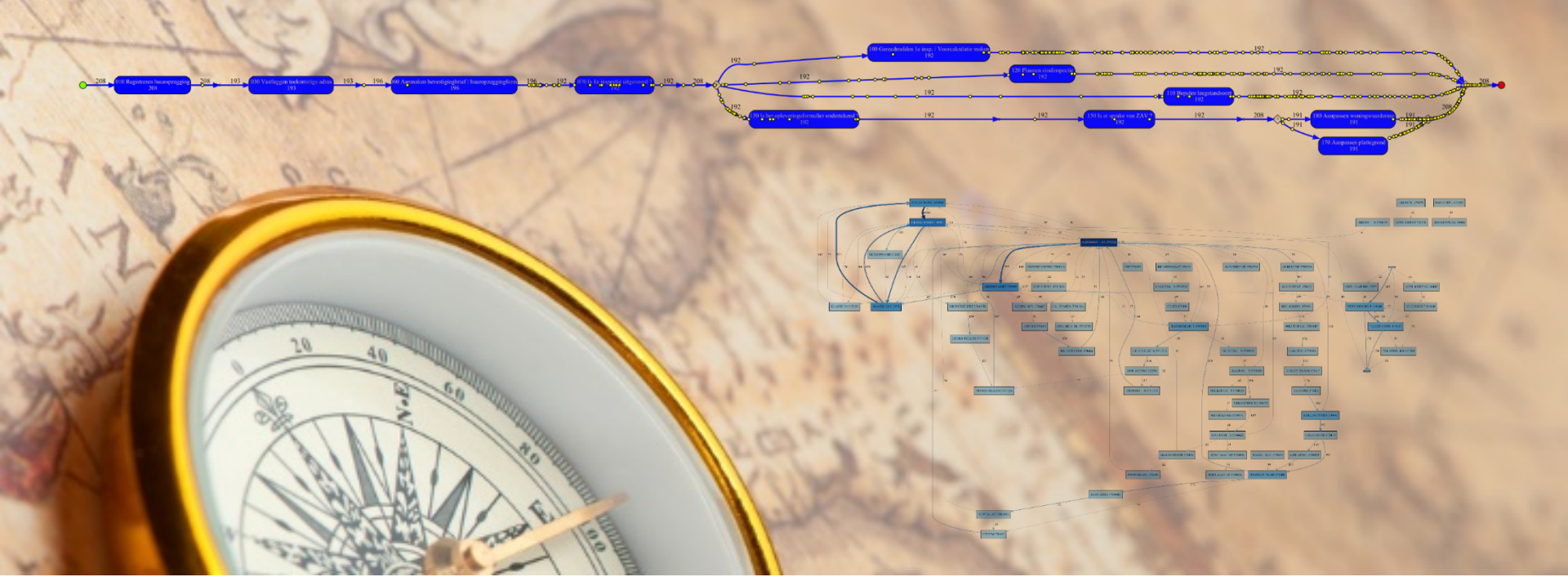


Unlock Your Event Data!

Remove Operational Friction Using Process Mining

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

Fraunhofer FIT

celonis

Chair of Process and Data Science

RWTH AACHEN UNIVERSITY

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

A few words about Wil van der Aalst

With Anja Karliczek, German Minister of Education and Research

Chair of Process and Data Science

About Wil

- Approx. 22 PhDs and postdocs (next to me).
- 3 support staff and approx. 4 affiliated researchers)
- Tools: ProM, PM4Py, Stand-alone (e.g.,Cortado), Knime, RapidMiner, Celonis.

discovering models from event data	discovery	object-centric	object-centric process mining, multi-event logs, etc.
conformance checking and comparative process mining	conf./comp.	stoch./uncert.	stochastic process models, dealing with uncertainty in data
forward looking: prediction and simulation	pred./sim.	aggr./abstr.	multi-level process mining, abstraction, aggregation, LPMs, etc.
action-oriented process mining, planning, automated changes	act./plan./cha.	fairn./conf.	responsible data science, including fairness, causality, confidentiality

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

RWTH Center for Artificial Intelligence

www.ai.rwth-aachen.de

- **75+ groups distributed over:**
  - AI Methods
  - AI Enabling Technologies
  - Domain Specific AI
  - Ethical, Legal, Societal, and Economic Aspects
- **Activities:**
  - Larger consortium projects (e.g., NHR4CES)
  - Participation in networks (e.g., Claire)
  - Organization of events (e.g., KI Woche)
  - Several colloquium series
  - Developing teaching material
  - Industry collaboration

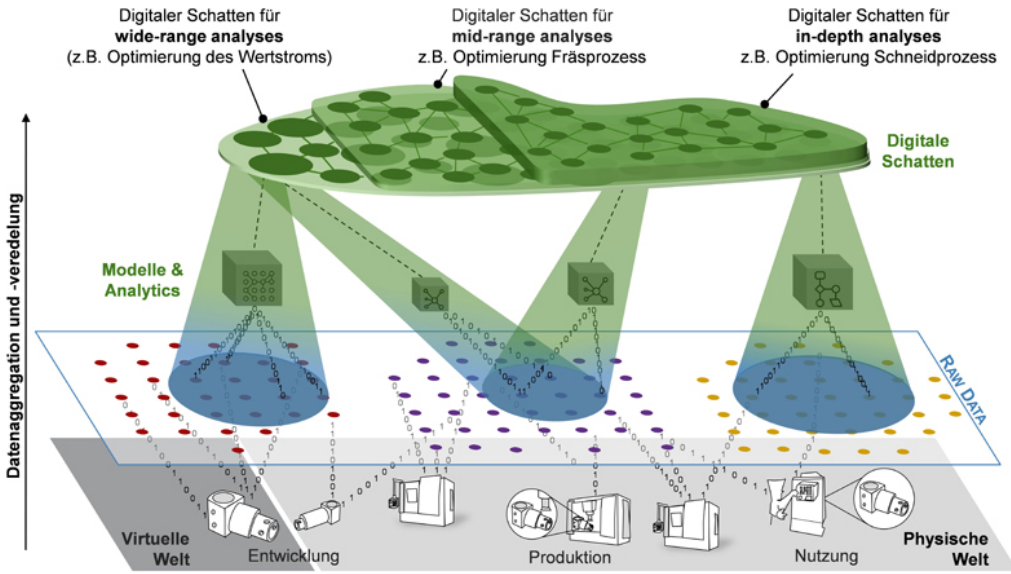
Center for Artificial Intelligence | RWTH AACHEN UNIVERSITY

Chair of Process and Data Science

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

Internet of Production (IoP)

Cluster of Excellence (€50 mil.)



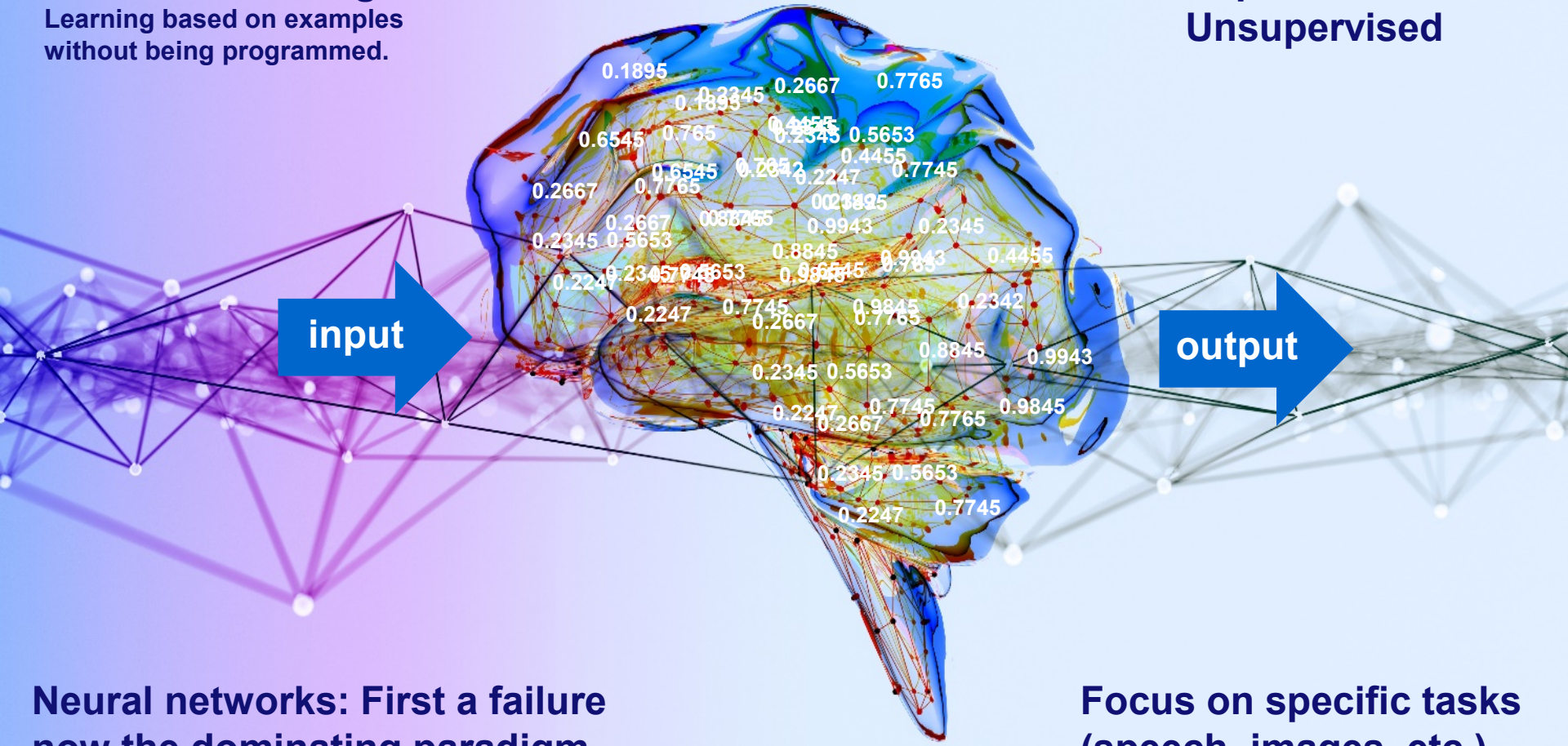
INTERNET OF PRODUCTION | RWTH AACHEN UNIVERSITY

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

Machine Learning =

Learning based on examples without being programmed.

Supervised and Unsupervised



Neural networks: First a failure now the dominating paradigm

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

How about managing and improving operational processes?

We need process models that are understandable!

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

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

Chair of Process and Data Science

RWTH AACHEN UNIVERSITY

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

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

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

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 6s 64 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 S6 32 GB	543.99 €	3	NL-7833HT-15
6347	send invoice	Jack	2018/02/13 15:57:42.000	SAMSUNG Galaxy S4	329,00 €	3	NL-7905AX-38
6351	place order	Zoe	2018/02/13 16:17:37.000	APPLE iPhone 5s 16 GB	449,00 €	3	NL-9521GC-32
6204	prepare delivery	Sophia	2018/02/13 16:31:28.000	SAMSUNG Galaxy S6 32 GB	543.99 €	1	NL-7828AM-11a
6204	make delivery	Kaylee	2018/02/13 16:51:54.000	SAMSUNG Galaxy S6 32 GB	543.99 €	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 = case + activity + timestamp + ...

