



Chair of Process
and Data Science

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Object-Centric Process Mining

Moving from 2D to 3D process analytics

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Process Mining in Korea

프로세스 마이닝



국내 최고의 프로세스 마이닝 전문가로서 Wil van der Aalst 교수와 조창기 프로세스 마이닝 연구를 시작하여, 조직 마이닝, 시뮬레이션, 프로세스 예측 등 프로세스 마이닝 핵심 개념을 제안하고, 프로세스 마이닝 분야 발전에 많은 기여를 했습니다. Process Mining Task Force, PODS4H의 멤버로 국제적으로 조직 마이닝과 제조/의료 분야 프로세스 마이닝 전문가로 알려져 있습니다.

- 포항공과대학교 산업경영공학과 박사
- 네덜란드 아인트호벤대학교 (프로세스 마이닝) 박사학위 연구원
- 포항공과대학교 산업경영공학과 교수

Speaker 1	Speaker 2	Speaker 3	Speaker 4
김봉구 부장 한진중공업	이진원 박사 삼성전자	차경환 총괄 LG화학	김병주 상무 KAI
Speaker 5	Speaker 6	Speaker 7	Speaker 8
이형주 이사 삼성전자	허상현 부장 삼성전자	이미연 교수 한양대학교	김영철 대표 지능데이터



How did we get here?



Prof. Minseok Song was at
TU/e 2003-2004 (PhD) and
2006-2009 (Postdoc).

Process mining with

- Social networks
- Org. mining
- Clustering
- Dotted charts
- Simulation
- Predictions

Current PADS group @ RWTH

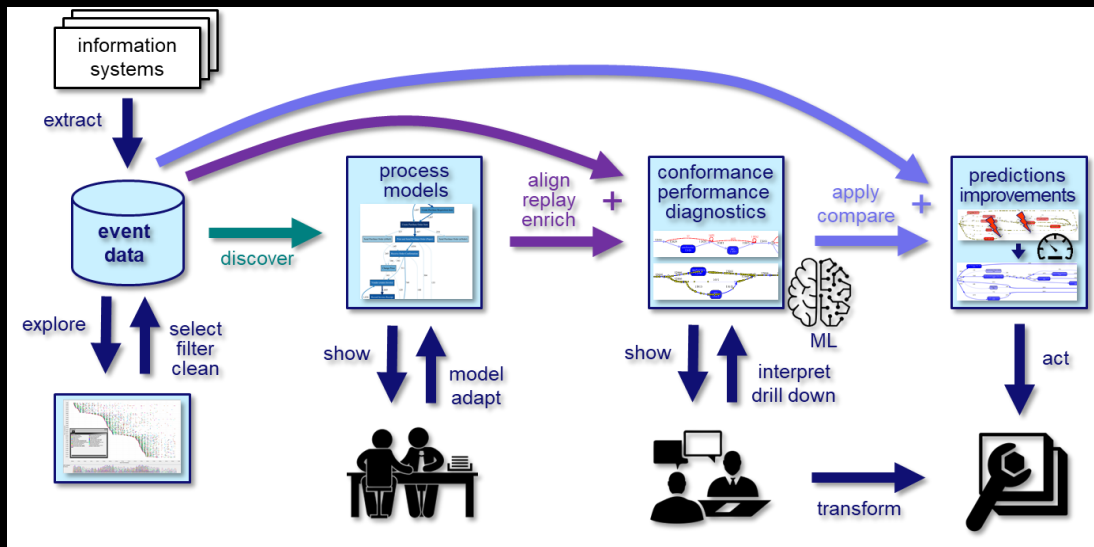


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What is Process Mining?

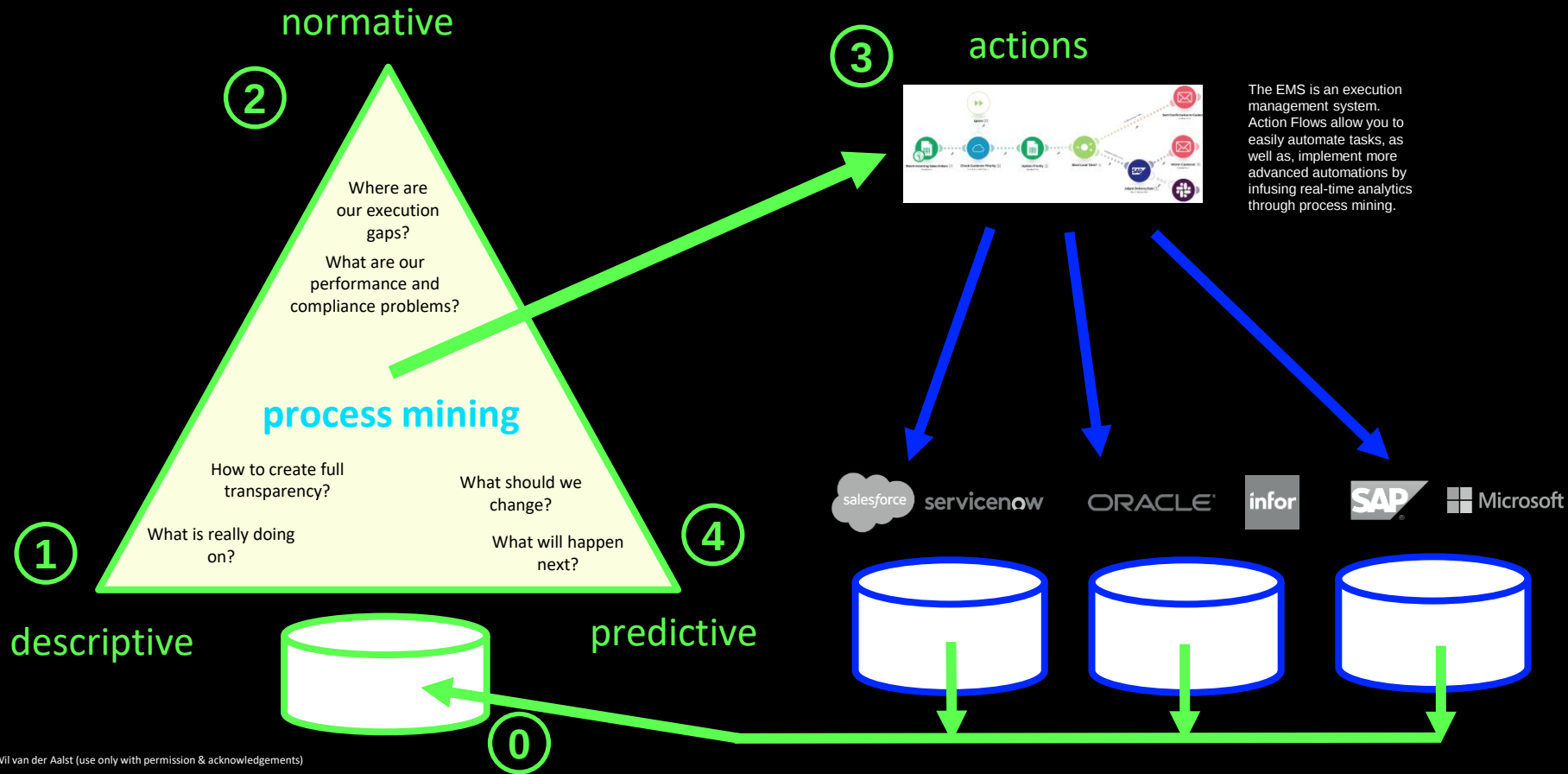


- Events (case, activity, time) are **everywhere!**
- **Generic**, widely applicable, technology
- True integration of processes and data
- **Robust** (from descriptive to predictive and prescriptive)
- Very **different** from traditional “model & automate” BPM
- Very **different** from traditional BI, AI, ML, etc.
- **Enabler** for ML, complementing automation, process modeling, RPA, etc.
- Rapidly **growing** (now at 1%)

Normal 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	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
...	...	...	...	...	...	...	...

What is Process Mining?





Object-Centric Process Mining

Look at processes from different angles





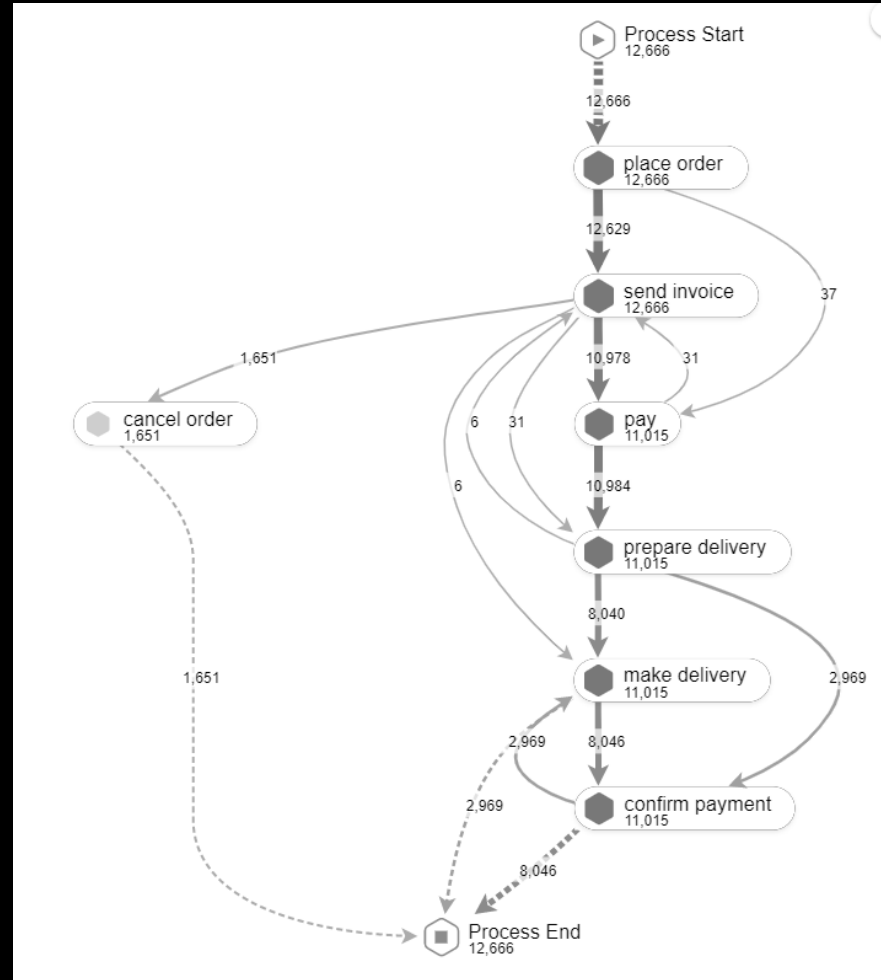






We tend to look at a process from just one angle

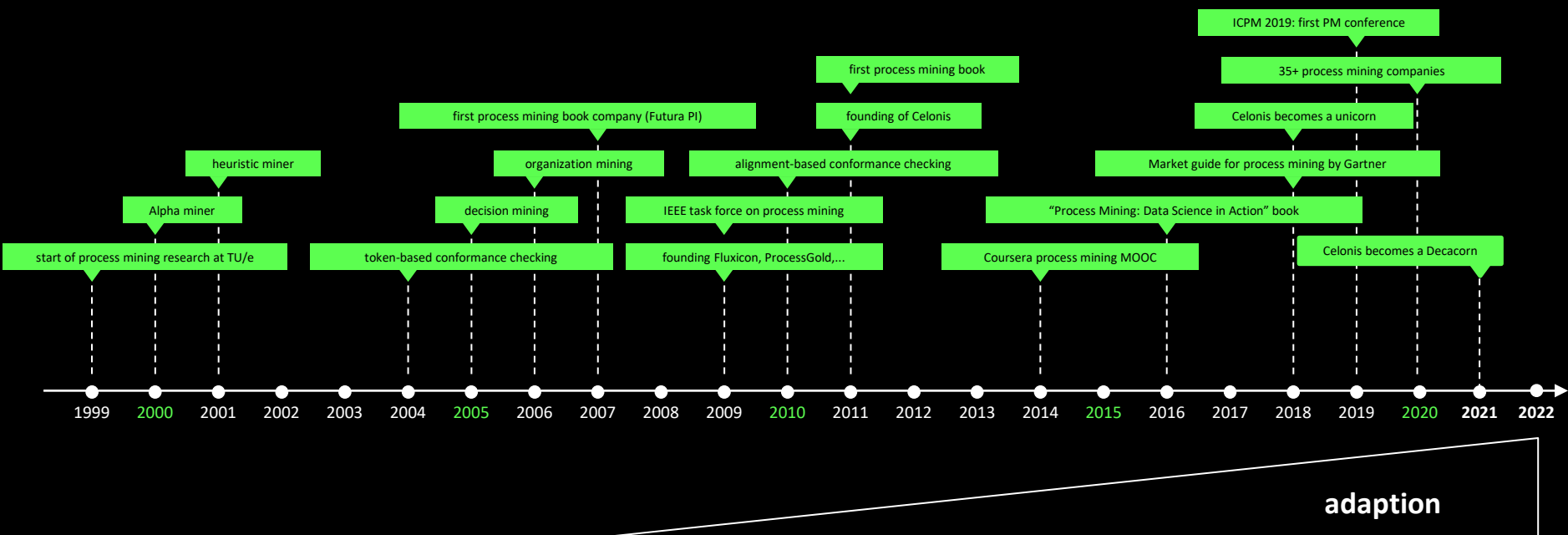
Why?



History and Uptake of Process Mining

research

commercial tools



Over 40

process mining
vendors today



Many

of the larger
organizations in
Europe are using
process mining
already

(And we are just at
the beginning!)





A big success

But, ...

