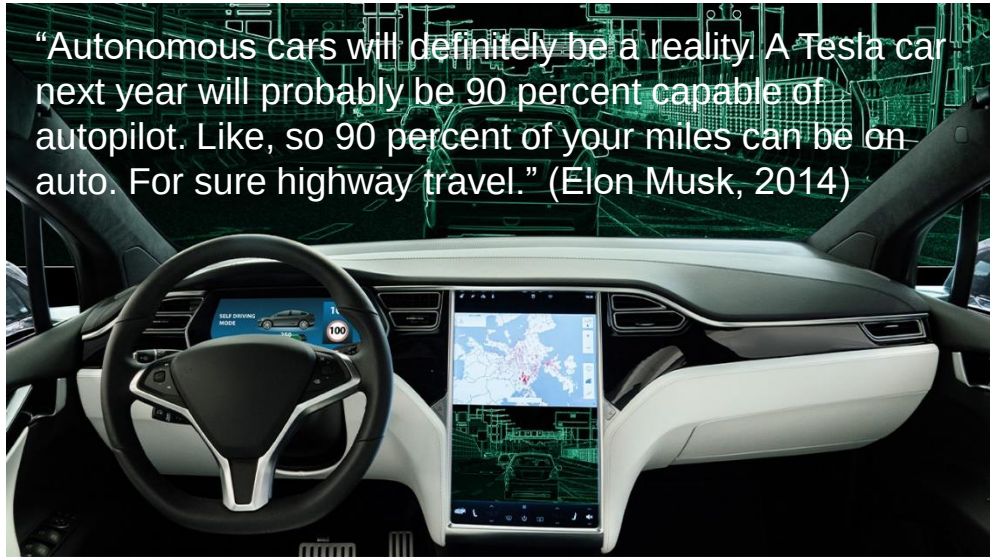
Wil van der Aalst, Six Levels of Autonomous Process Execution Management (APEM), 2022, https://arxiv.org/abs/2204.11328

	SAE levels for autonomous driving	Levels of autonomous process execution management
Level 0	A human is driving, and features are limited to breaking assistance, blind-spot warning, lane departure warning, etc.	There is no PEMS. All orchestration and management are done by humans. Features are limited to dashboards, reporting, key performance indicators, hard-coded workflows, and manually created simulations to conduct what-if analysis.
Level 1	A human is driving, but the car provides steering or brake/ acceleration support, e.g., lane centering or adaptive cruise control.	The PEMS is able to detect and quantify known and unknown performance and compliance problems. Features include process discovery and conformance checking. The PEMS may create alerts. However, humans need to interpret the diagnostics and, if needed, select appropriate actions.
Level 2	A human is driving, but the car provides steering and brake/ acceleration support. The difference with Level 1 is the combination of systems.	The PEMS is able to detect and quantify known and unknown performance and compliance problems. Moreover, the PEMS is able to recommend actions in case of detected known performance and compliance problems (execution gaps) and support the user in triggering corresponding actions. These actions may be automated, but in-the-end a human decides.
Level 3	Under selected circumstances, the car is driving. However, the driver needs to be alert and ready to take over control at any time.	The PEMS automatically responds to performance and compliance problems by taking appropriate actions. However, this is limited to a subset of problems and humans need to be alert and ready to take over control.
Level 4	Under selected circumstances, the car is driving. If the conditions are not met, the vehicle stops. The driver does not need to constantly monitor the situation.	The PEMS automatically responds to performance and compliance problems by taking appropriate actions. In principle, all management and orchestration decisions are made by the PEMS. Humans do not need to constantly monitor the PEMS, but the system may decide to call on the help of humans in case of diverging or unexpected behaviors.
Level 5	The car can drive itself under all circumstances (comparable to a human driver).	The PEMS functions fully autonomous also under diverging or unexpected circumstances.

Yet a log way to go …



1925: first “driverless” car by Houdina



2022: Tesla is still at level 2

Level 5 Autonomous Process Execution Management (APEM) will take a few years, but the lower levels are already in reach.