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

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

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

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

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

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

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

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

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

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

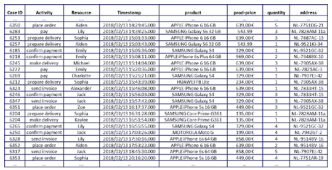
Order 6352

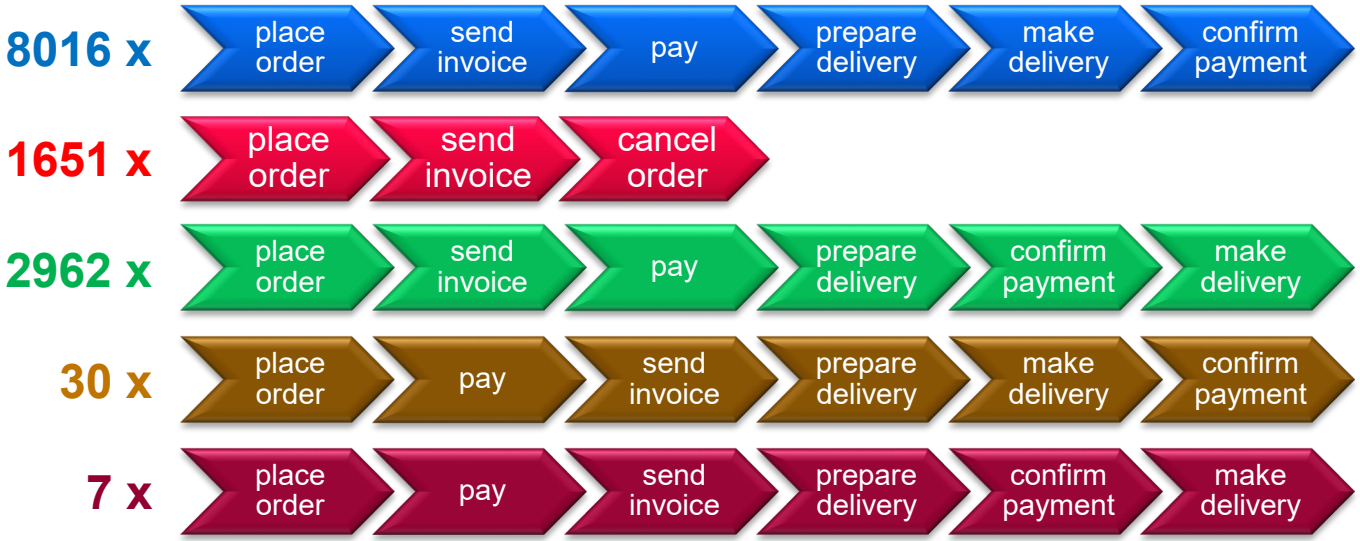
© Wil van der Aalst (use only with permission & acknowledgments)

Chair of Process and Data Science

Let’s look at the whole event log again

71,043 events
12,666 cases
7 activities





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

Chair of Process and Data Science

Using the whole event log

8016 x place order → send invoice → pay → prepare delivery → make delivery → confirm payment

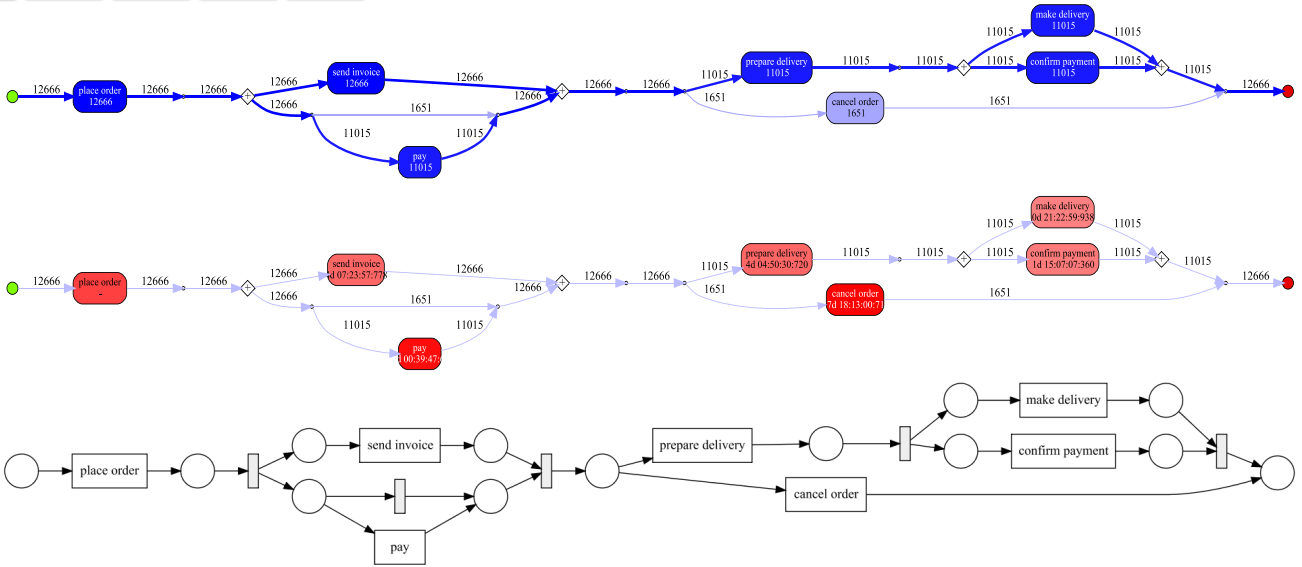
1651 x place order → send invoice → cancel order

2962 x place order → send invoice → pay → prepare delivery → confirm payment → make delivery

30 x place order → pay → send invoice → prepare delivery → make delivery → confirm payment

7 x place order → pay → send invoice → prepare delivery → confirm payment → make delivery

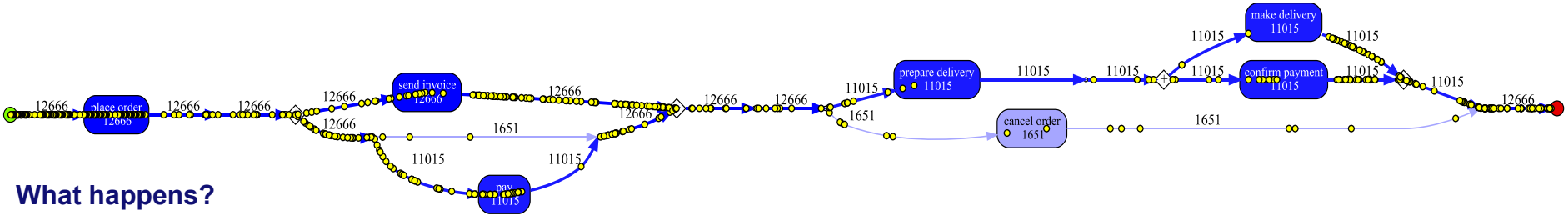
No modeling needed!



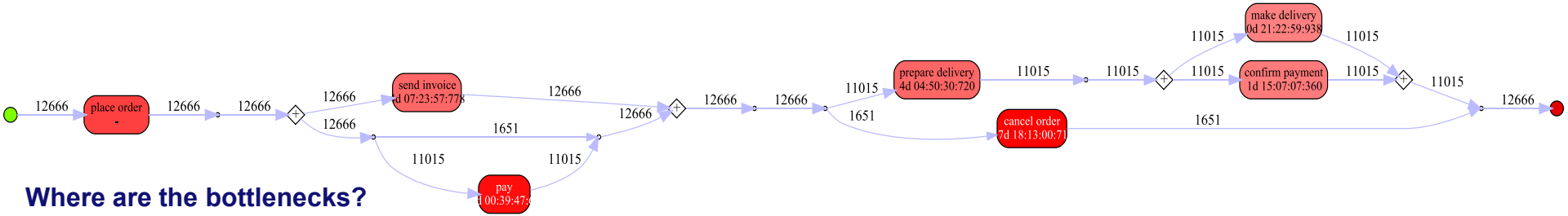
© Wil van der Aalst (use only with permission & acknowledgments)

Chair of Process and Data Science

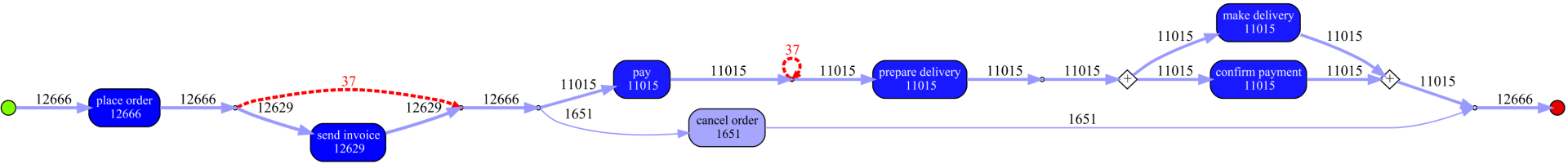
Performance and Compliance



What happens?



Where are the bottlenecks?

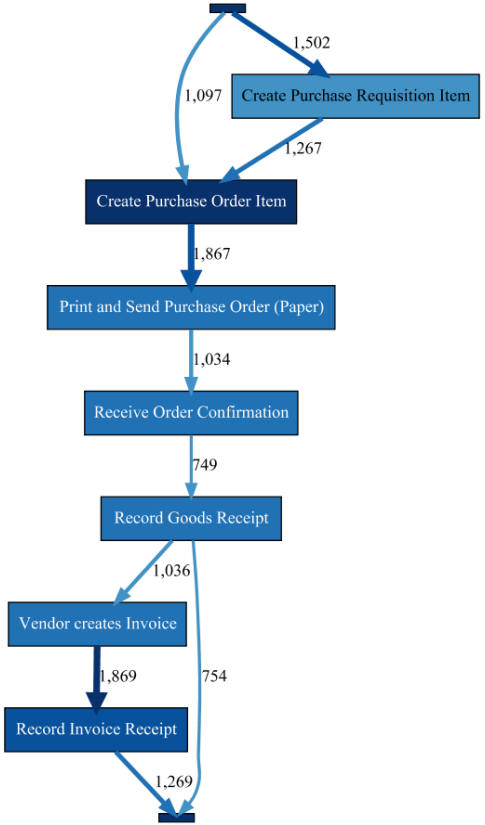


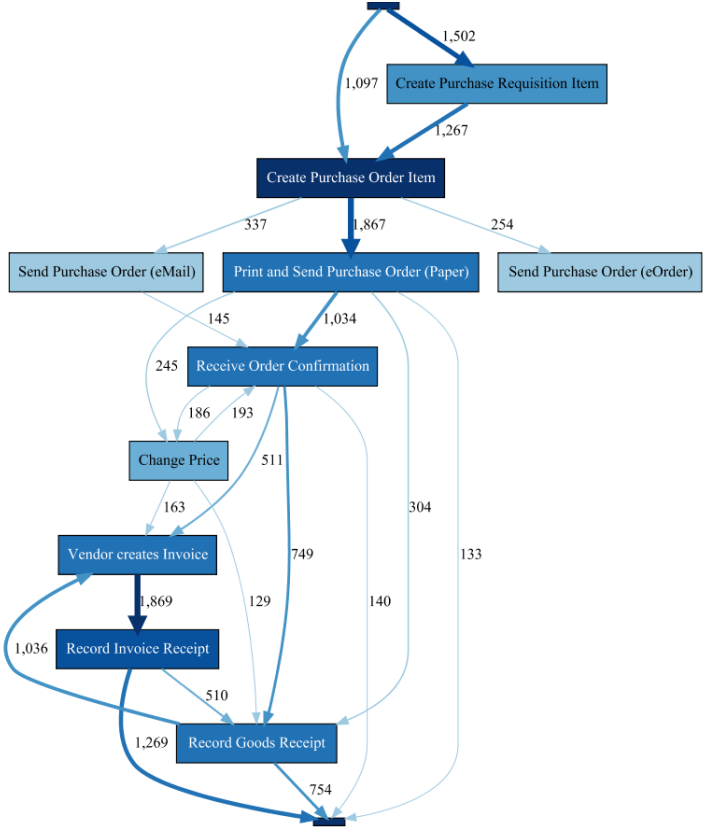
Where do we deviate from the happy path?