Challenges

- Finding the data
- Extracting the data
- Understand the meaning
- Dealing with quality problems
- Scalability
- **Picking a case identifier**

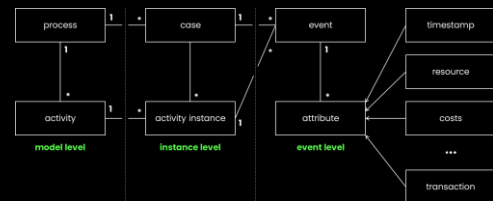
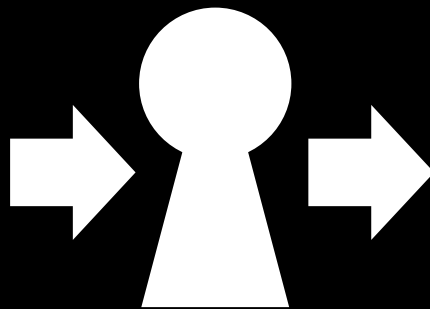
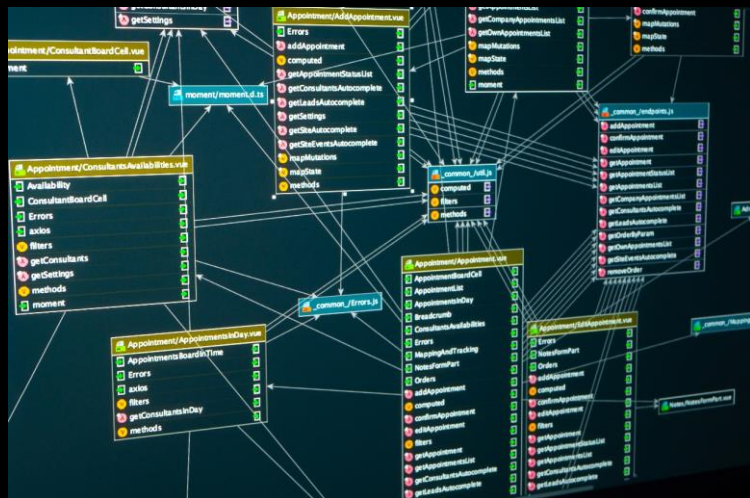


Hundreds
of systems
Thousands
of tables



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	638,00 €	5	NL-7950G-21
6283	pay	Lily	2018/02/13 14:39:25.000	SAMSUNG Galaxy S6 32 GB	543,99 €	3	NL-7828AM-16
6283	prepare delivery	Sophia	2018/02/13 16:03:13.000	APPLE iPhone 6 16 GB	638,00 €	3	NL-7807AC-19
6287	prepare delivery	Aiden	2018/02/13 16:03:43.000	SAMSUNG Galaxy S6 32 GB	543,99 €	1	NL-9697K-34
6185	confirm payment	Emily	2018/02/13 15:06:38.000	SAMSUNG Galaxy S4	328,00 €	1	NL-9529C-32
6218	confirm payment	Emily	2018/02/13 15:08:11.000	APPLE iPhone 6s Plus 64 GB	969,00 €	2	NL-79488K-10
6245	make delivery	Michael	2018/02/13 15:54:04.000	APPLE iPhone 6 16 GB	638,00 €	3	NL-7905AX-38
6272	pay	Emily	2018/02/13 16:20:36.000	APPLE iPhone 6 16 GB	638,00 €	1	NL-7829AC-3
6219	pay	Charlotte	2018/02/13 16:26:21.000	SAMSUNG Galaxy S4	328,00 €	1	NL-7960T-42
6212	prepare delivery	Sophia	2018/02/13 16:43:39.000	HUAWEI P8 Lite	234,00 €	1	NL-7905AX-38
6323	send invoice	Alexander	2018/02/13 16:46:58.000	APPLE iPhone 6 16 GB	638,00 €	1	NL-7833H-15
6246	confirm payment	Jack	2018/02/13 16:56:03.000	SAMSUNG Galaxy S4	328,00 €	3	NL-7833H-15
6347	send invoice	Jack	2018/02/13 16:57:42.000	SAMSUNG Galaxy S4	328,00 €	3	NL-7905AX-38
6381	place order	Isa	2018/02/13 16:59:37.000	APPLE iPhone 6s 16 GB	448,00 €	3	NL-9529C-32
6204	prepare delivery	Sophia	2018/02/13 16:30:28.000	SAMSUNG Core Prime Q361	135,00 €	1	NL-7828AM-16
6204	make delivery	Kaylee	2018/02/13 16:51:54.000	SAMSUNG Core Prime Q361	135,00 €	1	NL-7828AM-16
6285	confirm payment	Lily	2018/02/13 16:55:55.000	SAMSUNG Galaxy S4	328,00 €	4	NL-9529C-32
6250	confirm payment	Jack	2018/02/13 17:03:38.000	MOTOROLA Moto G	196,00 €	4	NL-79420T-2
6302	send invoice	Lily	2018/02/13 17:30:16.000	APPLE iPhone 6s 64 GB	868,00 €	4	NL-96148V-16
6352	place order	Aiden	2018/02/13 17:53:22.000	APPLE iPhone 6 16 GB	638,00 €	2	NL-96148V-16
6317	send invoice	Jack	2018/02/13 18:46:30.000	APPLE iPhone 6s 64 GB	868,00 €	5	NL-7907J-42
6353	place order	Sophia	2018/02/13 20:16:20.000	APPLE iPhone 6s 16 GB	448,00 €	4	NL-7751AR-19

Pushing an elephant through a keyhole



Case ID	Activity	Resource	Timestamp	Product	Prod-price	Quantity	Address
6350	place order	Aiden	2016/02/13 14:29:45.500	APPLE iPhone 6 16 GB	639.00 €	5	NL-7765DC-21
6363	pay	Livy	2016/02/13 14:39:25.000	SAMSUNG Galaxy S6 32 GB	543.99 €	3	NL-7638AM-76
6353	prepare delivery	Sophia	2016/02/13 15:03:33.000	APPLE iPhone 6 16 GB	639.00 €	3	NL-7638AC-13
6293	prepare delivery	Aiden	2016/02/13 15:03:43.000	SAMSUNG Galaxy S6 32 GB	543.99 €	1	NL-9529K-34
6385	confirm payment	Emily	2016/02/13 15:06:36.000	SAMSUNG Galaxy S4	329.50 €	1	NL-9529C-32
6258	confirm payment	Emily	2016/02/13 15:08:01.000	APPLE iPhone 5s Plus 64 GB	969.00 €	2	NL-74828D-32
6245	make delivery	Michael	2016/02/13 15:14:04.000	APPLE iPhone 6 16 GB	639.00 €	3	NL-7605AX-38
6272	pay	Emily	2016/02/13 15:20:36.000	APPLE iPhone 6 16 GB	639.00 €	1	NL-7625AC-3
6269	pay	Charlotte	2016/02/13 15:25:21.000	SAMSUNG Galaxy S4	329.50 €	1	NL-7607K-42
6323	prepare delivery	Sophia	2016/02/13 15:43:38.000	Huawei P8 Lite	234.00 €	1	NL-7605AX-38
6323	send invoice	Alexander	2016/02/13 15:46:08.000	APPLE iPhone 6 16 GB	639.00 €	1	NL-7638HF-15
6248	confirm payment	Jack	2016/02/13 15:56:03.000	SAMSUNG Galaxy S4	329.50 €	3	NL-7638HF-15
6347	send invoice	Jack	2016/02/13 16:57:42.000	SAMSUNG Galaxy S4	329.50 €	3	NL-7605AX-38
6351	place order	Zoe	2016/02/13 16:17:37.000	APPLE iPhone 5s 16 GB	449.00 €	3	NL-9529C-32
6204	prepare delivery	Sophia	2016/02/13 16:31:28.000	SAMSUNG Core Prime Q381	139.50 €	1	NL-7638AM-76
6204	make delivery	Kaylee	2016/02/13 16:51:54.000	SAMSUNG Core Prime Q381	139.50 €	1	NL-7638AM-76
6293	confirm payment	Livy	2016/02/13 16:55:56.000	SAMSUNG Galaxy S4	329.50 €	4	NL-9529C-32
6290	confirm payment	Jack	2016/02/13 17:03:28.000	MOTOROLA Moto G	199.00 €	4	NL-76420T-2
6328	send invoice	Livy	2016/02/13 17:30:56.000	APPLE iPhone 6s 64 GB	896.00 €	4	NL-9548BY-16
6353	place order	Aiden	2016/02/13 17:53:23.000	APPLE iPhone 6 16 GB	639.00 €	2	NL-9548BY-16
6377	send invoice	Jack	2016/02/13 18:45:30.000	APPLE iPhone 6s 64 GB	896.00 €	5	NL-7607K-42
6353	place order	Sophia	2016/02/13 20:16:20.000	APPLE iPhone 6s 16 GB	449.00 €	4	NL-7755AR-19

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

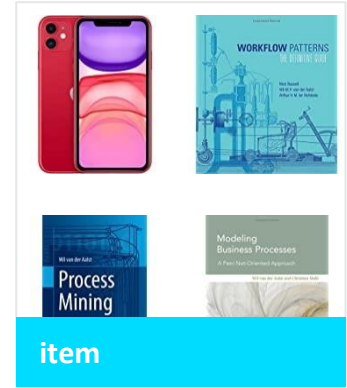
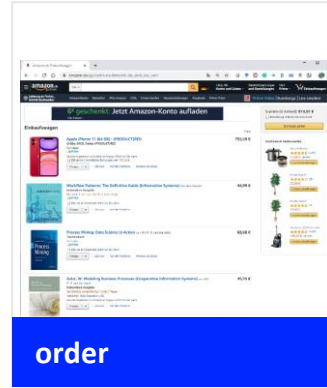
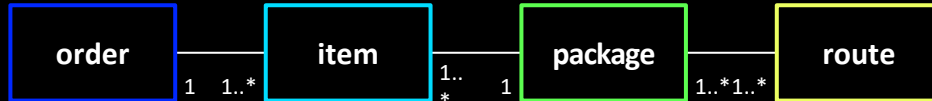
... to create a single viewpoint

Example: Amazon

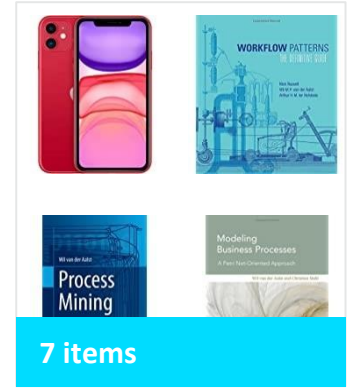
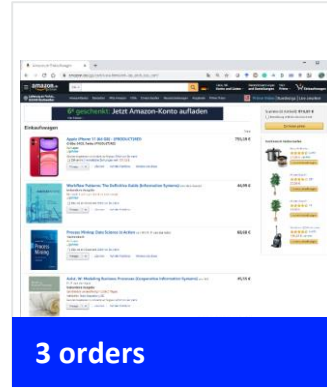
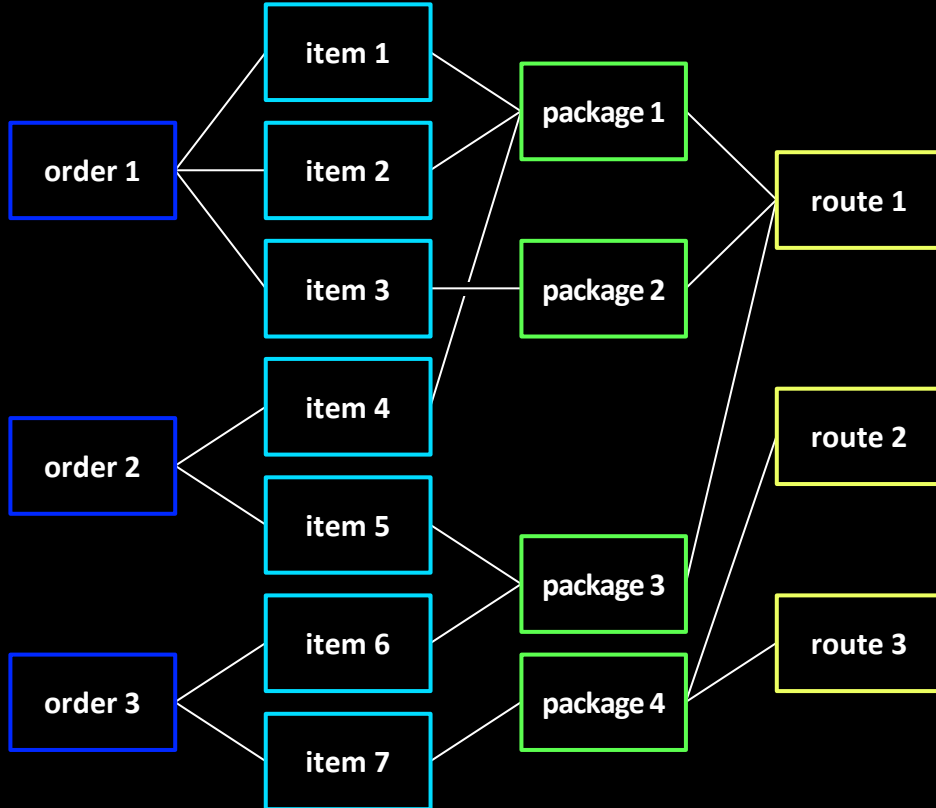
1-to-many

many-to-1

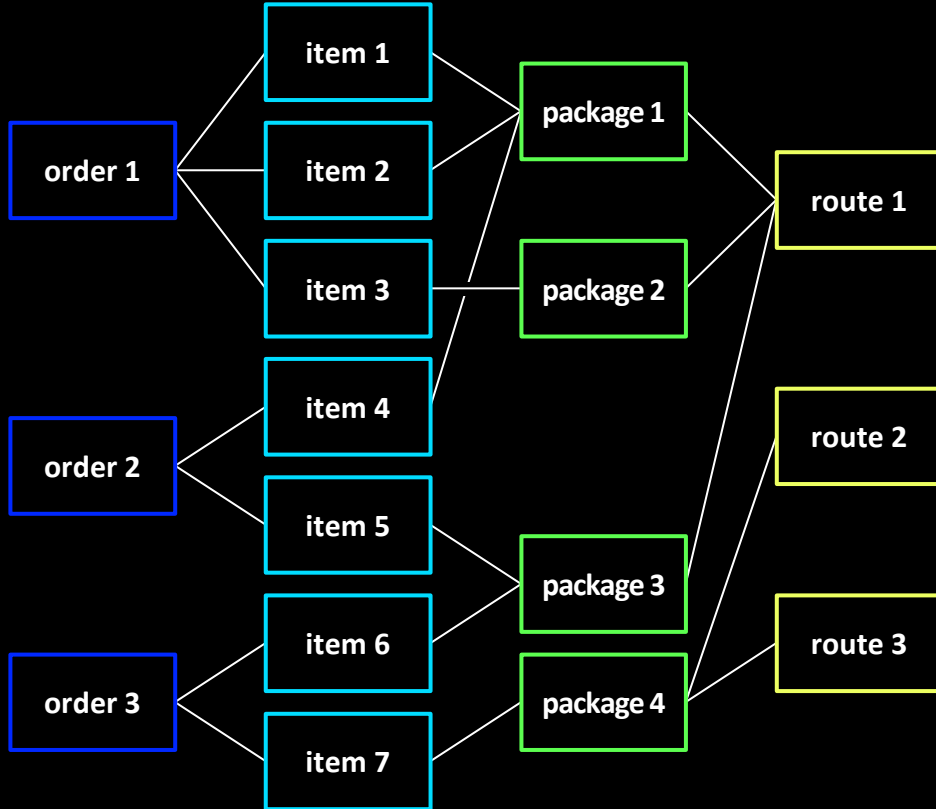
many-to-many



Example objects



Example objects



Items of order 1 end up in packages 1 and 2

Package 1 contains items of orders 1 and 2

Etc.