	SAE levels for autonomous driving	Levels of autonomous process execution management
Level 0	A human is driving, and features are limited to breaking assistance, blind-spot warning, lane departure warning, etc.	There is no PEMS. All orchestration and management are done by humans. Features are limited to dashboards, reporting, key performance indicators, hard-coded workflows, and manually created simulations to conduct what-if analysis.
Level 1	A human is driving, but the car provides steering or brake/ acceleration support, e.g., lane centering or adaptive cruise control.	The PEMS is able to detect and quantify known and unknown performance and compliance problems. Features include process discovery and conformance checking. The PEMS may create alerts. However, humans need to interpret the diagnostics and, if needed, select appropriate actions.
Level 2	A human is driving, but the car provides steering and brake/ acceleration support. The difference with Level 1 is the combination of systems.	The PEMS is able to detect and quantify known and unknown performance and compliance problems. Moreover, the PEMS is able to recommend actions in case of detected known performance and compliance problems (execution gaps) and support the user in triggering corresponding actions. These actions may be automated, but in-the-end a human decides.
Level 3	Under selected circumstances, the car is driving. However, the driver needs to be alert and ready to take over control at any time.	The PEMS automatically responds to performance and compliance problems by taking appropriate actions. However, this is limited to a subset of problems and humans need to be alert and ready to take over control.
Level 4	Under selected circumstances, the car is driving. If the conditions are not met, the vehicle stops. The driver does not need to constantly monitor the situation.	The PEMS automatically responds to performance and compliance problems by taking appropriate actions. In principle, all management and orchestration decisions are made by the PEMS. Humans do not need to constantly monitor the PEMS, but the system may decide to call on the help of humans in case of diverging or unexpected behaviors.
Level 5	The car can drive itself under all circumstances (comparable to a human driver).	The PEMS functions fully autonomous also under diverging or unexpected circumstances.

A Few Pointers and Conclusion

Chair of Process and Data Science

RWTH AACHEN UNIVERSITY

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.