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

Chair of Process and Data Science

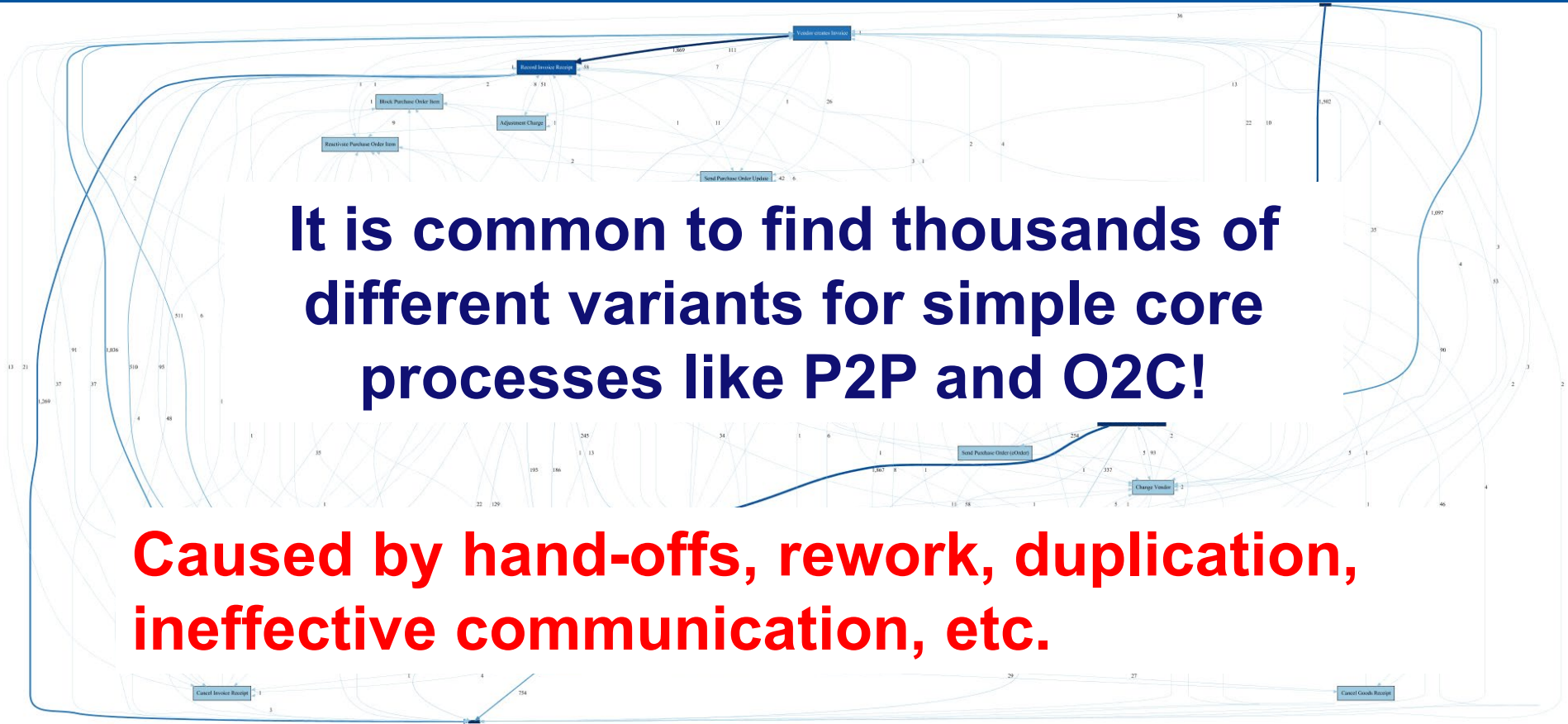
Reality is not so simple





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

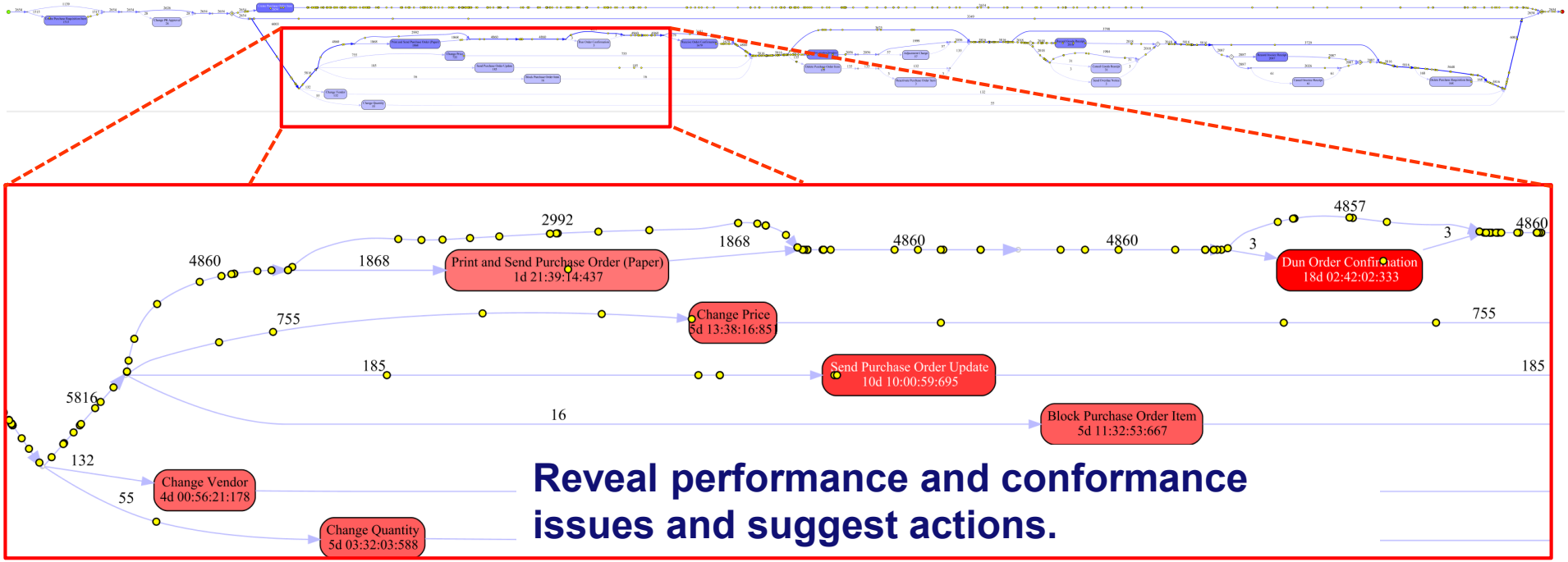
Reality is not so simple



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.

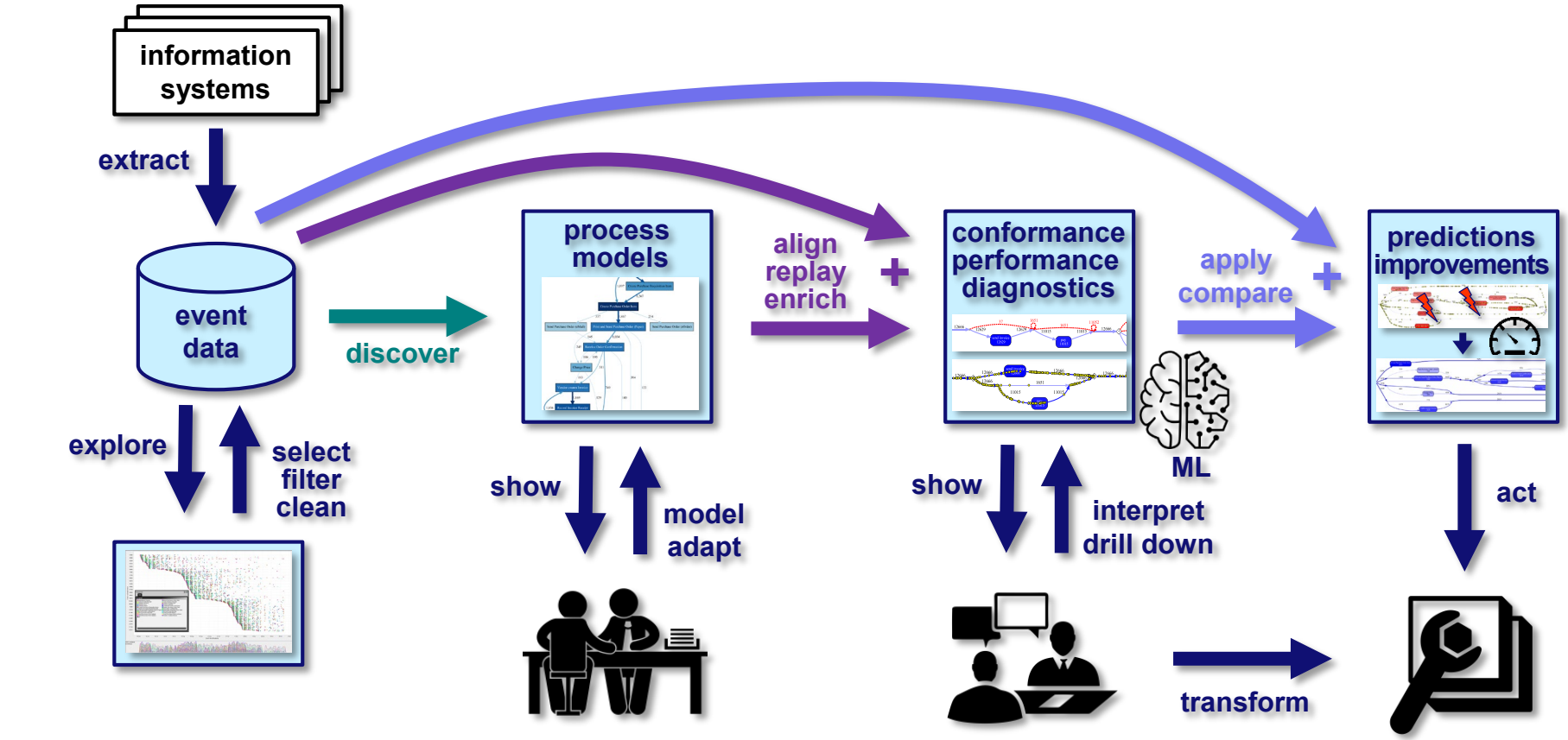
Process mining helps organizations to address compliance and performance problems



Reveal performance and conformance issues and suggest actions.

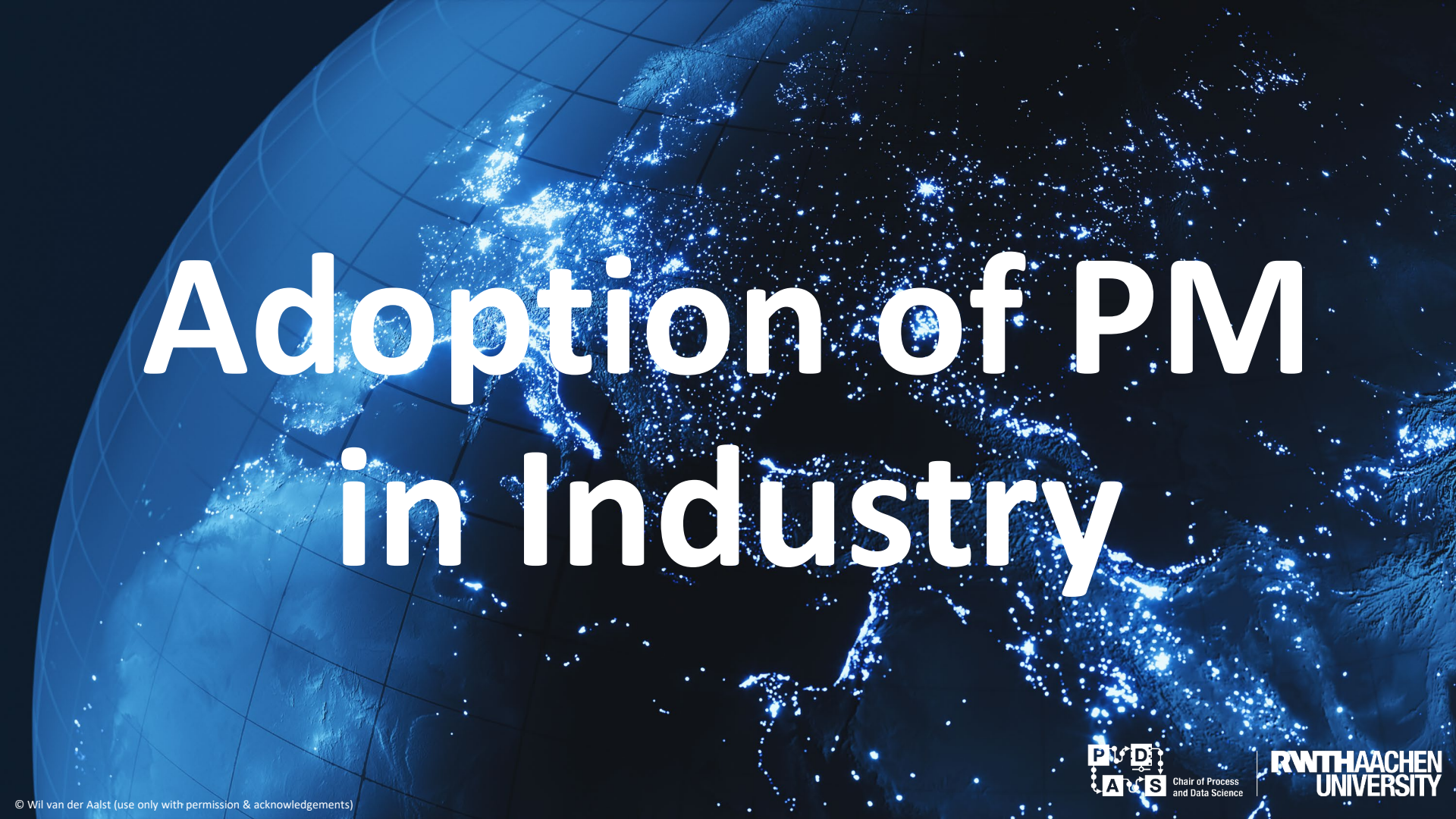
© Wil van der Aalst (use only with permission & acknowledgments)