What is a suitable case notion?



Let's make the following assumption

Activity	Time	Orders	Items	Packages	Customers	Products	Price	Weight
pick item	2019/12/26 12:04:46	{991224}	{884803}	{}	{Wil van der Aalst}	{iPhone 8}	529.0	0.21
reorder item	2019/12/26 12:27:26	{991271}	{885002}	{}	{Mohammadreza Fani Sani}	{Kindle Paperwhite}	129.0	0.495
place order	2019/12/26 12:44:23	{991283}	{885038, 885039}	{}	{Luis Santos}	{MacBook Air, iPad}	2700.0	1.733
pick item	2019/12/26 14:01:16	{991266}	{884983}	{}	{Marco Pegoraro}	{Macbook Air}	2200.0	1.25
create package	2019/12/26 14:01:16	{991264}	{884975, 884974, 884978, 884971, 884970, 884973}	{660798}	{Seran Uysal}	{Fire Stick 4K, iPad Pro, iPad Pro, iPad Pro, Fire Stick, Kindle}	3506.97	2.412
send package	2019/12/26 14:16:11	{991264}	{884975, 884974, 884978, 884971, 884970, 884973}	{660798}	{Seran Uysal}	{Fire Stick 4K, iPad Pro, iPad Pro, iPad Pro, Fire Stick, Kindle}	3506.97	2.412
pick item	2019/12/26 14:16:48	{991279}	{885027}	{}	{Claudia Graf}	{iPhone 11}	799.0	0.166
confirm order	2019/12/26 14:26:01	{991283}	{885038, 885039}	{}	{Luis Santos}	{MacBook Air, iPad}	2700.0	1.733
reorder item	2019/12/26 14:32:43	{991251}	{884912}	{}	{Tobias Brockhoff}	{Fire Stick}	39.99	0.2
confirm order	2019/12/26 14:32:44	{991272}	{885036, 885037}	{}	{Luis Santos}	{Echo Dot}	134.98	1.16
pick item	2019/12/26 14:33:28	{885024}	{885024}	{}	{Luis Santos}	{Book Pro}	2500.0	1.37
place order	2019/12/26 14:48:33	{991284}	{885040, 885041, 885042, 885043}	{}	{Luis Santos}	{iPhone, Fire Stick, MacBook Air, Echo Show 8, iPhone 11}	4222.98	2.79
failed delivery	2019/12/26 15:04:53	{991240, 991168}	{884879, 884561, 884873, 884874}	{}	{Gyungam Park}	{Air, Echo Studio, Echo Studio, Kindle, Kindle Echo, mini, iPad Pro, iPad Pro}	5982.95	7.642
pick item	2019/12/26 15:20:05	{991278}	{885025}	{}	{Gyungam Park}	{iPhone 8}	699.0	0.172
confirm order	2019/12/26 15:25:00	{991248}	{884938, 884939, 884940, 884941}	{}	{Seran Uysal}	{Kindle Paperwhite}	3247.98	2.666
send package	2019/12/26 15:26:49	{991247, 881253}	{884902, 884922, 884923, 885001}	{}	{Seran Uysal}	{Book Air, iPad}	8496.0	4.054
failed delivery	2019/12/26 15:36:16	{991264}	{884975, 884974, 884978, 884979}	{}	{Seran Uysal}	{Macbook Air}	3506.97	2.412
confirm order	2019/12/26 15:40:51	{991274}	{885008, 885009, 885010, 885011}	{}	{Seran Uysal}	{iPhone X, Fire Stick, iPhone 8}	1352.98	1.065
failed delivery	2019/12/26 15:46:21	{991128, 991255}	{884426, 884932, 884999, 885000}	{}	{Junxiang Gao}	{Echo Show 8, Kindle Paperwhite, iPad mini, Kindle, iPhone X, iPhone 8, Echo Show}	2145.97	3.6
payment reminder	2019/12/26 15:54:44	{991169}	{884565, 884566, 884567, 884568}	{}	{Gyungam Park}	{iPhone 8, Echo Plus, iPad Air, iPad mini}	1608.99	2.21
pick item	2019/12/26 15:55:38	{991201}	{884717}	{}	{Seran Uysal}	{Echo Show 8}	129.99	0.98
pick item	2019/12/26 16:00:38	{991251}	{884912}	{}	{Tobias Brockhoff}	{Fire Stick}	39.99	0.2
reorder item	2019/12/26 16:04:42	{991265}	{884977}	{}	{Seran Uysal}	{Fire Stick 4K}	80.59	0.28
payment reminder	2019/12/26 16:11:39	{991164}	{884542, 884543, 884544, 884545, 884546, 884547}	{}	{Junxiang Gao}	{Kindle Paperwhite, iPad Air, iPhone 11, Macbook Air, iPad mini, Echo Dot}	4087.99	3.011
pick item	2019/12/26 16:22:04	{991241}	{884882}	{}	{Lisa Mannel}	{iPhone 8}	529.0	0.21
create package	2019/12/26 16:22:04	{991263, 99162}	{884967, 884964, 884966}	{660799}	{Luis Santos}	{iPad Air, iPhone 8, Pad}	1500.0	1.133

- products
- customers
- machines
- parts
- locations
- packages
- patients
- orders

event = activity + timestamp + objects + attributes

Let's make the following assumption

Activity	Time	Orders	Items	Packages	Customers	Products	Price	Weight
pick item	2019/12/26 12:04:46	{991224}	{884803}	{}	{Wil van der Aalst}	{iPhone 8}	529.0	0.21
reorder item	2019/12/26 12:27:26	{991271}	{885002}	{}			129.0	0.495
place order	2019/12/26 12:44:23	{991283}	{885038, 885039}				2700.0	1.733
pick item	2019/12/26 14:01:16	{991266}	{884983}	{}			2200.0	1.25
create package	2019/12/26 14:01:16	{991264}	{884975, 884974, 884978, 884971, 884970, 884973}	{660798}			3506.97	2.412
send package	2019/12/26 14:16:11	{991264}	{884975, 884974, 884978, 884971, 884970, 884973}	{660798}			3506.97	2.412
pick item	2019/12/26 14:16:48	{991279}	{885027}	{}	{Claudia Graf}	{iPhone 11}	799.0	0.166
confirm order	2019/12/26 14:26:01	{991283}	{885038, 885039}	{}	{Luis Santos}	{MacBook Air, iPad}	2700.0	1.733
reorder item	2019/12/26 14:32:43	{991251}	{884912}	{}	{Tobias Brockhoff}	{Fire Stick}	39.99	0.2
confirm order	2019/12/26 14:32:44	{991272}	{885037}	{}	{Lisa Mannell}	{Echo, Echo Dot}	134.98	1.16
pick item	2019/12/26 14:33:28	{885024}		{}	{Junxiong Gao}	{MacBook Pro}	2500.0	1.37
pick item			{85043, 885044}	{}	{Christine Dobbert}	{iPhone, Fire Stick, MacBook Air, Echo Show 8, iPhone 11 Pro}	4222.98	2.79
failed delivery			{84913, 884876, 884938, 884914, 884941, ...}	{660790}	{Tobias Brockhoff}	{iPad Air, Echo Studio, Echo Studio, Kindle, Kindle Echo, iPad mini, iPad Pro, iPad Pro}	5982.95	7.642
pick item				{}	{Junxiong Gao}	{iPhone 8}	699.0	0.172
confirm order			{84941, 884942, 884943}	{}	{Tobias Brockhoff}			
failed delivery			{85004, 885005, 884901}	{660796}	{Mohammadreza Fani Sami}			
failed delivery			{84971, 884970, 884973}	{660798}	{Seran Uysal}			
confirm order	2019/12/26 15:40:51	{991274}	{885008, 885009, 885010, 885011}	{}	{Junxiong Gao}			
failed delivery	2019/12/26 15:46:21	{991128, 991255}	{884426, 884932, 884999, 885008, 885009, 885011, 884903}	{660797}	{Junxiong Gao}			
payment reminder	2019/12/26 15:54:44	{991169}	{884565, 884566, 884567, 884568}	{}	{Gyunam Park}			
pick item	2019/12/26 15:55:38	{991201}	{884717}	{}	{Seran Uysal}			
pick item	2019/12/26 16:00:38	{991251}	{884912}	{}	{Tobias Brockhoff}			
reorder item	2019/12/26 16:04:42	{991265}	{884977}	{}	{Seran Uysal}			
payment reminder	2019/12/26 16:11:39	{991164}	{884542, 884543, 884544, 884545, 884546, 884547}	{}	{Junxiong Gao}			
pick item	2019/12/26 16:22:04	{991241}	{884882}	{}	{Lisa Mannell}	{iPhone 8}	529.0	0.21
create package	2019/12/26 16:22:04	{991263, 99162}	{884967, 884964, 884966}	{660799}	{Luis Santos}	{iPad Air, iPhone 8, iPad}	1500.0	1.133

this "place order" event refer to two items

every "pick item" event refers to one item

this "failed delivery" event refers to one package, seven items, two orders, etc.

event = activity + timestamp + objects + attributes



No case notion

Activity	Time	Orders	Items	Packages	Customers	Products	Price	Weight
pick item	2019/12/26 12:04:46	[991224]	[884803]	{}	{Wil van der Aalst}	{iPhone 8}	529.0	0.21
reorder item	2019/12/26 12:27:26	[991271]	[885002]	{}	{Mohammadreza Fani Sani}	{Kindle Paperwhite}	129.0	0.495
place order	2019/12/26 12:44:23	[991283]	[885038, 885039]	{}	{Luis Santos}	{MacBook Air, iPad}	2700.0	1.733
pick item	2019/12/26 14:01:16	[991266]	[884983]	{}	{Marco Pegoraro}	{Macbook Air}	2200.0	1.25
create package	2019/12/26 14:01:16	[991264]	[884975, 884974, 884978, 884971, 884970, 884973]	{660798}	{Seran Uys}			412
send package	2019/12/26 14:16:11	[991264]	[884975, 884974, 884978, 884971, 884970, 884973]	{660798}	{Seran Uys}			412
pick item	2019/12/26 14:16:48	[991279]	[885027]	{}	{Claudia G}			166
confirm order	2019/12/26 14:26:01	[991283]	[885038, 885039]	{}	{Luis Santos}			733
reorder item	2019/12/26 14:32:43	[991251]	[884912]	{}	{Tobias Br}			0.2
confirm order	2019/12/26 14:32:44	[991272]	[885036, 885037]	{}	{Lisa Mann}			1.16
pick item	2019/12/26 14:33:28	[885024]	[885024]	{}	{Junxiong}			1.37
place order	2019/12/26 14:48:33	[991284]	[885040, 885041, 885042, 885043, 885044]	{}	{Christine}			2.79
failed delivery	2019/12/26 15:04:53	[991240, 991168]	[884879, 884561, 884873, 884913, 884876, 884938, 884914, 884941, ...]	{660790}	{Tobias Br}			642
pick item	2019/12/26 15:20:05	[991278]	[885025]	{}	{Junxiong}			172
confirm order	2019/12/26 15:25:00	[991248]	[884938, 884939, 884940, 884941, 884942, 884943]	{}	{Tobias Br}			666
send package	2019/12/26 15:26:49	[991247, 881253]	[884902, 884922, 884923, 885004, 885005, 884901]	{660796}	{Mohamim}			054
failed delivery	2019/12/26 15:36:16	[991264]	[884975, 884974, 884978, 884971, 884970, 884973]	{660798}	{Seran Uys}			412
confirm order	2019/12/26 15:40:51	[991274]	[885008, 885009, 885010, 885011]	{}	{Junxiong}			065
failed delivery	2019/12/26 15:46:21	[991128, 991255]	[884426, 884932, 884999, 885008, 885009, 885011, 884903]	{660797}	{Junxiong}			3.6
payment reminder	2019/12/26 15:54:44	[991169]	[884565, 884566, 884567, 884568]	{}	{Gyunam I}			2.21
pick item	2019/12/26 15:55:38	[991201]	[884717]	{}	{Seran Uys}			0.98
pick item	2019/12/26 16:00:38	[991251]	[884912]	{}	{Tobias Br}			0.2
reorder item	2019/12/26 16:04:42	[991265]	[884977]	{}	{Seran Uys}			1.28
payment reminder	2019/12/26 16:11:39	[991164]	[884542, 884543, 884544, 884545, 884546, 884547]	{}	{Junxiong}			011
pick item	2019/12/26 16:22:04	[991241]	[884882]	{}	{Lisa Mannell}	{iPad mini, Echo Dot}	529.0	0.21
create package	2019/12/26 16:22:04	[991263, 99162]	[884967, 884964, 884966]	{660799}	{Luis Santos}	{iPad Air, iPhone 8, iPad}	1500.0	1.133

Five object types:
Orders,
Items,
Packages,
Customers, and
Products.