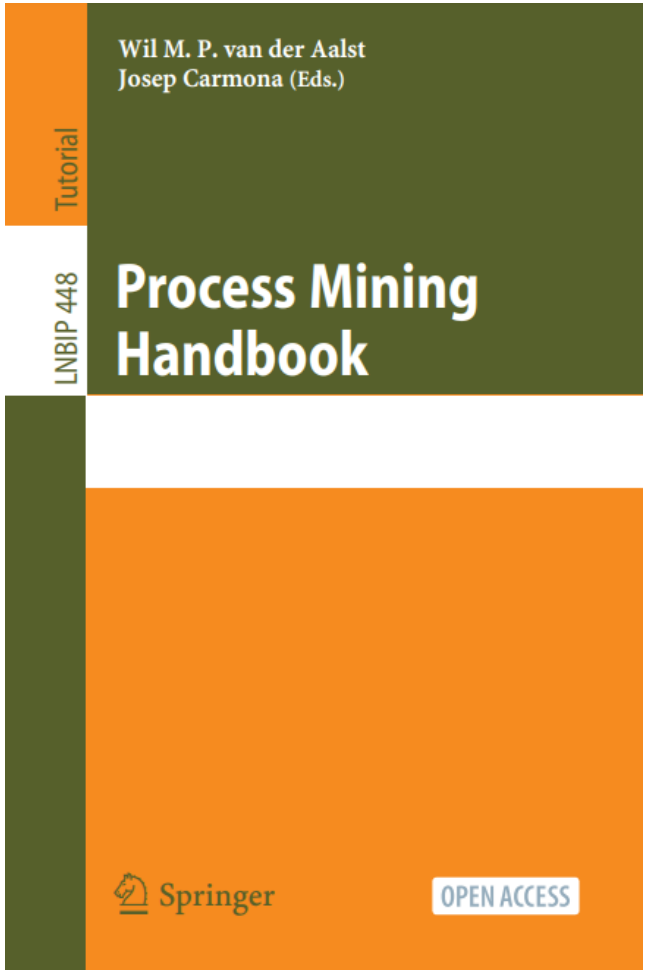
coursera TU/e

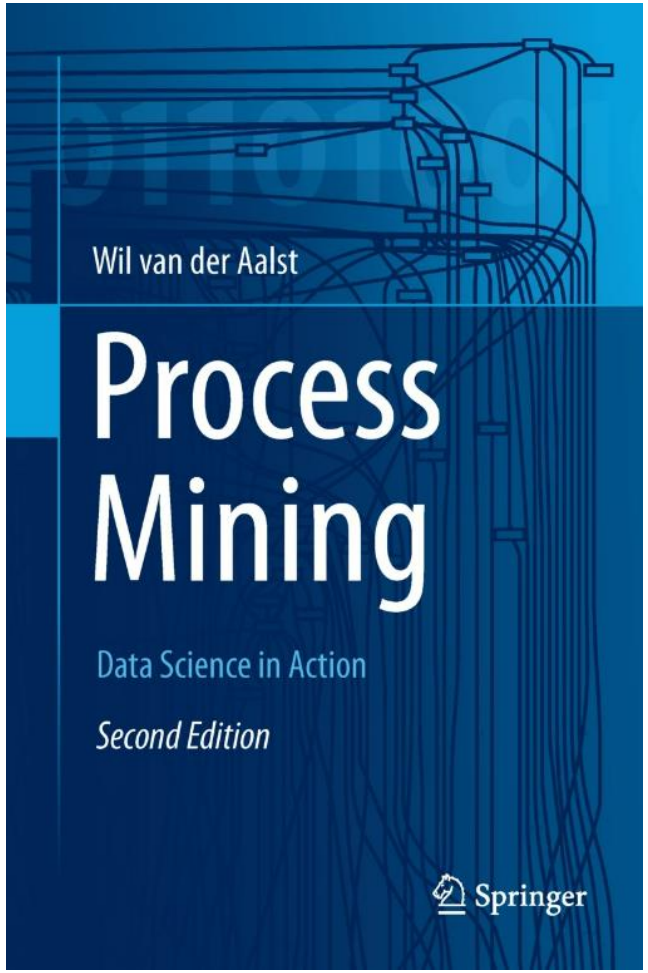
celonis RWTH RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN

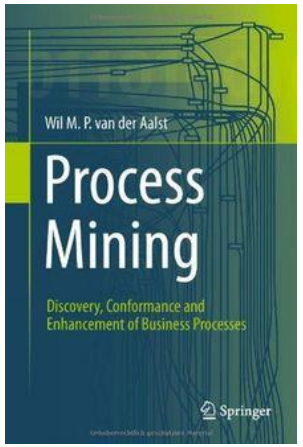
(edX is coming)

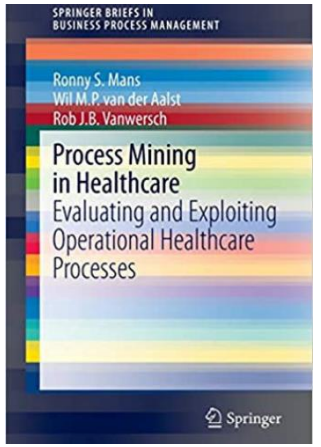
P D A S Chair of Process and Data Science

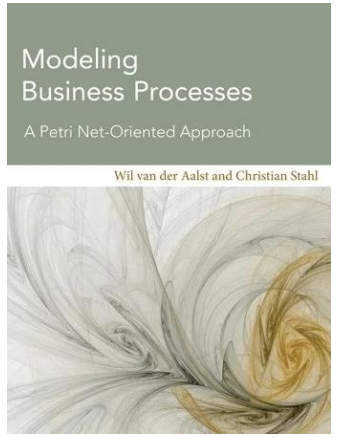
Books (not intended to be complete)