Chair of Process and Data Science



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

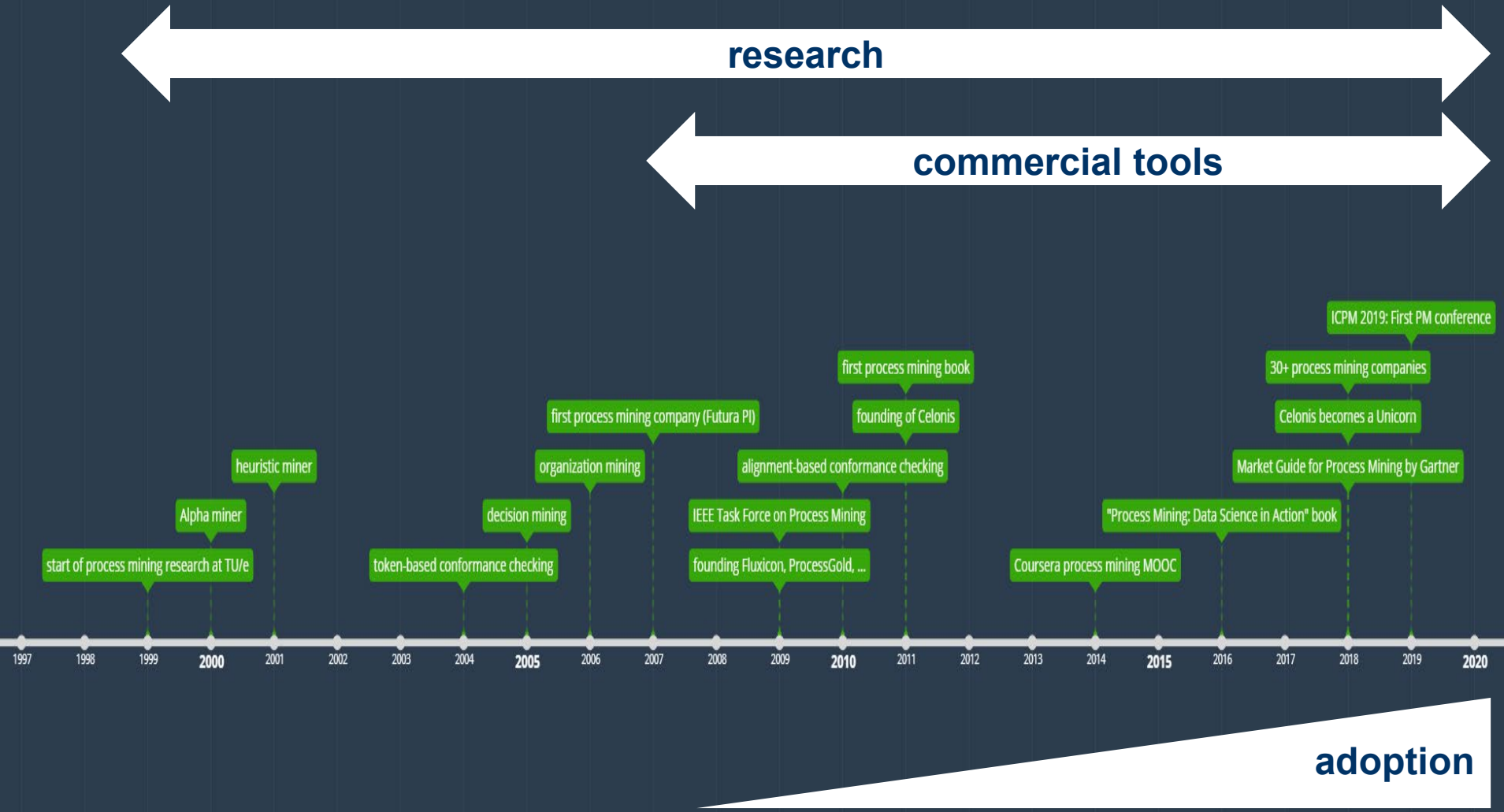
Chair of Process and Data Science



Chair of Process and Data Science

RWTH AACHEN UNIVERSITY

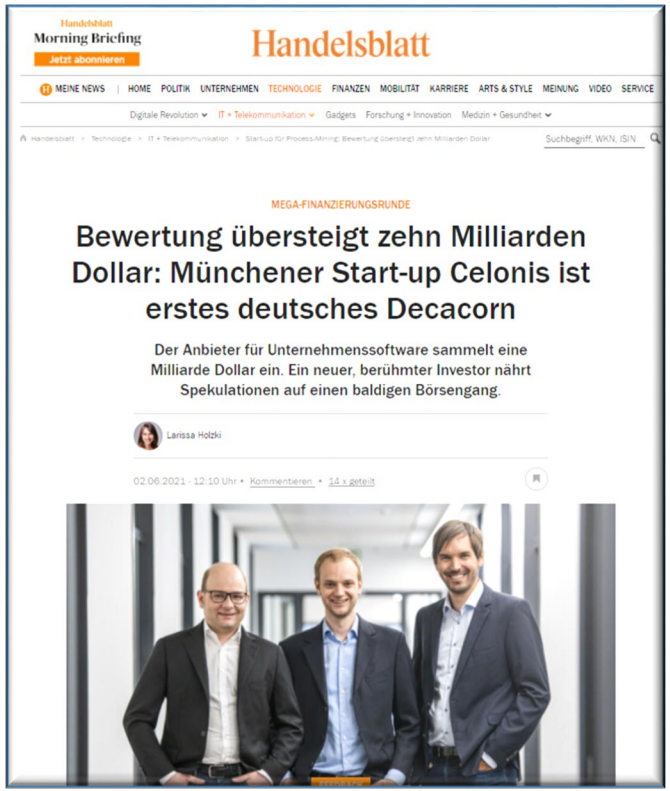
© Wil van der Aalst (use only with permission & acknowledgements)


research
commercial tools
start of process mining research at TU/e
Alpha miner
heuristic miner
token-based conformance checking
decision mining
organization mining
first process mining company (Futura PI)
IEEE Task Force on Process Mining
founding Fluxicon, ProcessGold, ...
alignment-based conformance checking
first process mining book
founding of Celonis
Coursera process mining MOOC
"Process Mining: Data Science in Action" book
Market Guide for Process Mining by Gartner
Celonis becomes a Unicorn
30+ process mining companies
ICPM 2019: First PM conference
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
adoption

Over 35 process mining vendors today

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

Example: Celonis, Germany's first Decacorn



Handelsblatt Morning Briefing

Jetzt abonnieren

Handelsblatt

MEINE NEWS | HOME POLITIK UNTERNEHMEN TECHNOLOGIE FINANZEN MOBILITÄT KARRIERE ARTS & STYLE MEINUNG VIDEO SERVICE

Digitale Revolution IT + Telekommunikation Gadgets Forschung + Innovation Medizin + Gesundheit

Suchbegriff, WKN, ISIN

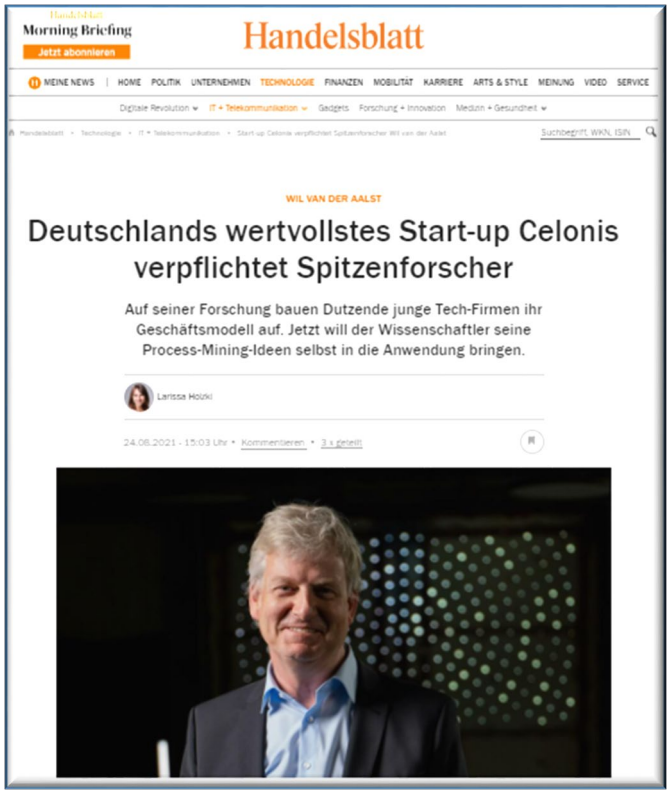
MEGA-FINANZIERUNGSRUNDE

Bewertung übersteigt zehn Milliarden Dollar: Münchener Start-up Celonis ist erstes deutsches Decacorn

Der Anbieter für Unternehmenssoftware sammelt eine Milliarde Dollar ein. Ein neuer, berühmter Investor nährt Spekulationen auf einen baldigen Börsengang.

Larissa Holzki

02.06.2021 - 12:10 Uhr • Kommentieren • 14 x geteilt



Handelsblatt Morning Briefing

Jetzt abonnieren

Handelsblatt

MEINE NEWS | HOME POLITIK UNTERNEHMEN TECHNOLOGIE FINANZEN MOBILITÄT KARRIERE ARTS & STYLE MEINUNG VIDEO SERVICE

Digitale Revolution IT + Telekommunikation Gadgets Forschung + Innovation Medizin + Gesundheit

Suchbegriff, WKN, ISIN

WIL VAN DER AALST

Deutschlands wertvollstes Start-up Celonis verpflichtet Spitzenforscher

Auf seiner Forschung bauen Dutzende junge Tech-Firmen ihr Geschäftsmodell auf. Jetzt will der Wissenschaftler seine Process-Mining-Ideen selbst in die Anwendung bringen.