event = activity + timestamp + objects + attributes



Creating a conventional event log

Activity	Time	Orders	Items	Packages	Customers	Products	Price	Weight
pick item	2019/12/26 12:04:46	{991224}	{884803}	{}	{Wil van der Aalst}	{iPhone 8}	529.0	0.21
reorder item	2019/12/26 12:27:26	{991271}	{885002}	{}	{Mohammadreza Fani Sani}	{Kindle Paperwhite}	129.0	0.495
place order	2019/12/26 12:44:23	{991283}	{885038, 885039}	{}	{Luis Santos}	{MacBook Air, iPad}	2700.0	1.733
pick item	2019/12/26 14:01:16	{991266}	{884983}	{}	{Marco Pegoraro}	{Macbook Air}	2200.0	1.25
create package	2019/12/26 14:01:16	{991264}	{884975, 884974, 884978, 884971, 884970, 884973}	{660798}	{Seran Uysal}	{Fire Stick 4K, iPad Pro, iPad Pro, iPad Pro, Fire Stick, Kindle}	3506.97	2.412
send package	2019/12/26 14:16:11	{991264}	{884975, 884974, 884978, 884971, 884970, 884973}	{660798}	{Seran Uysal}	{Fire Stick 4K, iPad Pro, iPad Pro, iPad Pro, Fire Stick, Kindle}	3506.97	2.412
pick item	2019/12/26 14:16:48	{991279}	{885027}	{}	{Claudia Graf}	{iPhone 11}	799.0	0.166
confirm order	2019/12/26 14:26:01	{991283}	{885038, 885039}	{}	{Luis Santos}	{MacBook Air, iPad}	2700.0	1.733
reorder item	2019/12/26 14:32:43	{991251}	Need to pick a case identifier! How?				39.99	0.2
confirm order	2019/12/26 14:32:44	{991272}					134.98	1.16
pick item	2019/12/26 14:33:28	{885024}					2500.0	1.37
place order	2019/12/26 14:48:33	{991284}					4222.98	2.79
failed delivery	2019/12/26 15:04:53	{991240, 991168}					5982.95	7.642
pick item	2019/12/26 15:20:05	{991278}					699.0	0.172
confirm order	2019/12/26 15:25:00	{991248}					3247.98	2.666
send package	2019/12/26 15:26:49	{991247, 881253}					8496.0	4.054
failed delivery	2019/12/26 15:36:16	{991264}					3506.97	2.412
confirm order	2019/12/26 15:40:51	{991274}	{885008, 885009, 885010, 885011}	{}	{Junxiong Gao}	{Kindle, iPhone X, Fire Stick, iPhone 8}	1352.98	1.065
failed delivery	2019/12/26 15:46:21	{991128, 991255}	{884426, 884932, 884999, 885008, 885009, 885011, 884903}	{660797}	{Junxiong Gao}	{Echo Show 8, Kindle Paperwhite, iPad mini, Kindle, iPhone X, iPhone 8, Echo Show}	2145.97	3.6
payment reminder	2019/12/26 15:54:44	{991169}	{884565, 884566, 884567, 884568}	{}	{Gyunam Park}	{iPhone 8, Echo Plus, iPad Air, iPad mini}	1608.99	2.21
pick item	2019/12/26 15:55:38	{991201}	{884717}	{}	{Seran Uysal}	{Echo Show 8}	129.99	0.98
pick item	2019/12/26 16:00:38	{991251}	{884912}	{}	{Tobias Brockhoff}	{Fire Stick}	39.99	0.2
reorder item	2019/12/26 16:04:42	{991265}	{884977}	{}	{Seran Uysal}	{Fire Stick 4K}	80.59	0.28
payment reminder	2019/12/26 16:11:39	{991164}	{884542, 884543, 884544, 884545, 884546, 884547}	{}	{Junxiong Gao}	{Kindle Paperwhite, iPad Air, iPhone 11, MacBook Air, iPad mini, Echo Dot}	4087.99	3.011
pick item	2019/12/26 16:22:04	{991241}	{884882}	{}	{Lisa Mannel}	{iPhone 8}	529.0	0.21
create package	2019/12/26 16:22:04	{991263, 99162}	{884967, 884964, 884966}	{660799}	{Luis Santos}	{iPad Air, iPhone 8, iPad}	1500.0	1.133

event = activity + timestamp + objects + attributes

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	2020-6-20	{99001} 1	{88001, 88002} 2	{ } 0
...	...	...	...	...

- 1 one event if order is used as a case notion
- 2 two events if item is used as a case notion
- 0 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 items	2020-6-22	{99001}	{88001}	{}
pick item	2022-6-23	{99001}	{88002}	{}
...	...	...	...	...
send package	2020-6-25	{99001, 99002}	{88002, 88003, 88004}	{66001}
...	...		...	...

Events may be duplicated

activity	time	orders	items	packages
...	...		...	...
place order	2020-6-20	99001	{88001, 88002}	{}
pick item	2022-6-22	99001	{88001}	{}
pick item	2022-6-23	99001	{88002}	{}
...	...		...	...
send package	2020-6-25	99001	{88002, 88003, 88004}	{66001}
send package	2020-6-25	99002	88002, 88003, 88004}	{66001}
...	...		...	...

Item as a case notion

activity	time	orders	items	packages
...	...	...	...	...
place order	2020-6-20	{99001}	{88001, 88002}	{}
pick items	2020-6-22	{99001}	{88001}	{}
pick item	2022-6-23	{99001}	{88002}	{}
...	...	...	...	...
send package	2020-6-25	{99001, 99002}	{88002, 88003, 88004}	{66001}
...	...	...	...	...

Events may be duplicated

case

activity	time	orders	items	packages
...	...	...	...	...
place order	2020-6-20	{99001}	88001	{}
place order	2020-6-20	{99001}	88002	{}
pick item	2022-6-22	{99001}	88001	{}
pick item	2022-6-23	{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}
...	...	...	...	...

Package as a case notion

activity	time	orders	items	packages
...	...	...	...	...
place order	2020-6-20	{99001}	{88001, 88002}	{}
pick items	2020-6-22	{99001}	{88001}	{}
pick item	2022-6-23	{99001}	{88002}	{}
...	...	...	...	...
send package	2020-6-25	{99001, 99002}	{88002, 88003, 88004}	{66001}
...	...	...	...	...

case

activity	time	orders	items	packages
...	...	...	...	...
send package	2020-6-25	99002	88002	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.

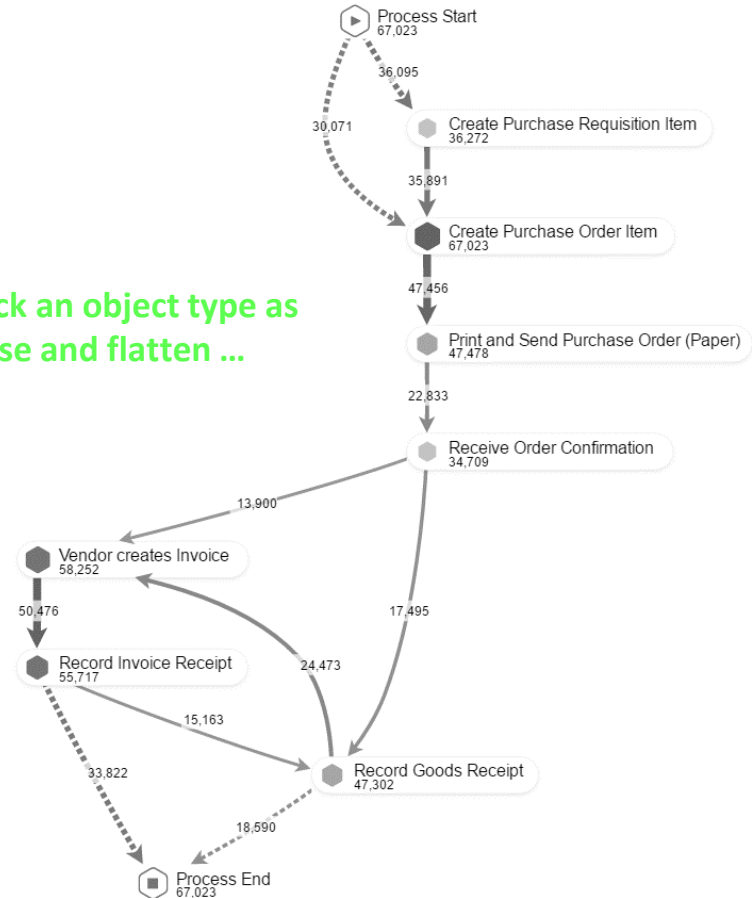
Convergence

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

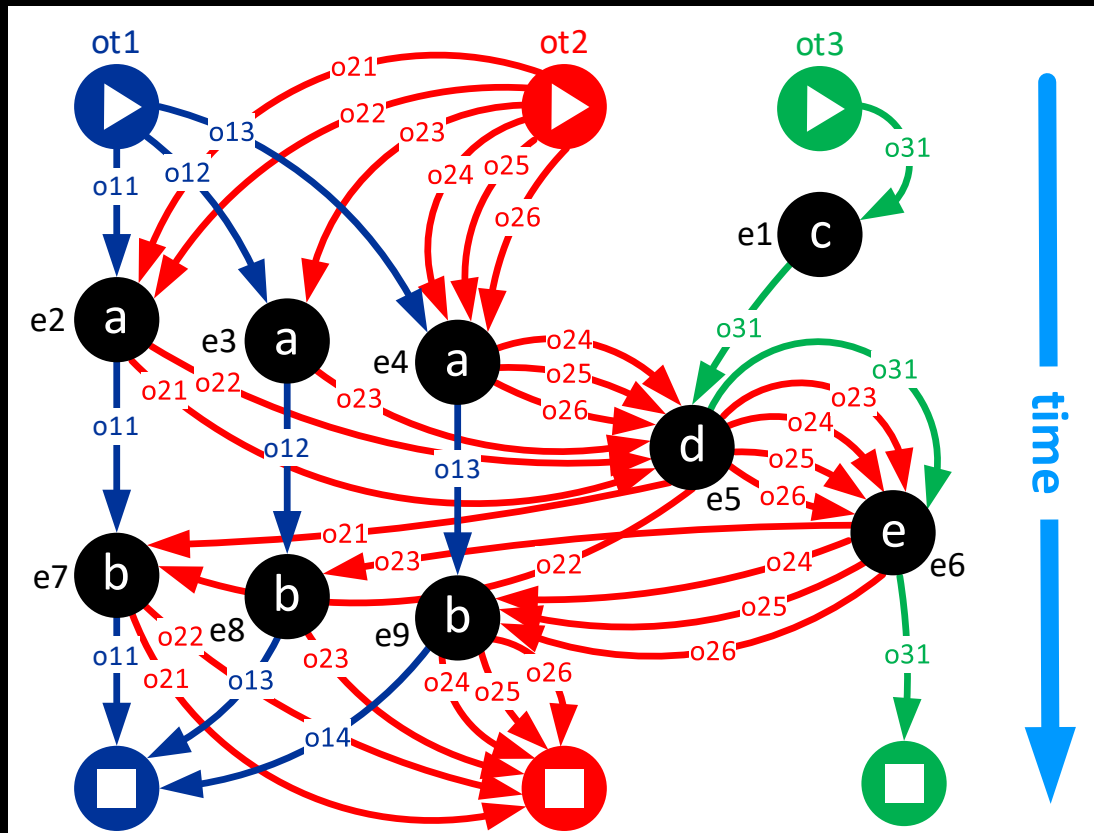
Divergence

Two events referring to two **different objects** of a type not selected as the case notion may be considered to be **causally related** but are not.

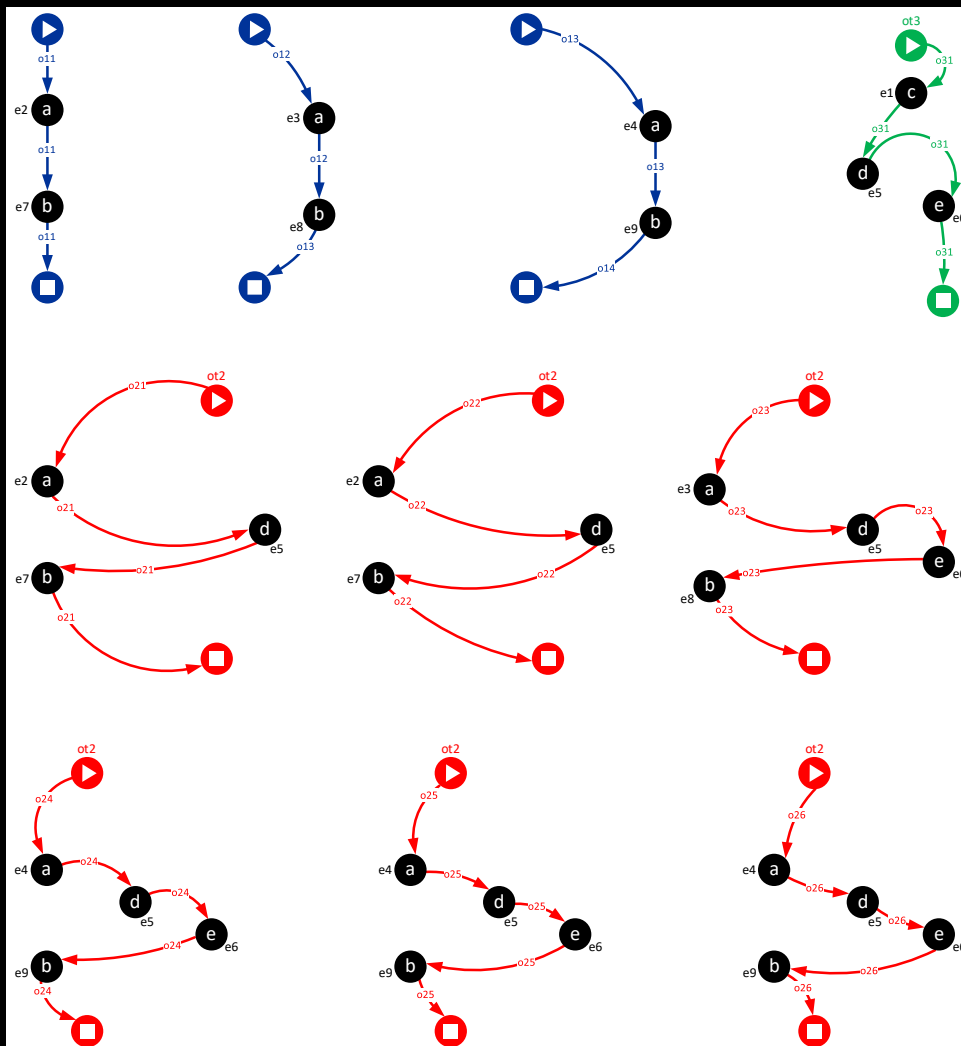
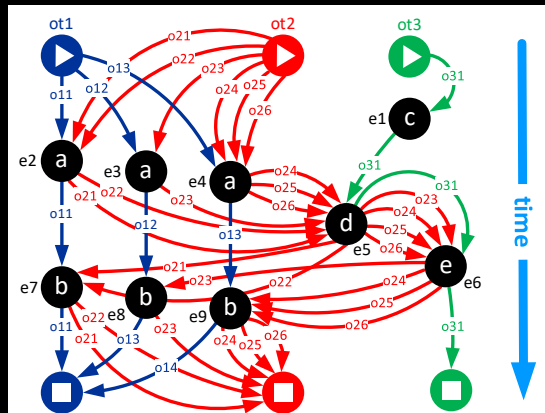
Pick an object type as case and flatten ...