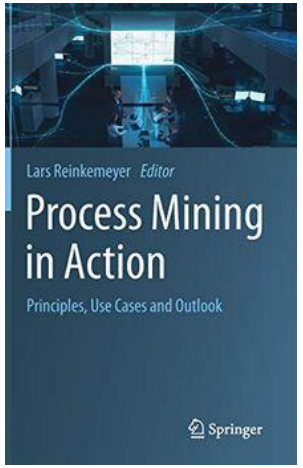


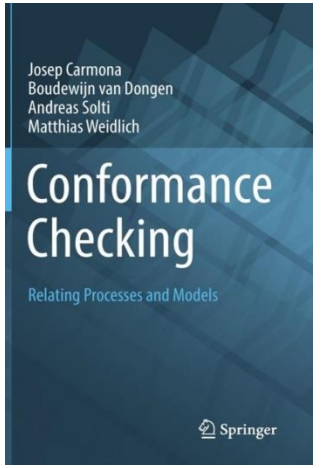


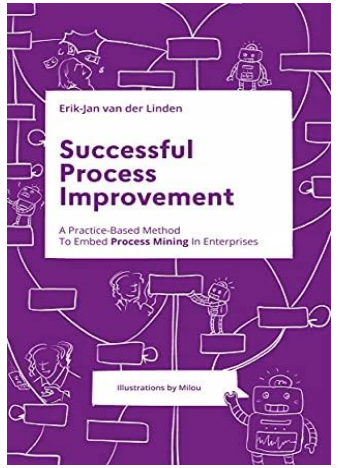






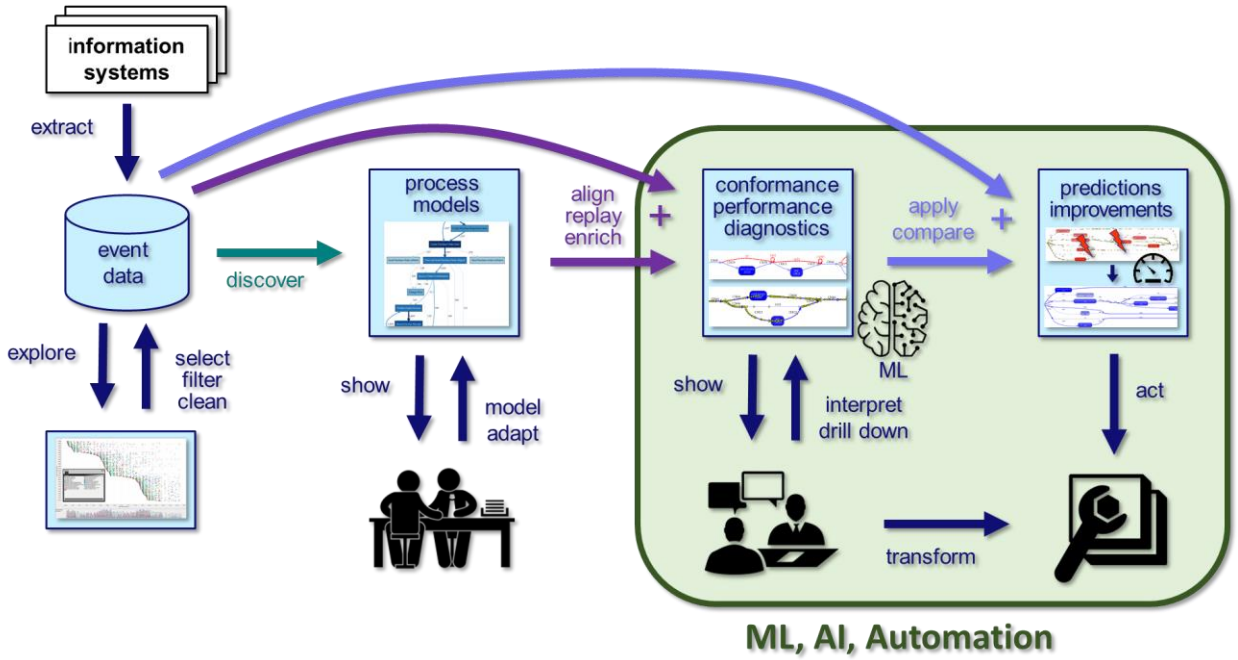






Chair of Process and Data Science

Conclusion



	SAE levels for autonomous driving	Levels of autonomous process execution management
Level 0	A human is driving, and features are limited to breaking assistance, blind-spot warning, lane departure warning, etc.	There is no PEMS. All orchestration and management are done by humans. Features are limited to dashboards, reporting, key performance indicators, hard-coded workflows, and manually created simulations to conduct what-if analysis.
Level 1	A human is driving, but the car provides steering or brake/ acceleration support, e.g., lane centering or adaptive cruise control.	The PEMS is able to detect and quantify known and unknown performance and compliance problems. Features include process discovery and conformance checking. The PEMS may create alerts. However, humans need to interpret the diagnostics and, if needed, select appropriate actions.
Level 2	A human is driving, but the car provides steering and brake/ acceleration support. The difference with Level 1 is the combination of systems.	The PEMS is able to detect and quantify known and unknown performance and compliance problems. Moreover, the PEMS is able to recommend actions in case of detected known performance and compliance problems (execution gaps) and support the user in triggering corresponding actions. These actions may be automated, but in-the-end a human decides.
Level 3	Under selected circumstances, the car is driving. However, the driver needs to be alert and ready to take over control at any time.	The PEMS automatically responds to performance and compliance problems by taking appropriate actions. However, this is limited to a subset of problems and humans need to be alert and ready to take over control.
Level 4	Under selected circumstances, the car is driving. If the conditions are not met, the vehicle stops. The driver does not need to constantly monitor the situation.	The PEMS automatically responds to performance and compliance problems by taking appropriate actions. In principle, all management and orchestration decisions are made by the PEMS. Humans do not need to constantly monitor the PEMS, but the system may decide to call on the help of humans in case of diverging or unexpected behaviors.
Level 5	The car can drive itself under all circumstances (comparable to a human driver).	The PEMS functions fully autonomous also under diverging or unexpected circumstances.

- **Process mining as the enabler for ML/AI in business!**
- **Needs to be combined with automation to be most effective!**
- **Towards Autonomous Process Execution Management (APEM).**

Chair of Process and Data Science