Larissa Holzki

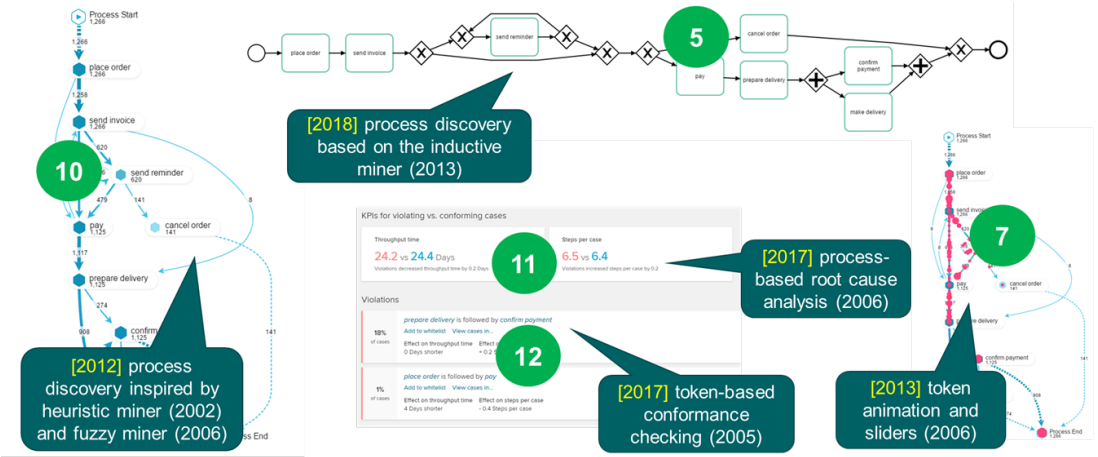
24.08.2021 - 15:03 Uhr • Kommentieren • 3 x geteilt

A Decacorn is a startup company valued at over $10 billion

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

Chair of Process and Data Science

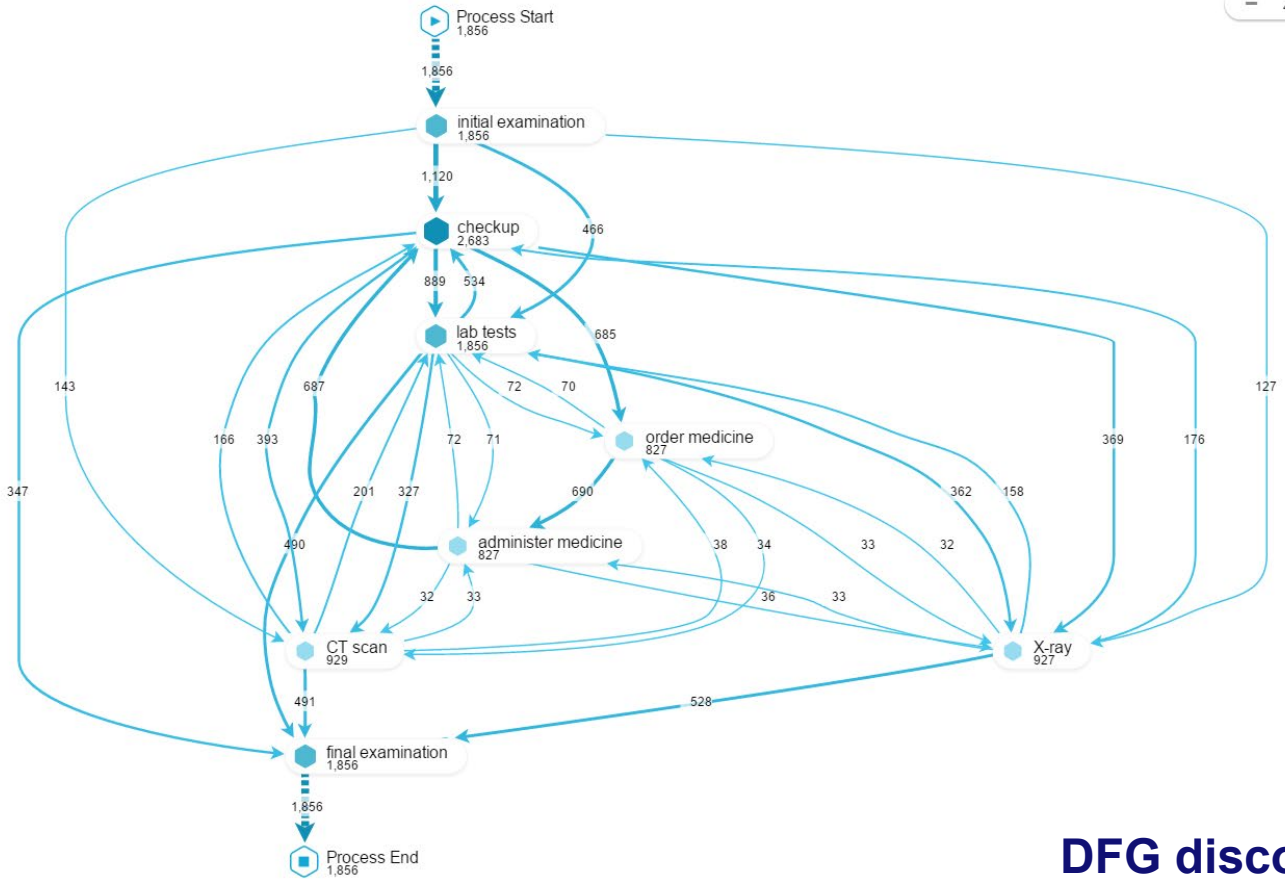
Example Process Mining Software: Celonis



- **Germany's youngest most promising IT company (valued > 11 billion $).**
- **Successfully adopted many ideas from research a decade earlier.**
- **Combining analytics with actions.**