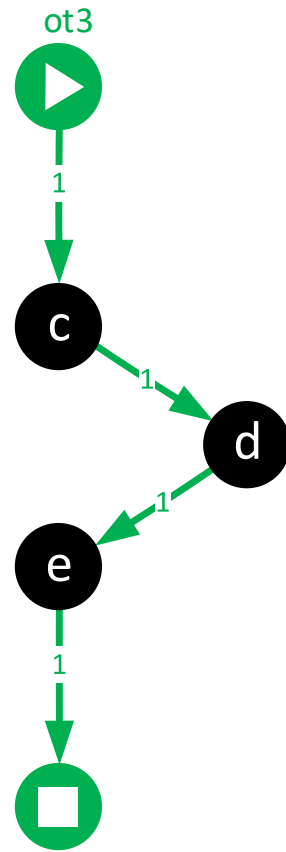
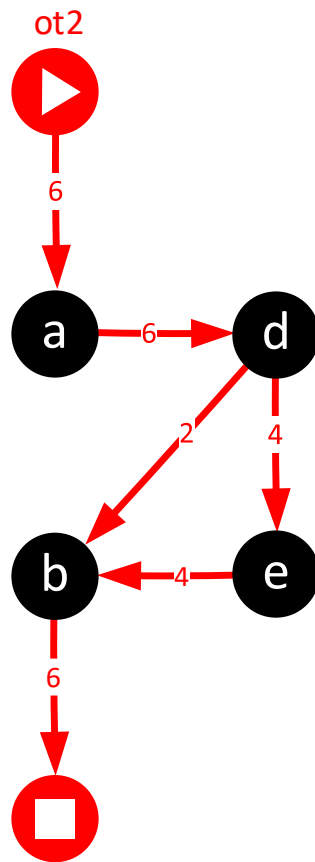
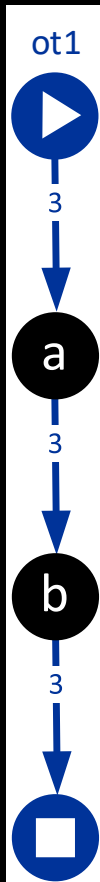
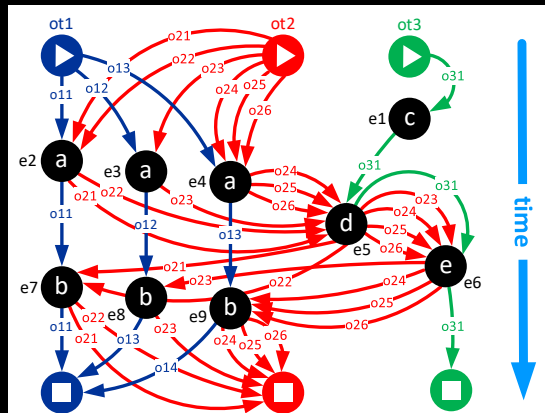
Visualizing objects and events



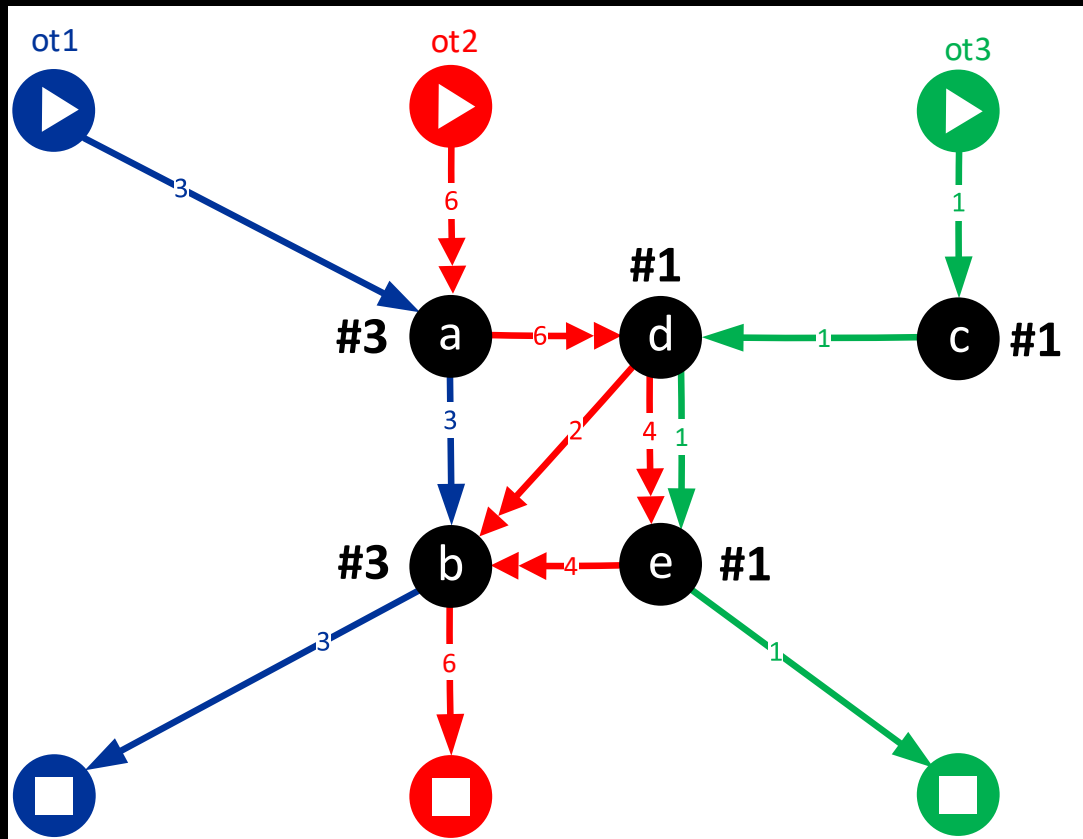
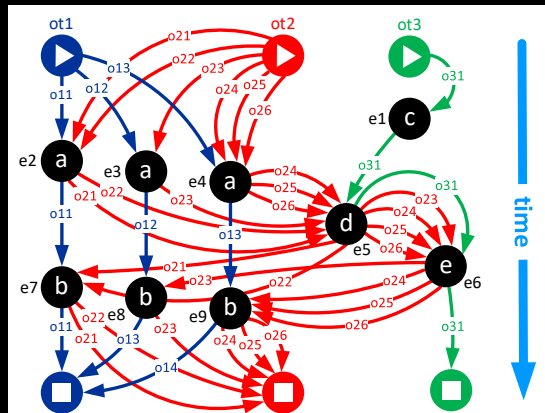
Object flows



Three DFGs



Multi-Object DFG



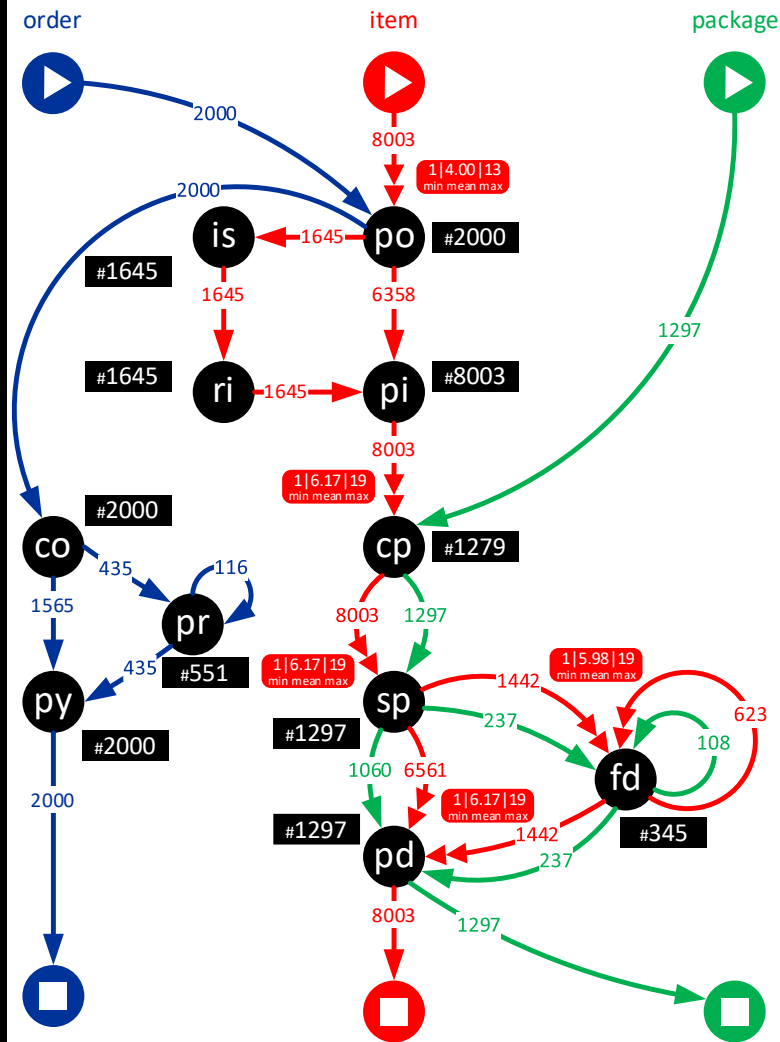
Bigger example

Object types:

- 2000 orders
- 8003 items
- 1297 packages

Activities:

- co = confirm order
- cp = create package
- fd = failed delivery
- is = item out of stock
- pd = package delivered
- po = place order
- pr = payment reminder
- pi = pick item
- py = pay order
- ri = reorder item
- sp = send package



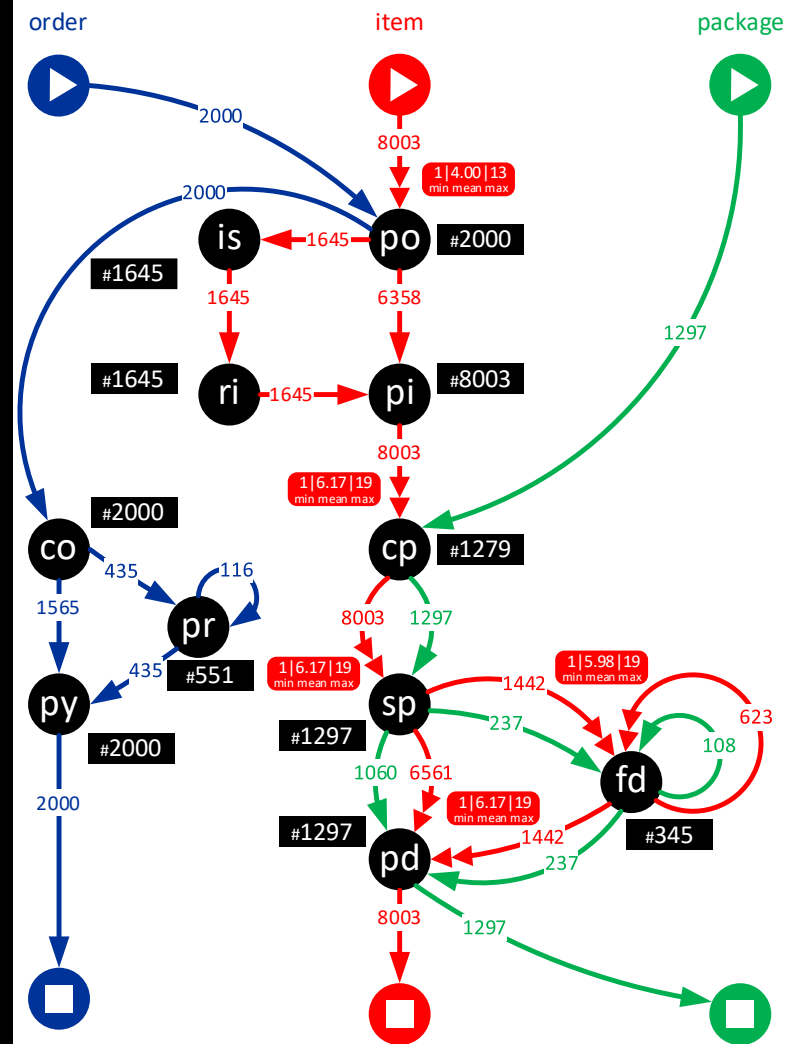
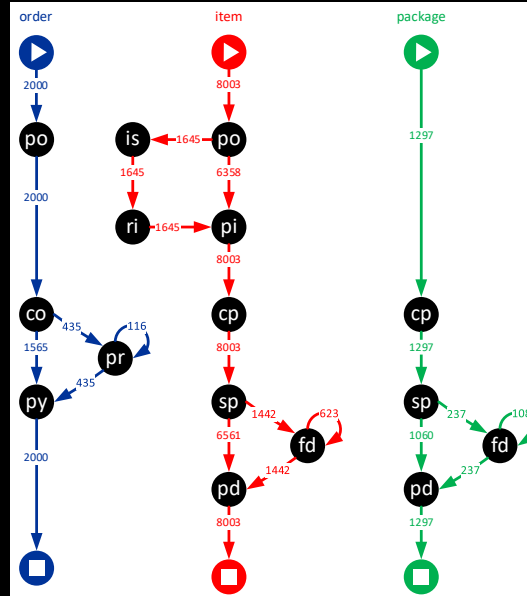
Bigger example

Object types:

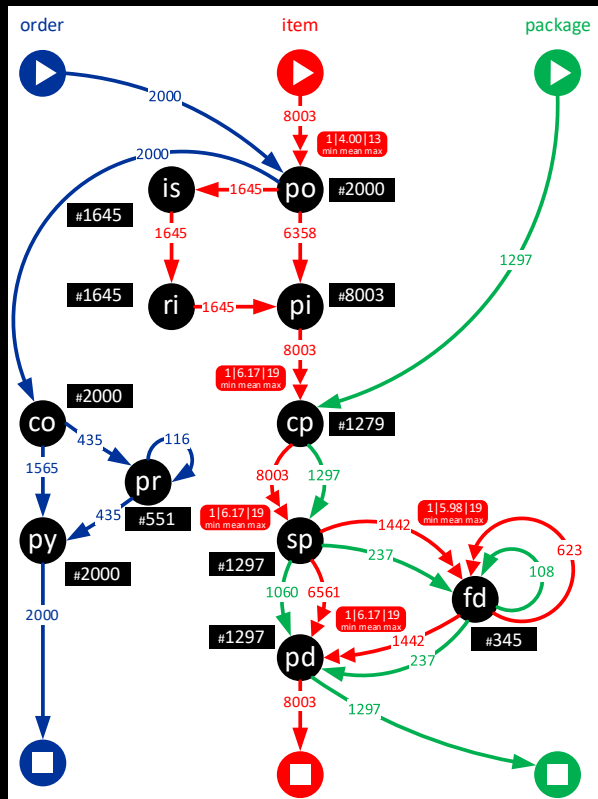
- 2000 orders
- 8003 items
- 1297 packages

Activities:

- co = confirm order
- cp = create package
- fd = failed delivery
- is = item out of stock
- pd = package delivered
- po = place order
- pr = payment reminder
- pi = pick item
- py = pay order
- ri = reorder item
- sp = send package



More Sophisticated Solutions



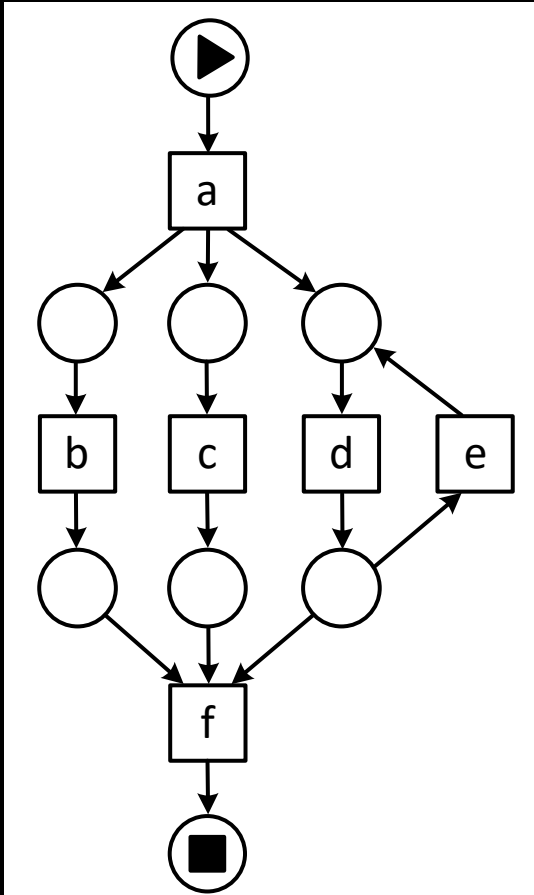
- Store data without limiting yourself to a single view.
- Check out the **Object-Centric Event Log (OCEL)** standard: ocel-standard.org
- Read up on research on **Object-Centric Process Mining**: vdaalst.com
- Check out our software @PADS
- Check out the **Multi-Event Log (MEL)** solution in the current **Celonis EMS**.



Object-Centric Accepting Petri Nets

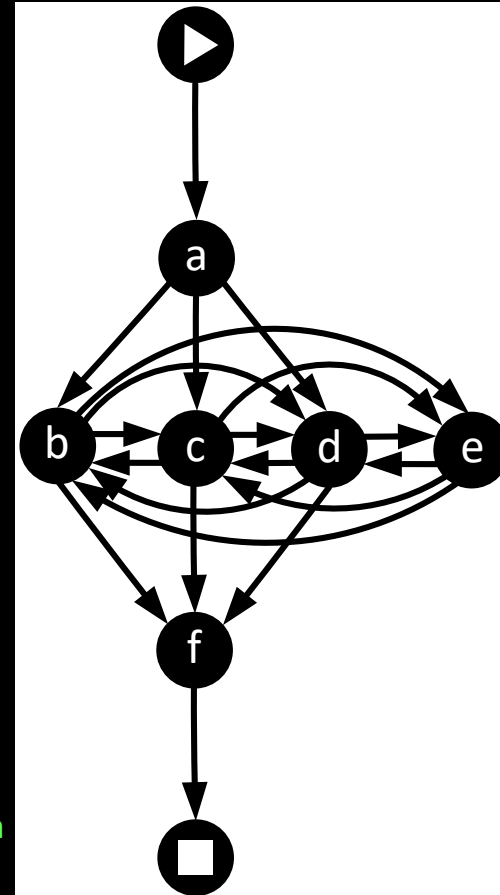
- **Directly-Follows Graphs** (DFGs) are simple but also very **problematic**.
- If two activities **a** and **b** occur as $\langle \dots, a, b, \dots \rangle$ and $\langle \dots, b, a, \dots \rangle$, there will be a loop.
- DFGs are **too low level**.
- People model in languages such as **BPMN** (Business Process Model and Notation, an OMG standard) which are **Petri nets in disguise** 😊 Process mining need to use such notations also.
- All ideas discussed **can be lifted to Petri nets and BPMN!**

Compare the following two models



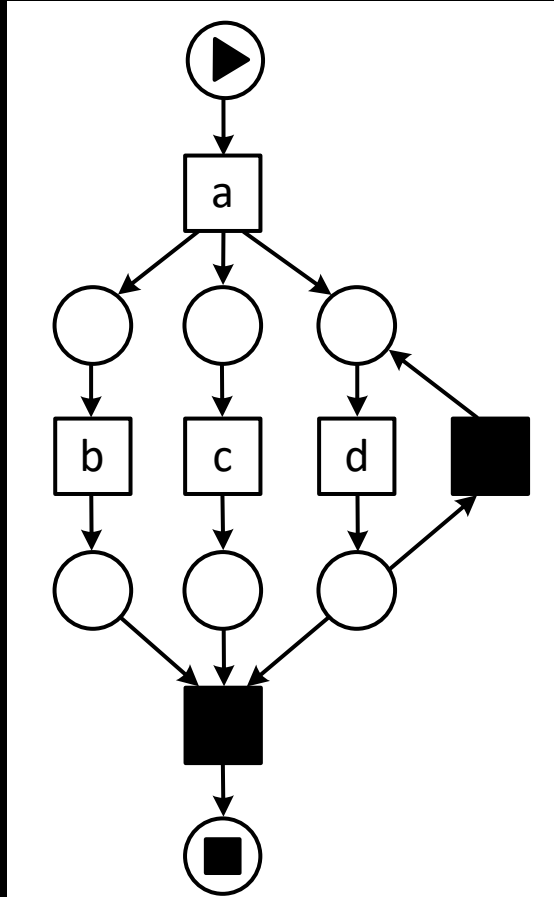
<a,b,c,d,f>
<a,c,b,d,f>
<a,b,d,e,d,e,d,c,f>
<a,b,d,c,f>
<a,c,d,e,d,b,f>
<a,d,e,b,d,c,f>
<a,d,e,d,c,b,f>
<a,c,d,b,f>
<a,d,b,c,f>
<a,c,b,d,e,d,f>
<a,d,c,b,f>
<a,b,c,d,e,d,f>
<a,b,d,e,c,d,f>
...

- starts with a and ends with f
- b, c and the loop involving d and e are in parallel.



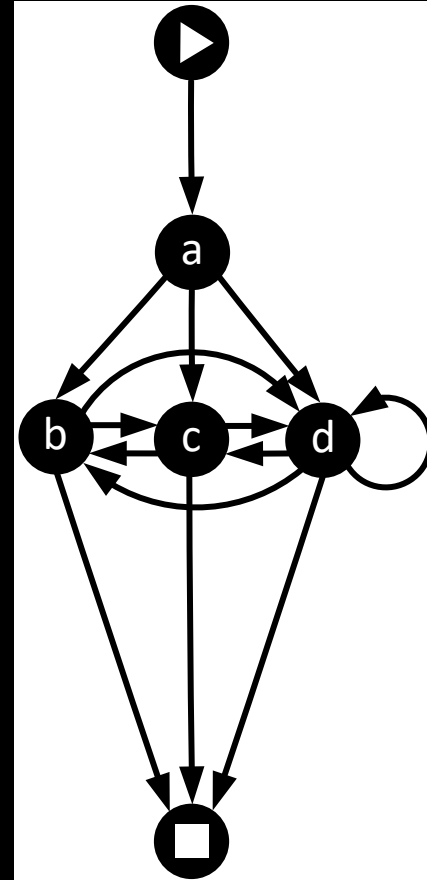
- The DFG is unable to express this.
- Many loops are added.

Compare the following two models



<a,b,c,d>
 <a,c,b,d>
 <a,b,d,e,d,d,c>
 <a,b,d,c>
 <a,c,d,d,b>
 <a,d,b,d,c>
 <a,d,d,c,b>
 <a,c,d,b>
 <a,d,b,c>
 <a,c,b,d,d>
 <a,d,c,b>
 <a,b,c,d,d>
 <a,b,d,c,d>
 ...

- b, c, and d can happen in any order.
- d can happen multiple times



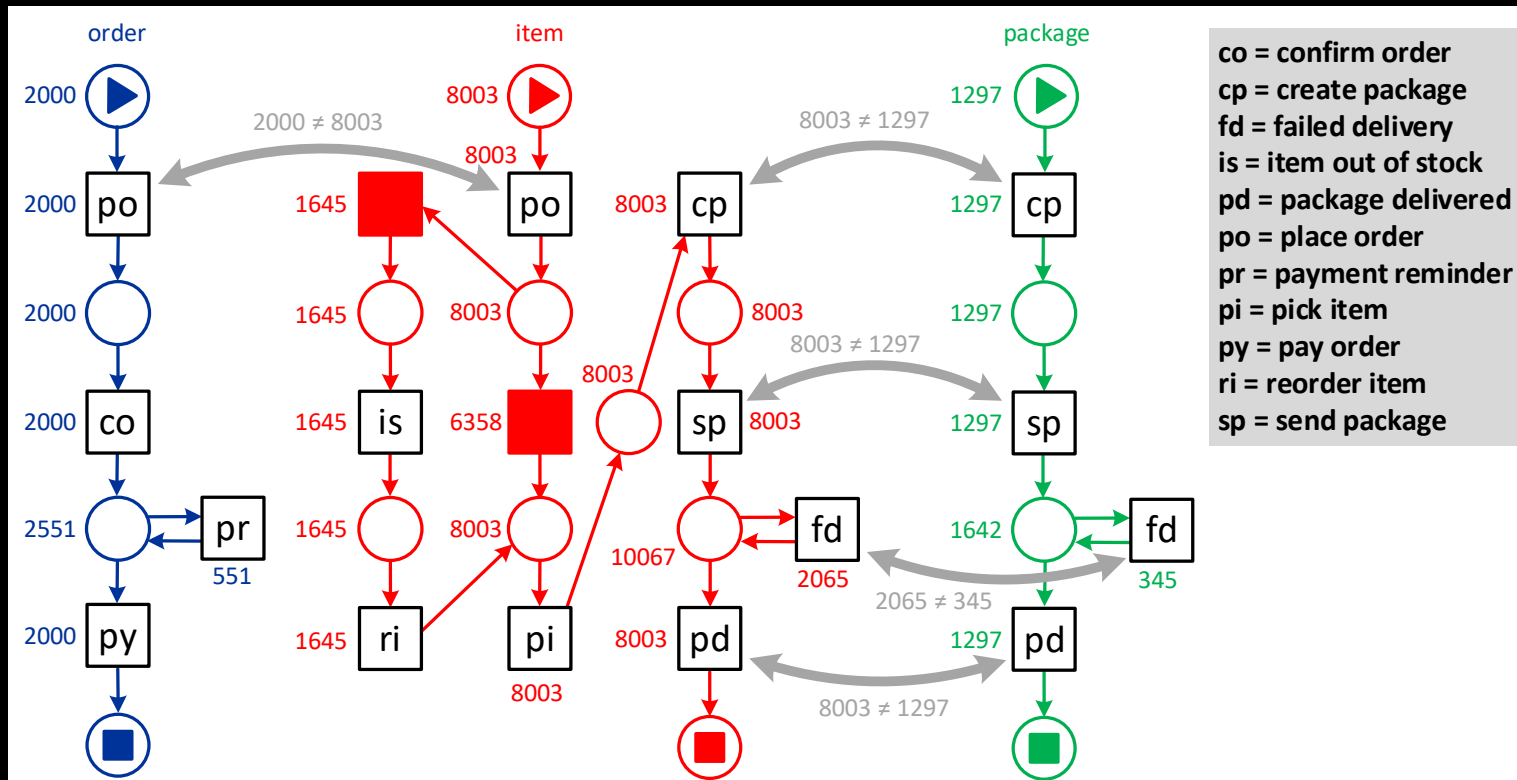
- b, c, and d can happen in any order.
- b, c, and d can be skipped.
- b, c, and d can all happen 0 or more times