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

Chair of Process and Data Science

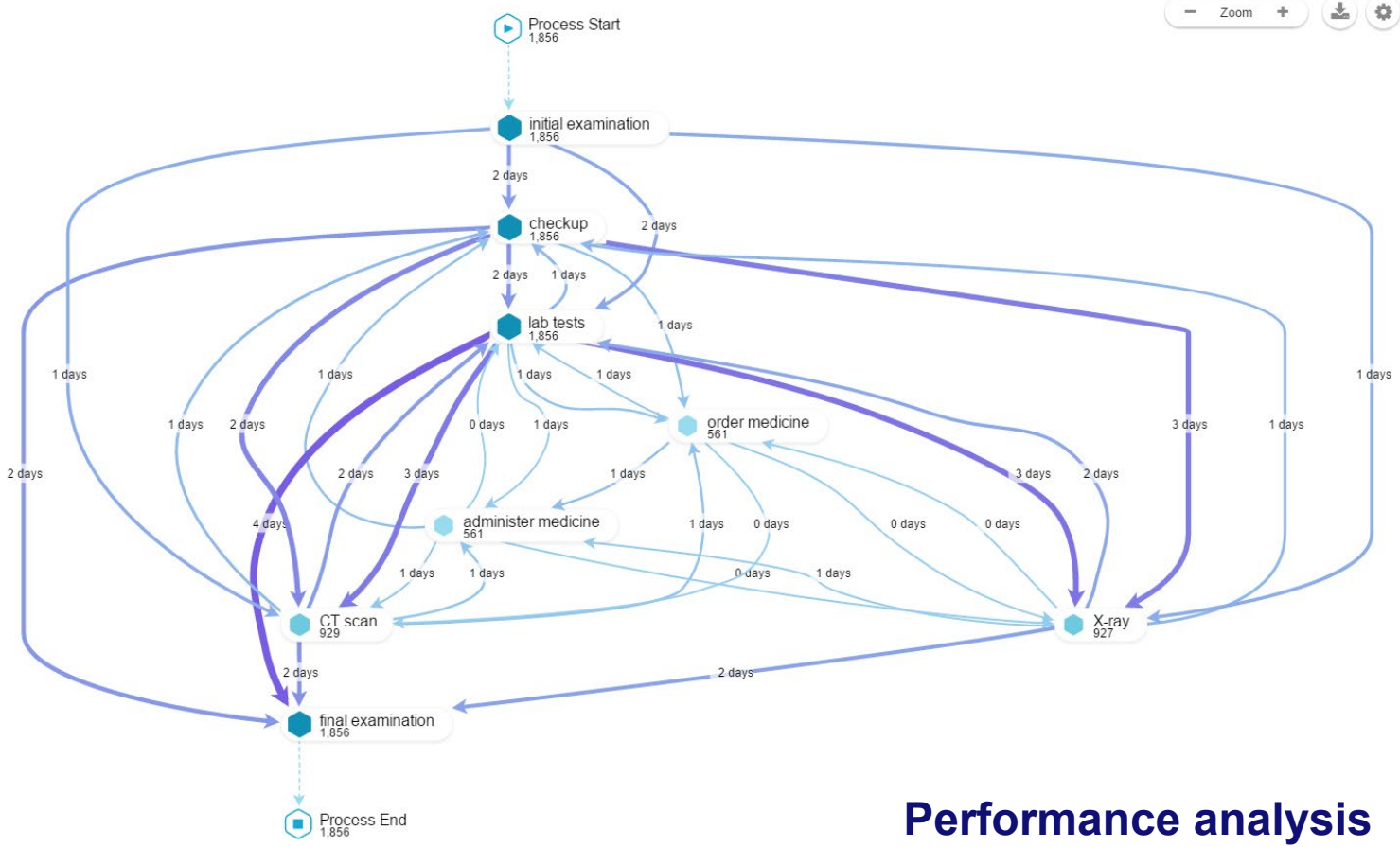


DFG discovery

Zoom

Activities
List view
100%
of activities
Reset
Less
More

Connections
List view
100%
of connections
Reset
Less
More
Fixed layout

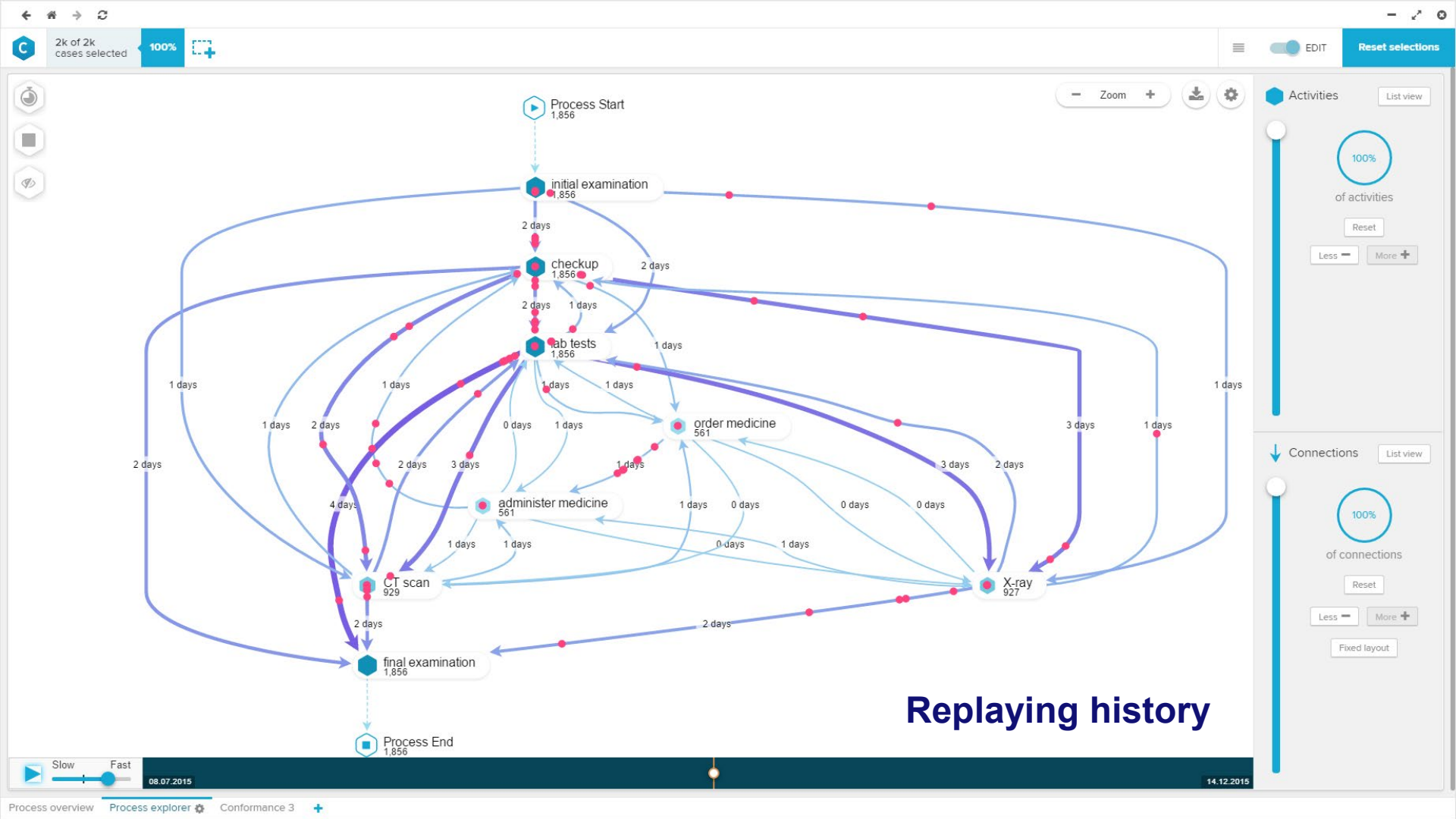


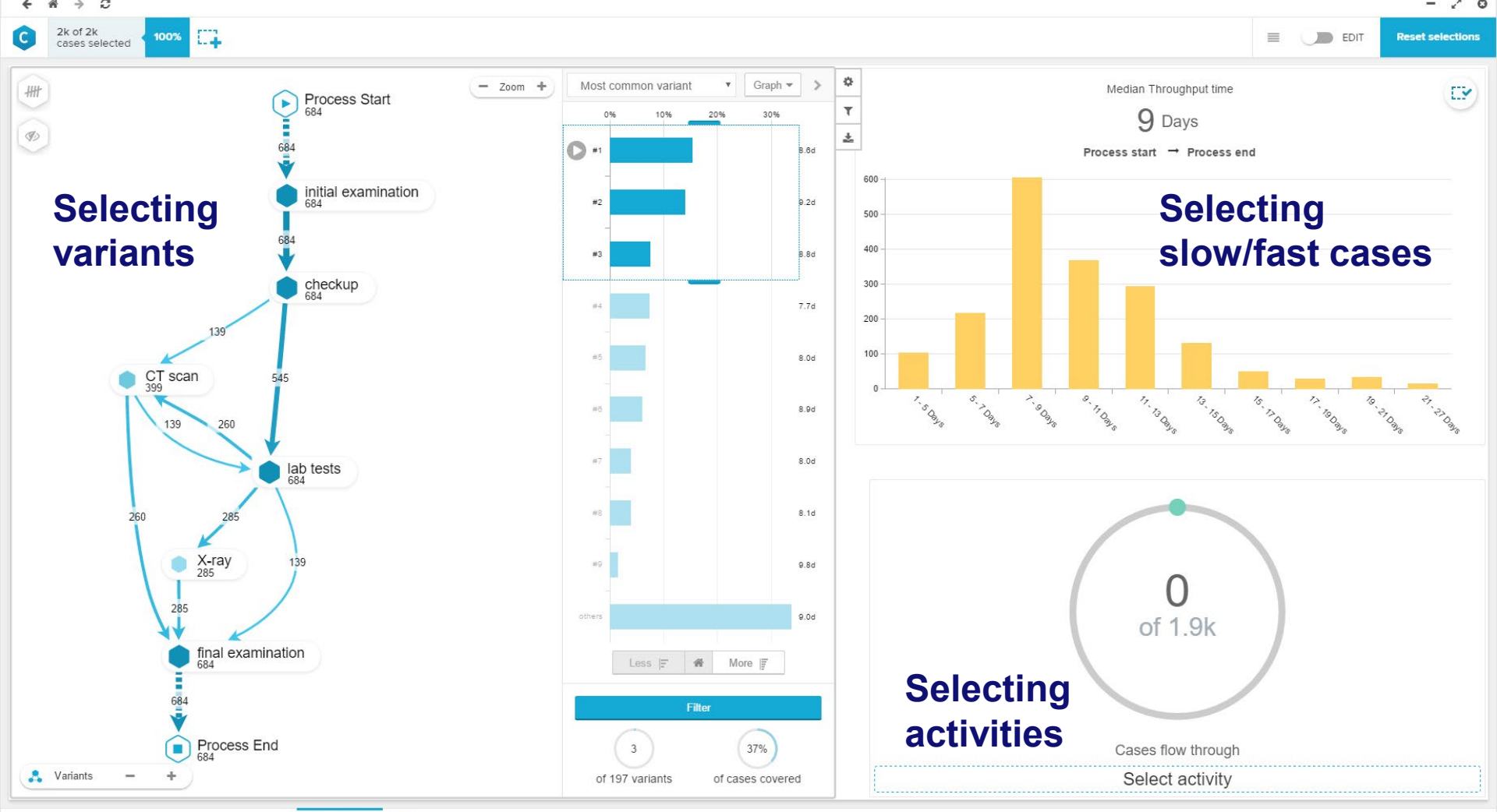
Zoom

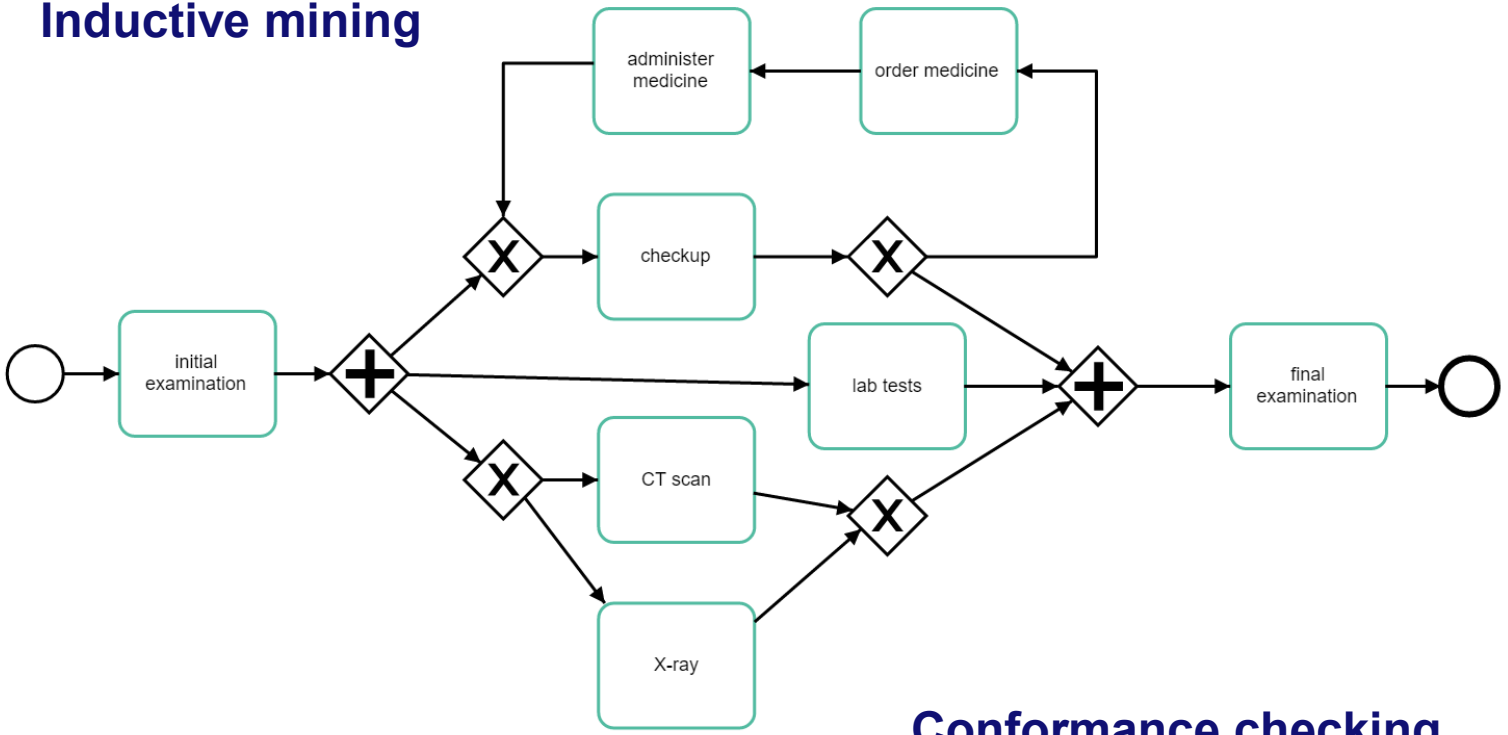
Activities
List view
100%
of activities
Reset
Less
More

Connections
List view
100%
of connections
Reset
Less
More
Fixed layout

Performance analysis


2k of 2k cases selected
100%
EDIT
Reset selections
Zoom
Process Start
1,856
initial examination
1,856
checkup
1,856
lab tests
1,856
order medicine
561
administer medicine
561
CT scan
929
X-ray
927
final examination
1,856
Process End
1,856
Activities
List view
100%
of activities
Reset
Less
More
Connections
List view
100%
of connections
Reset
Less
More
Fixed layout
Replaying history
Slow
Fast
08.07.2015
14.12.2015
Process overview
Process explorer
Conformance 3


2k of 2k cases selected
100%
EDIT
Reset selections
Selecting variants
Process Start
684
initial examination
684
checkup
684
CT scan
399
lab tests
684
X-ray
285
final examination
684
Process End
684
Variants
Zoom
Most common variant
Graph
Less
More
Filter
3
of 197 variants
37%
of cases covered
Selecting slow/fast cases
Median Throughput time
9 Days
Process start → Process end
1 - 5 Days
5 - 7 Days
7 - 9 Days
9 - 11 Days
11 - 13 Days
13 - 15 Days
15 - 17 Days
17 - 19 Days
19 - 21 Days
21 - 27 Days
Selecting activities
0
of 1.9k
Cases flow through
Select activity
Process overview
Process explorer
Conformance 3
New App 4


Inductive mining
administer medicine
order medicine
checkup
initial examination
lab tests
final examination
CT scan
X-ray
Conformance checking

2k of 2k cases selected | 100% | EDIT | Reset selections

Zoom

Process Start 1,856

initial examination 1,856

check 1,856

lab tests 1,856

order medicine 561

administer medicine 561

Activities | List view

100% of activities

Reset | Less | More

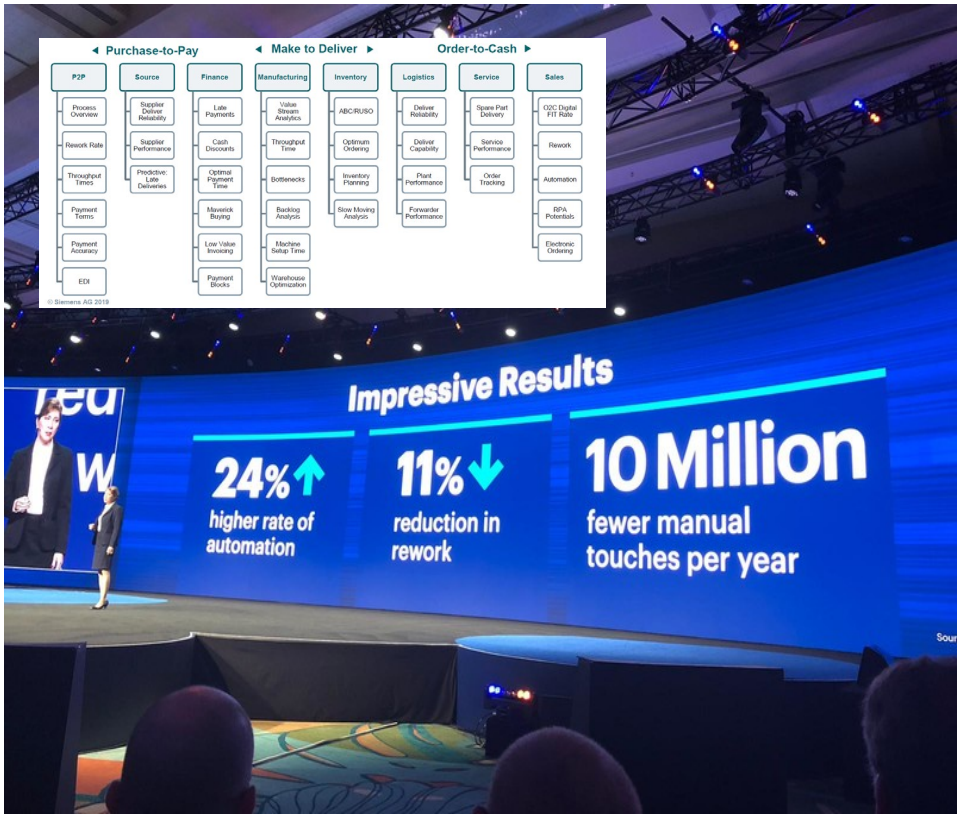
14.12.2015

Many of the larger organizations in Europe are using process mining already (and we are just at the beginning!)