Example of an Object-Centric Event Log

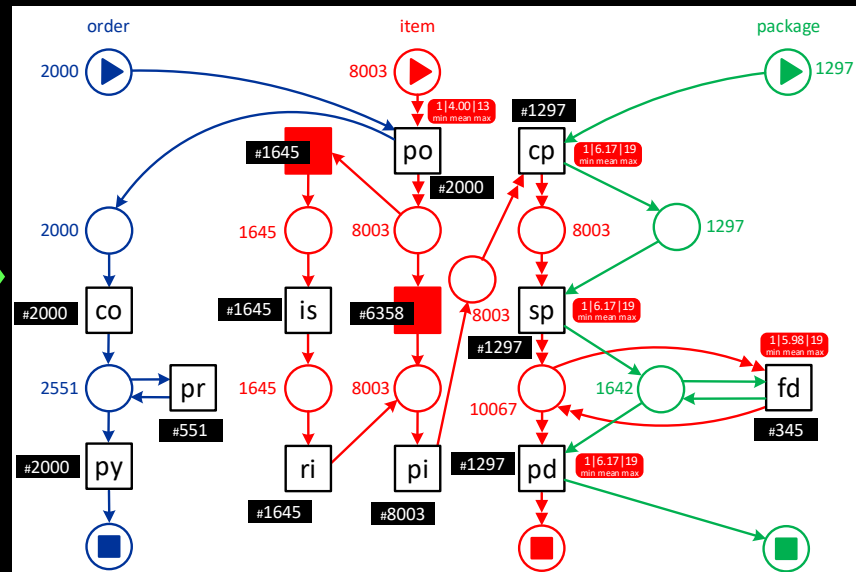
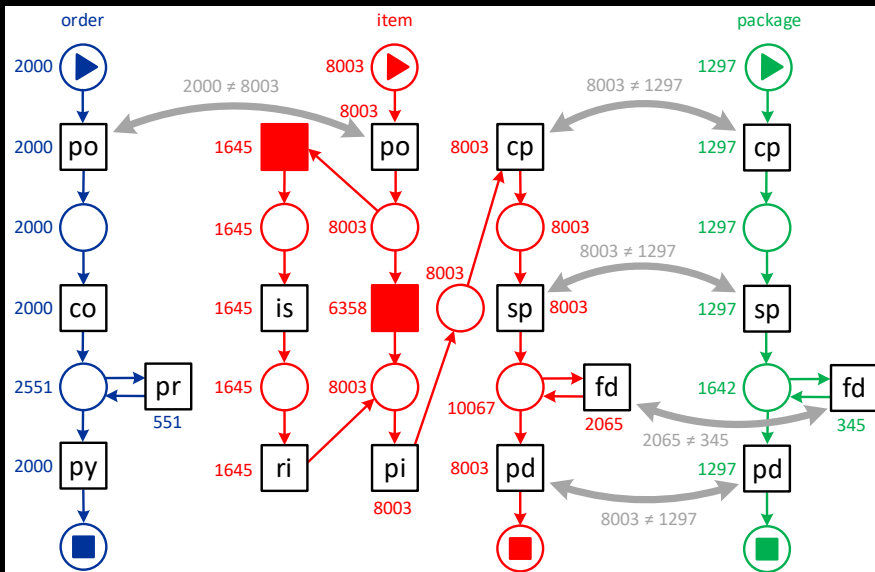
e_i	activity	time	orders	items	packages	price	weight
13226	pick item	2022-09-27 17:08:09	{}	{884875}	{}	€ 129,99	0,98
13227	item out of stock	2022-09-27 17:18:12	{}	{884873}	{}	€ 2.200,00	1,25
13228	pick item	2022-09-27 17:26:02	{}	{884872}	{}	€ 129,99	0,98
13229	pick item	2022-09-27 17:29:36	{}	{884939}	{}	€ 495,00	0,48
13230	create package	2022-09-27 17:29:36	{}	{884826,884790,884827,884824,884914,884913,884915,884916,884822}	{660768}	€ 10.231,99	5,81
13231	package delivered	2022-09-27 17:34:30	{}	{884828,884834,884830,884832,884829,884833}	{660763}	€ 1.924,96	3,15
13232	pick item	2022-09-27 17:40:24	{}	{884858}	{}	€ 129,99	0,98
13233	place order	2022-09-27 17:53:09	{991222}	{884950,884951,884952}	{}	€ 5.534,00	2,95
13234	pay order	2022-09-27 17:55:19	{991094}	{}	{}	€ 3.463,98	2,90
13235	send package	2022-09-27 19:05:09	{}	{884788,884904,884889,884902,884903,884886,884887,884885,884787}	{660767}	€ 9.117,97	7,17
13236	place order	2022-09-27 20:15:42	{991223}	{884953,884954,884955}	{}	€ 2.674,98	2,55
13237	pick item	2022-09-27 20:24:50	{}	{884923}	{}	€ 99,99	0,78
13238	send package	2022-09-27 21:47:44	{}	{884826,884790,884827,884824,884914,884913,884915,884916,884822}	{660768}	€ 10.231,99	5,81
13239	place order	2022-09-27 23:07:38	{991224}	{884956}	{}	€ 134,00	0,50
13240	confirm order	2022-09-28 08:54:07	{991223}	{}	{}	€ 2.674,98	2,55
13241	place order	2022-09-28 08:57:24	{991225}	{884957,884958,884959,884960,884961}	{}	€ 2.431,98	2,37
13242	pick item	2022-09-28 09:13:17	{}	{884905}	{}	€ 29,99	0,38
13243	pick item	2022-09-28 09:17:41	{}	{884817}	{}	€ 699,00	0,17
13244	pick item	2022-09-28 09:25:34	{}	{884851}	{}	€ 495,00	0,48

Small fragment of a larger object-centric event log with 22080 events and 11300 objects (200 orders, 8003 items, and 1297 packages).

Flatten the event log for each object type and learn the accepting Petri nets



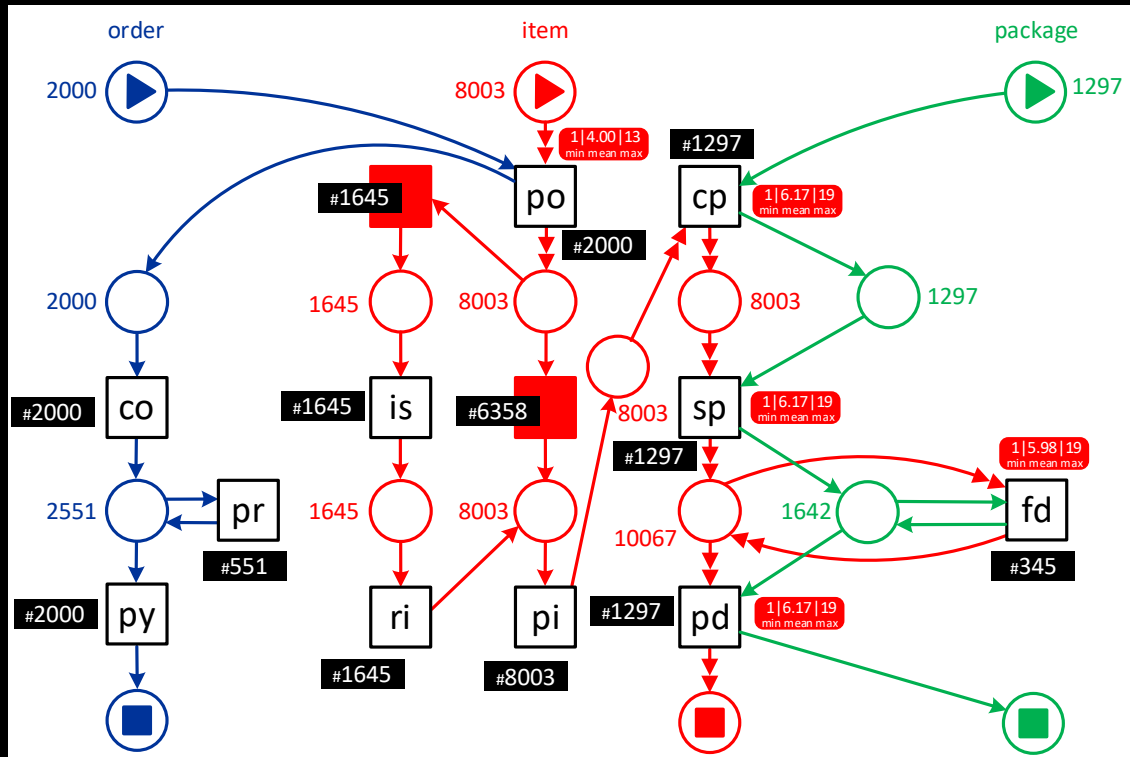
Fold the three accepting Petri nets into an Object-Centric Accepting Petri Net



co = confirm order
cp = create package
fd = failed delivery
is = item out of stock
pd = package delivered
po = place order

pr = payment reminder
pi = pick item
py = pay order
ri = reorder item
sp = send package

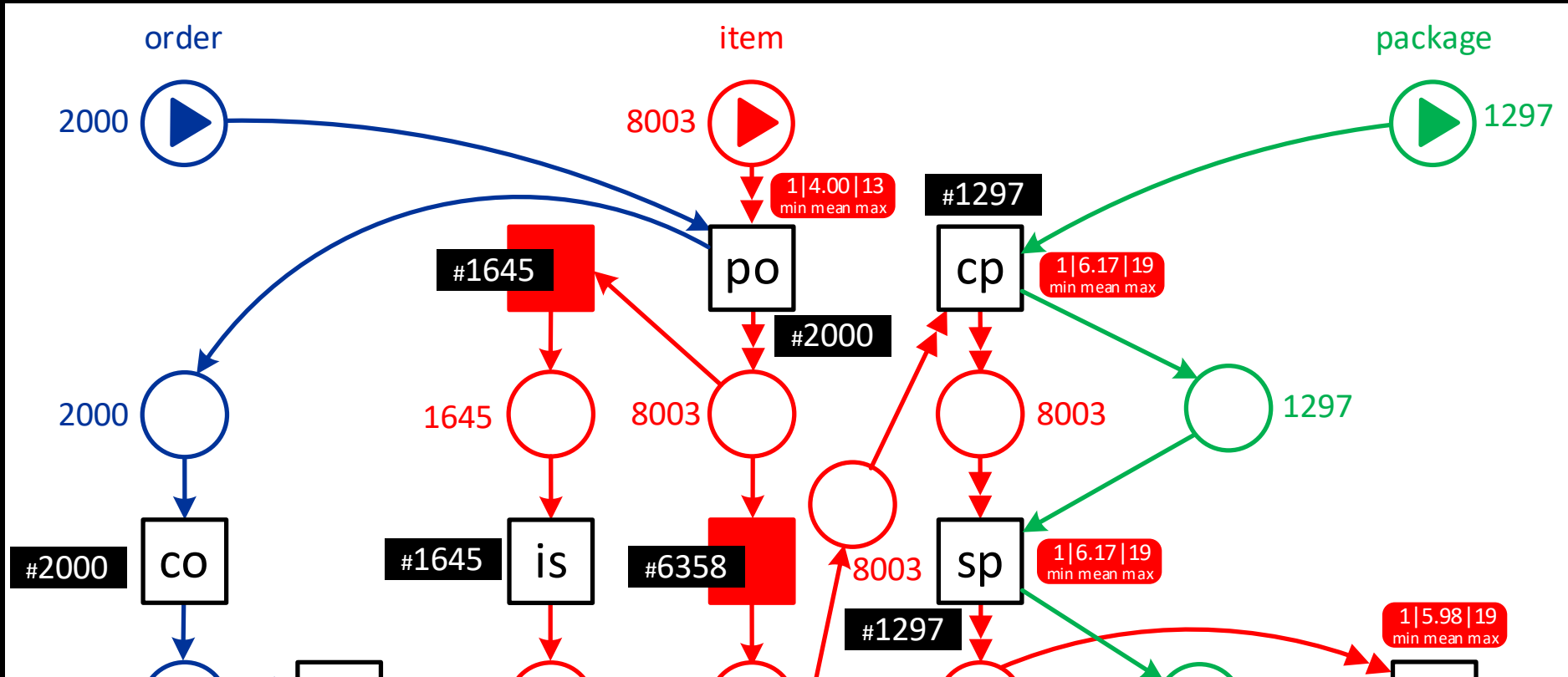
Fold the three accepting Petri nets into an Object-Centric Accepting Petri Net