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

Chair of Process and Data Science

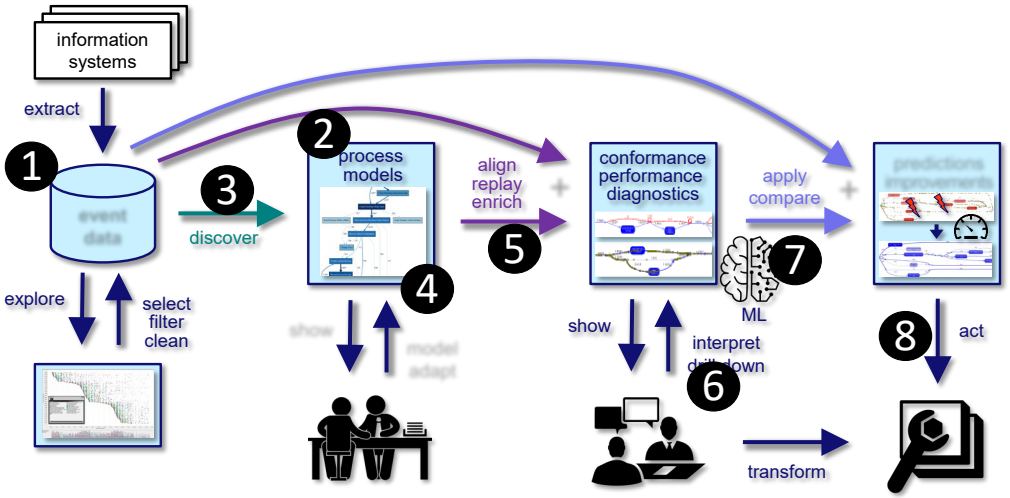
Example: Process Mining @ Siemens



- > 6000 active Celonis users (P2P, O2C, etc.)
- Millions of savings by reducing rework, process unification, etc.
- Improved reliability and responsiveness.
- At an amazing scale, e.g., Order to Cash (O2C) process with >30M cases, >300M events, and >900K variants.

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

Process Mining Offers Many Scientific Challenges (that also matter in the real world)



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).

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

Chair of Process and Data Science

The dream

Restart on fault
Control
Control
CONTROL PANEL
38/100
264
60%
85%
94%

Recording and analyzing data about operational processes is not new

OPERATION Wheel-barrow Excavation — DATE March 10 189

DEPARTMENT Construction.
MEN Mike Flaherty
MATERIALS Sand, requiring no pick. Hard clay in bank.
IMPLEMENTS No 2 shovel. Contractors wooden barrow
CONDITIONS Day work for contractor. By previous observation an average barrow load of sand is 2.32 cu ft mean in cut . . . . clay . 2.15 . . . .

OP	TIME	AV	NO SHVLS	OP	TIME	AV	NO SHVLS	OP	TIME	AV	NO SHVLS	OP	TIME	AV	NO SHVLS
a	1.27	1.27	1.5	a	1.12	1.12	1.2	a	1.86		11				
b	1.56	0.19		b	1.39	0.27		a	1.81		13				
c	1.82	0.26		c	1.58	0.19		a	2.16		16				
d	1.97	0.15		d	1.70	0.12		a	1.98		14				
e	2.27														
f	2.36														
a	1.24														
b	1.36														
c	1.59														
d	1.83														
e	2.08														
f	2.33														

COMPLETE OPERATIONS

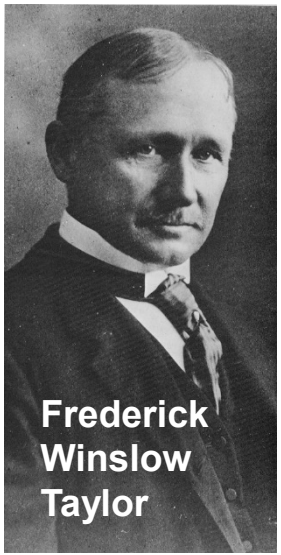
TIME		TOTAL TIME IN MIN	TOTAL TIME PICKING IN MIN	TOTAL SHOVLG IN MIN	TOTAL WHLNG IN MIN	TIME PER BARROW IN MIN
7AM	Commenced loading sand.					
9.02	43 loads wheeld 50 ft	122		122		2.84
9.50	Picking hard clay	48				
11.39	29 loads clay wheeld 50 ft	109				
11.46	Picking clay again	7	5.5			1.67
12.01	9 loads clay wheeld 50 ft	15		12.8		2.76
		301				

DETAIL
a Fill
b Star
c Whe
d Pum
e Retu
f Prop
g
Fill
SER

Data sheet used in time study to analyze performance of workers and to compare different approaches.

Material	Throw: Vertical	Throw: Horizontal	Length of walk	Actual Continuous Work with no Allowance for Rest or other Stops: Time to fill shovel	Time to throw shovelful	Time walking with load	Time of back walk	Total time of complete operation	Volume of shovelful	Weight of shovelful	No. shovelfuls per minute	No. cubic yards per hour	No. pounds per hour	Per cent. of rest	Allowing for Rests and other Necessary Stops: No. shovelfuls per minute	No. cubic yards per hour	No. pounds per hour
	Feet	*Feet*	*Feet*	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	*Cu. ft.*	*Lbs.*	*Shovels*	*Cu. yds.*	*Lbs.*	*P.c.*	*Shovels*	*Yards*	*Lbs.*
Sand, or Sandy loam	4	5	...	0.073	0.031	.....	.....	0.104	0.16	16	9.6	3.4	9,230	30	7.4	2.6	7,100
	6	5	...	0.073	0.043	.....	.....	0.116	0.14	14	8.6	2.7	7,250	30	6.6	2.0	5,580
	8	5	...	0.073	0.056	.....	.....	0.129	0.11	11	7.8	1.9	5,120	30	6.0	1.4	3,940
	4	7½	...	0.073	0.043	.....	.....	0.116	0.14	14	8.6	2.7	7,250	30	6.6	2.1	5,580
	6	7½	...	0.073	0.056	.....	.....	0.129	0.12	12	7.8	2.1	5,590	30	6.0	1.6	4,300
	4	10	...	0.073	0.058	.....	.....	0.131	0.13	13	7.6	2.2	5,960	30	5.9	1.7	4,580
	6	10	...	0.073	0.076	.....	.....	0.149	0.11	11	6.7	1.6	4,440	30	5.2	1.3	3,420
	...	...	20	0.073	0.020	0.080	0.080	0.253	0.20	20	4.0	1.8	4,750	5	3.8	1.7	4,520
	...	...	30	0.073	0.020	0.120	0.120	0.333	0.20	20	3.0	1.3	3,600	5	2.9	1.3	3,430
Loam, gravelly	4	5	...	0.092	0.031	.....	.....	0.123	0.14	15							3,920
	6	5	...	0.092	0.043	.....	.....	0.135	0.13	1							5,015
	8	5	...	0.092	0.056	.....	.....	0.148	0.10	1							3,530
	4	7½	...	0.092	0.043	.....	.....	0.135	0.13	1							5,010
	6	7½	...	0.092	0.056	.....	.....	0.148	0.11	1							3,870
	4	10	...	0.092	0.058	.....	.....	0.150	0.12	1							4,180
	6	10	...	0.092	0.076	.....	.....	0.168	0.10	1							3,100
	...	...	20	0.092	0.020	0.080	0.080	0.272	0.19	2							4,520
	...	...	30	0.092	0.020	0.120	0.120	0.352	0.19	21						1.1	3,490
Gravel, medium	4	5	...	0.084	0.031	.....	.....	0.115	0.12	17.0	8.7	2.3	8,870	30	6.7	1.8	6,820
	6	5	...	0.084	0.043	.....	.....	0.127	0.10	14.2	7.9	1.8	6,720	30	6.0	1.3	5,170
	8	5	...	0.084	0.056	.....	.....	0.140	0.08	11.4	7.1	1.3	4,880	30	5.5	1.0	3,750
	4	7½	...	0.084	0.043	.....	.....	0.127	0.11	15.6	7.9	1.9	7,370	30	6.0	1.5	5,670
	6	7½	...	0.084	0.056	.....	.....	0.140	0.09	12.8	7.1	1.4	5,480	30	5.5	1.1	4,220
	4	10	...	0.084	0.058	.....	.....	0.142	0.10	14.2	7.0	1.6	6,000	30	5.4	1.2	4,620
	6	10	...	0.084	0.076	.....	.....	0.160	0.08	11.4	6.2	1.1	4,270	30	4.8	0.8	3,280
	...	...	20	0.084	0.020	0.080	0.080	0.264	0.15	21.3	3.8	1.3	4,840	5	3.6	1.2	4,610
	...	...	30	0.084	0.020	0.120	0.120	0.344	0.15	21.3	2.9	1.0	3,720	5	2.8	0.9	3,540

Detailed analysis of shoveling earth data



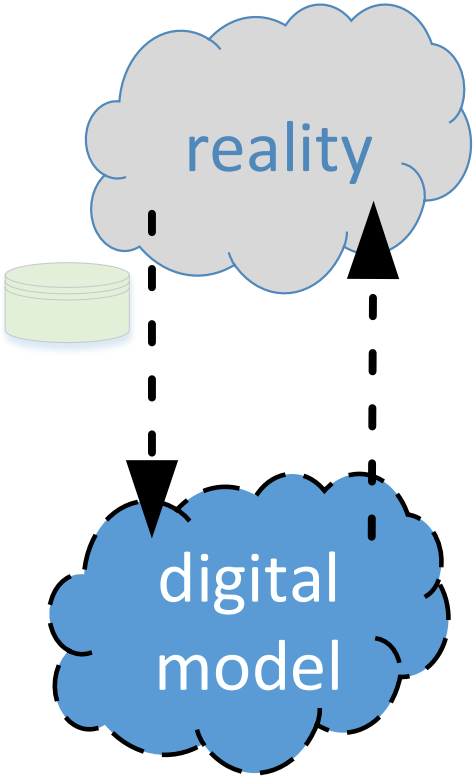
Frederick Winslow Taylor

F.W. Taylor. The Principles of Scientific Management. Harper and Bothers Publishers, New York, 1919.

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

Chair of Process and Data Science

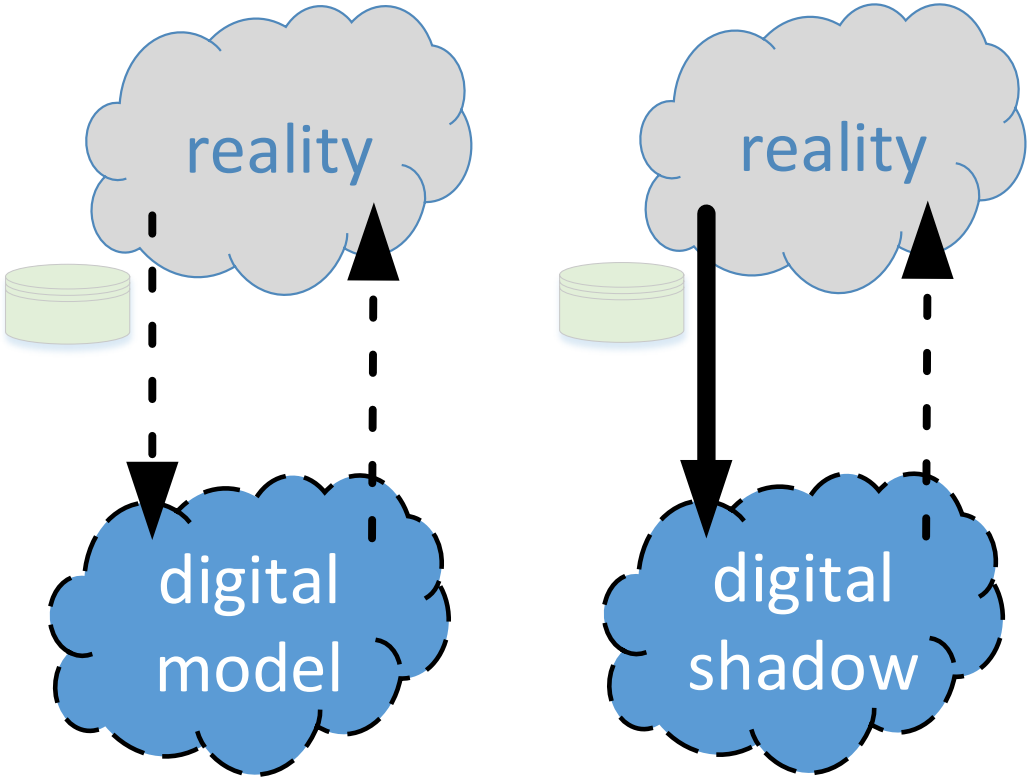
Towards a Digital Twin of an Organization (DTO)



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

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

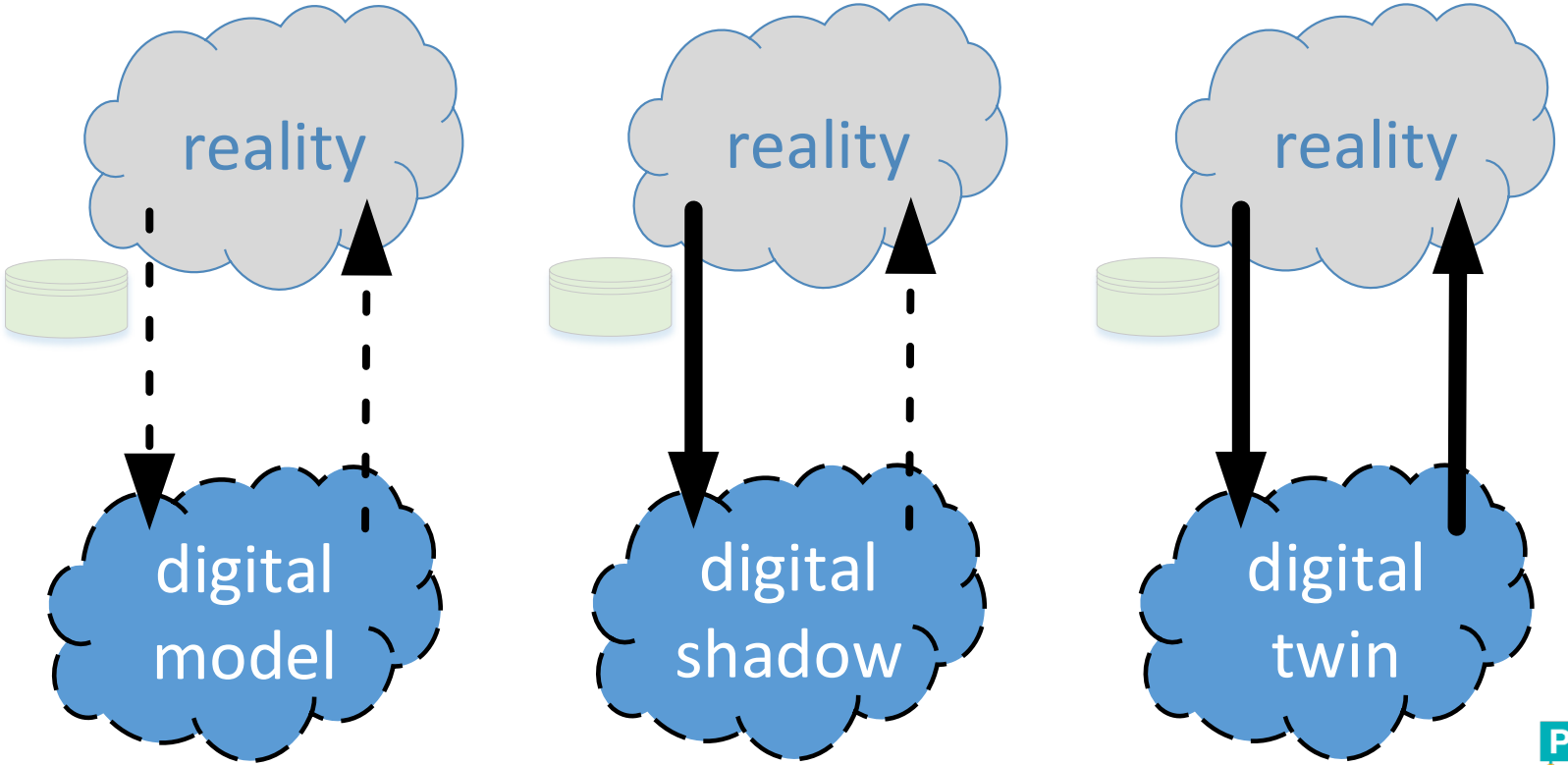
Towards a Digital Twin of an Organization (DTO)



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!

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

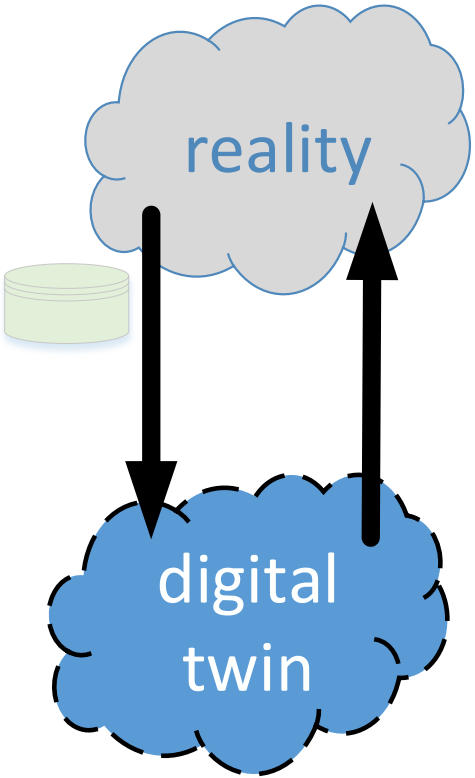
Towards a Digital Twin of an Organization (DTO)



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

Chair of Process and Data Science

Towards a Digital Twin of an Organization (DTO)



Traditional process mining techniques and tools can create a digital shadow from event data.

To create a digital twin, process mining techniques need to be more forward looking. This includes:

- **Operational support, including predictions and recommendations.**
- **Action-oriented process mining, triggering corrective workflows**

(Also see the Celonis Execution Management System.)

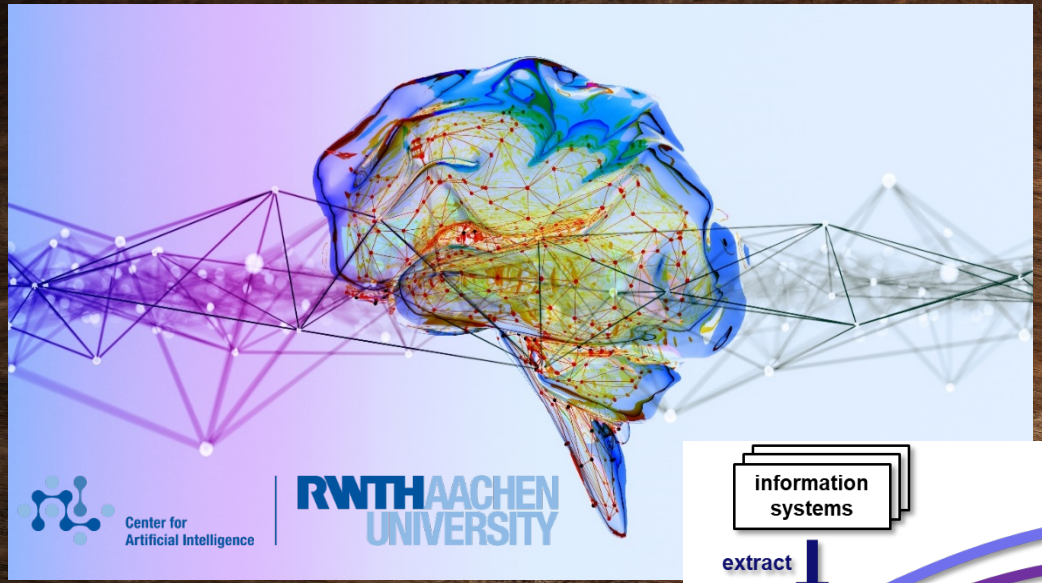
Chair of Process and Data Science

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

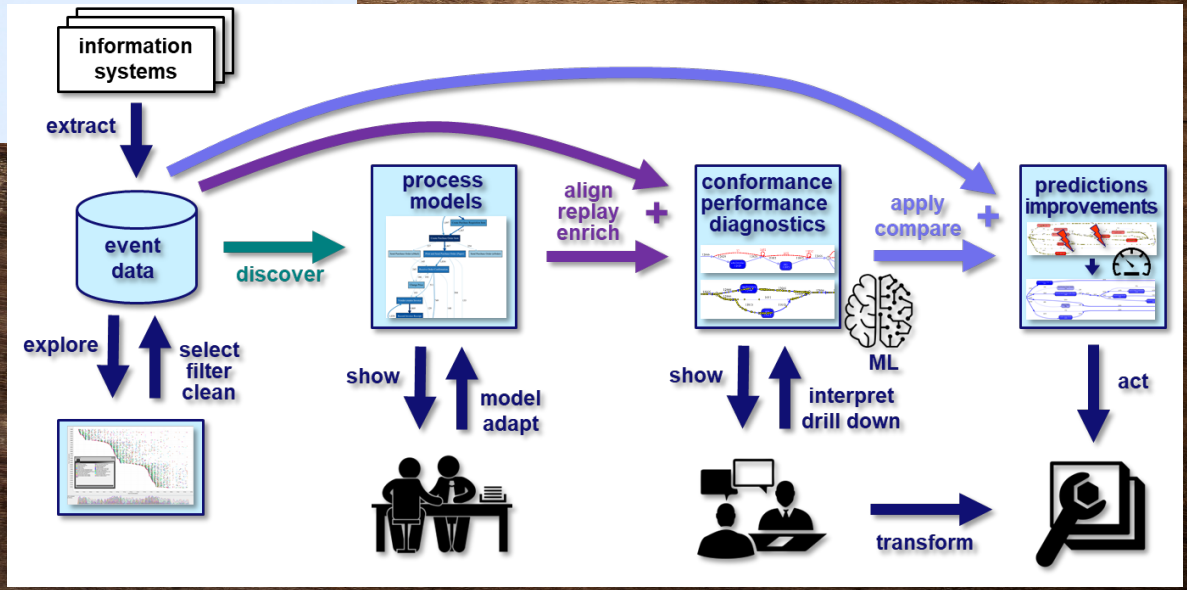
Chair of Process and Data Science

RWTH AACHEN UNIVERSITY

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



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



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

Learn more?
Wil van der Aalst
W: vdaalst.com
T:@wvdaalst
Over 140.000 participants
coursera
Process Mining: Data Science in Action
“PM Bible”
Wil M. P. van der Aalst
Process Mining
Discovery, Conformance and Enhancement of Business Proces
Josep Carmona
Boudewijn van Dongen
Andreas Solti
Matthias Weidlich
Conformanc Checking
Relating Processes and Models
Wil van der Aalst
Process Mining
Data Science in Action
Second Edition
Lars Reinkemeyer Editor
Process Mining in Action
Principles, Use Cases and Outlook
Springer