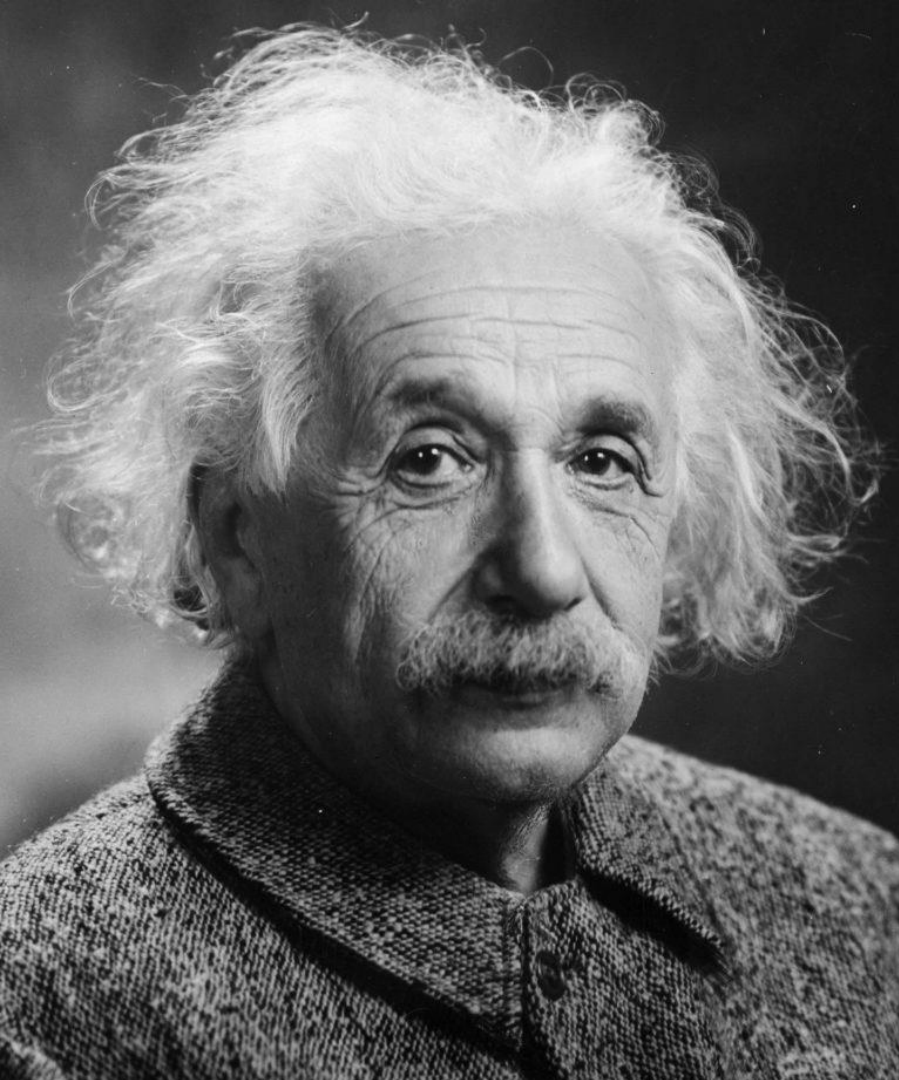


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Fold the three accepting Petri nets into an Object-Centric Accepting Petri Net

cp = create package
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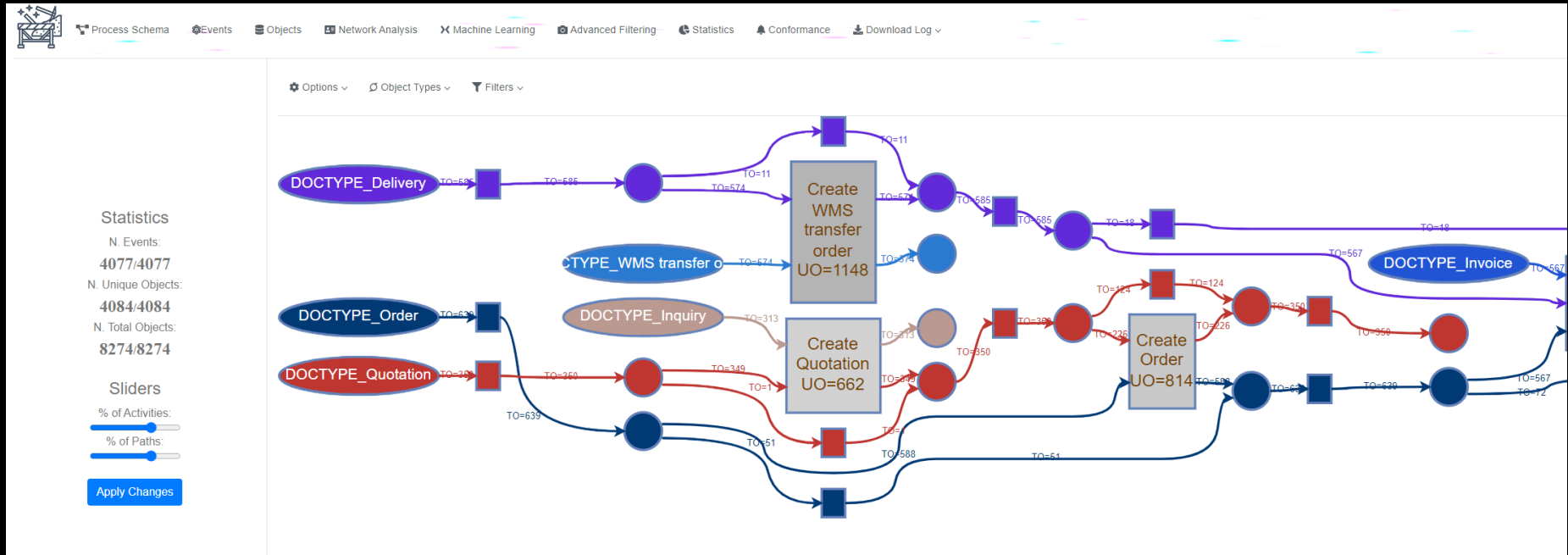




“Make as simple as possible, but not simpler!”

We are on a journey towards uncovering the true fabric of operational processes ...

Tooling @ PADS, e.g., www.ocpm.info



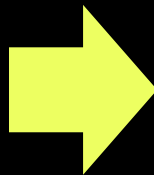
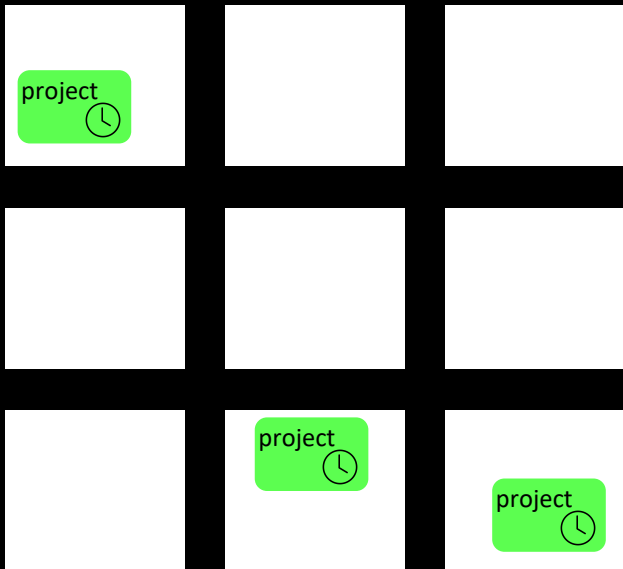
Alessandro Berti, Niklas Adams, Gyunam Park, Anahita Farhang, Benedikt Knopp, and many more.



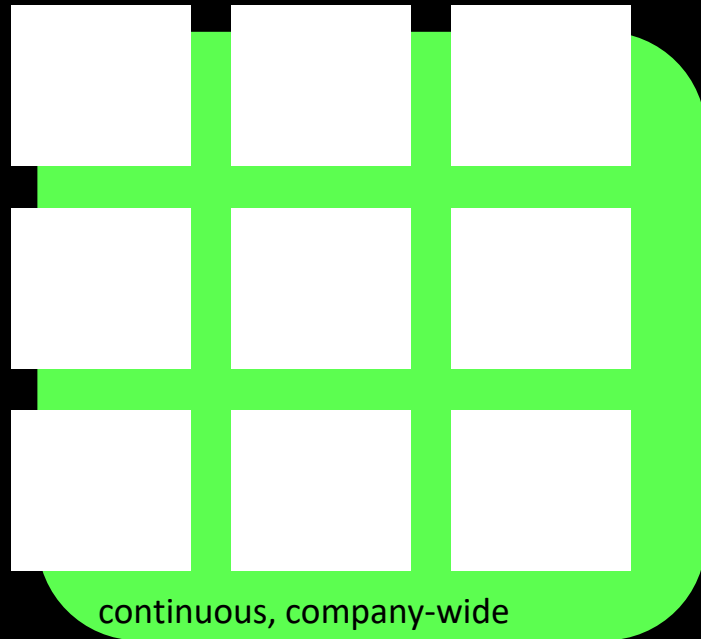
A few recommendations

Process mining is **not** a project, but should be used **continuously** and **company-wide** !

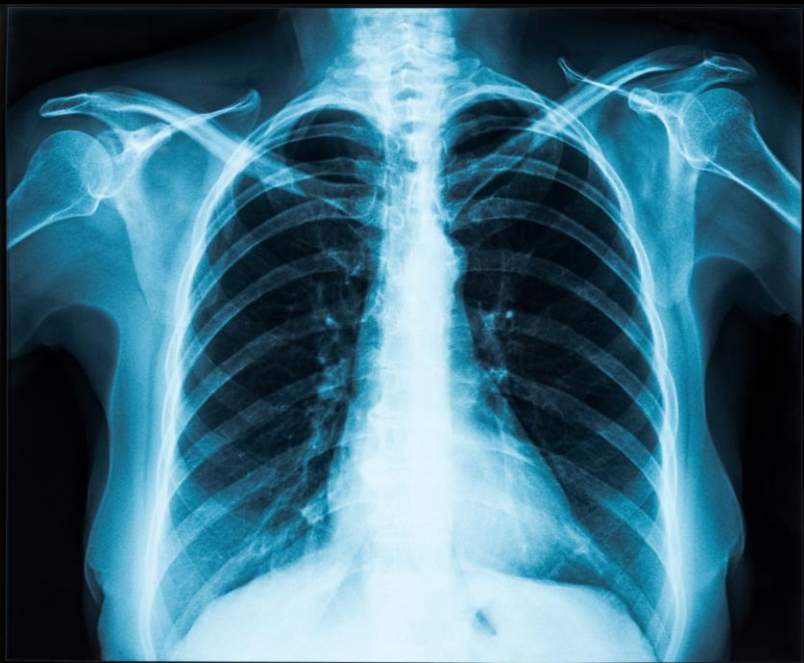
2010-2020



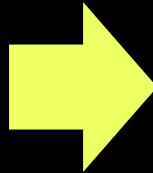
2020-2030



Do not forget:
The goal is to turn **insights** into **actions** !



insights



actions

Create a Process Mining Center of Expertise (CoE)



1. business/organizational
2. domain knowledge
3. systems knowledge
4. process mining expertise
5. data science skills

Process Mining needs scale!

No business case needed!



To Conclude ...

Amazing adoption, and we are just getting started



...



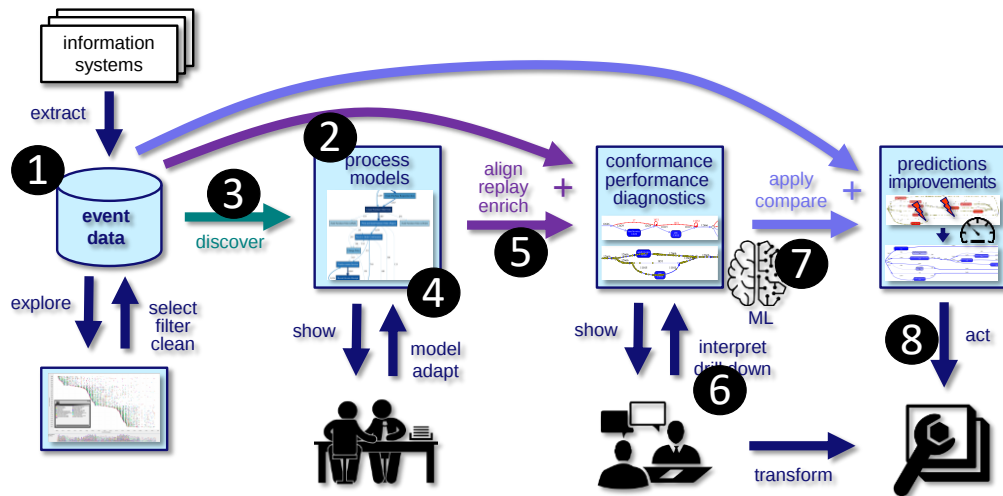
> 40 vendors, acquisitions by Microsoft, IBM, SAP, Appian, etc.

> 50% of Fortune 500 companies is already using process mining

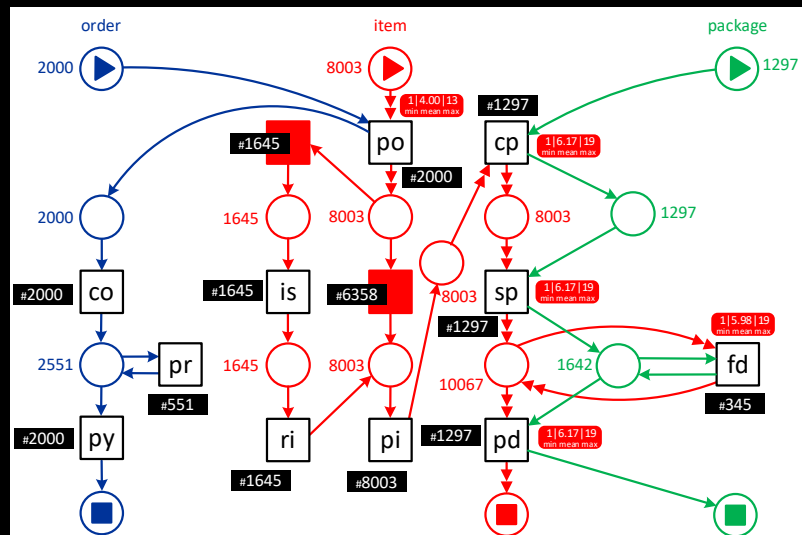
Compound Annual Growth Rate (CAGR)
of more than 50%



Process Mining: Many more challenges



- 1** Finding, extracting, and transforming event data is still taking up to 80% of the time.
- 2** Most techniques focus on a single case notion (i.e., a single process), whereas problems may be caused by interacting or competing processes.
- 3** Process discovery is not a solved problem despite powerful techniques like inductive mining. Concurrency is hard to discover from event data that provide only a sample.
- 4** There is a need to better integrate mining and modeling (e.g., user-guided discovery).
- 5** Conformance checking is time-consuming and diagnostics tend to be non-deterministic.
- 6** There is a need for techniques recommending process changes (i.e., moving beyond diagnostics).
- 7** Machine Learning (ML) techniques tend to perform poorly because essential aspects are missed (e.g., system load).
- 8** Process mining results need to trigger automated actions (e.g., start a corrective workflow).



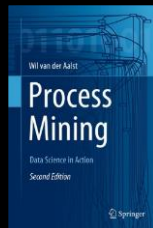
Learn More?

Visit www.processmining.org, www.celonis.com, www.vdaalst.com, read the “[process mining bible](#)”, and take one of the courses “[Process Mining: From Theory to Execution](#)” and “[Process Mining: Data Science in Action](#)”.



Process Mining: From Theory to Execution

Professor Wil van der Aalst pioneered the field of process mining in the 1990s, describing it as the missing link between data science and real-life processes. Enter an entirely new academic discipline, which has since become the industry standard for better business process execution. Learn about the science behind the technology and its real-life applications, including the way it's being used today by a large number of Fortune 500 companies, during this self-paced, virtual course.



Watch the trailer



<https://www.celonis.com/wils-process-mining-class/>