Process Mining in Healthcare

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www.processmining.org

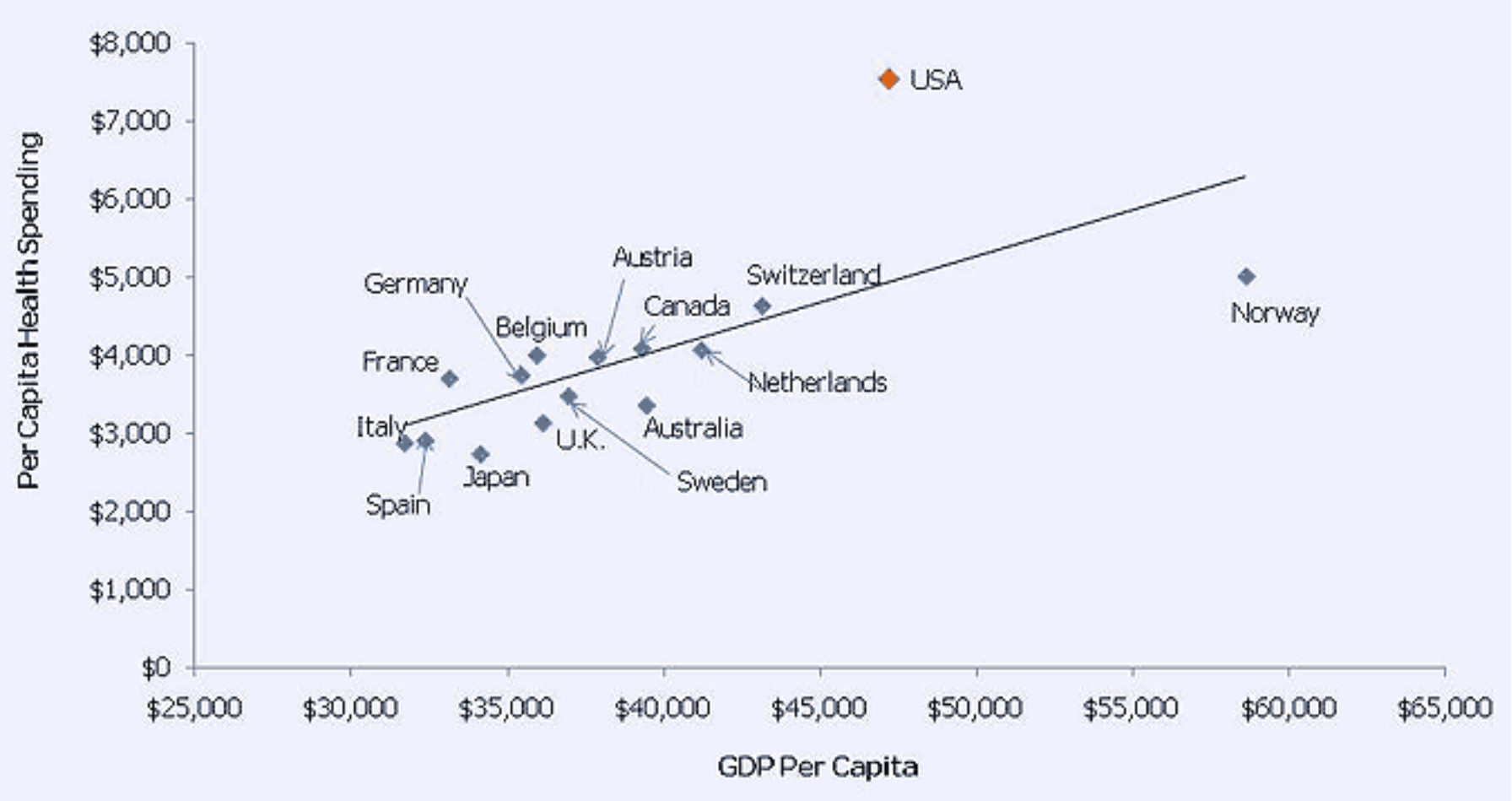
TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts

Technische Universiteit
Eindhoven
University of Technology
ProM
process mining workbench
The power of expressiveness
YAWL
QUT
Northern Ireland
United Kingdom
Ireland
Wales
England
Denmark
Belarus
Poland
Czech Rep
Ukraine
Austria
France
Kazakhstan
Mongolia
札幌
Uzbekistan
Kyrgyzstan
Turkmenistan
N Korea
S Korea
日本
Japan
東京
福岡
China
Syria
Iraq
Iran
Afghanistan
Pakistan
Nepal
India
Myanmar
Thailand
Vietnam
Malaysia
Indonesia
Papua New Guinea
Tunisia
Libya
Egypt
Saudi Arabia
Oman
Yemen
Mauritania
Mali
Niger
Chad
Sudan
Burkina Faso
Guinea
Ghana
Nigeria
Ivory Coast
Central African Republic
Cameroon
Ethiopia
Somalia
Kenya
Gabon
DR Congo
Tanzania
Angola
Zambia
Mozambique
Namibia
Zimbabwe
Botswana
Madagascar
South Atlantic Ocean
South Africa
Indian Ocean
NT
QLD
SA
NSW
VIC
TAS

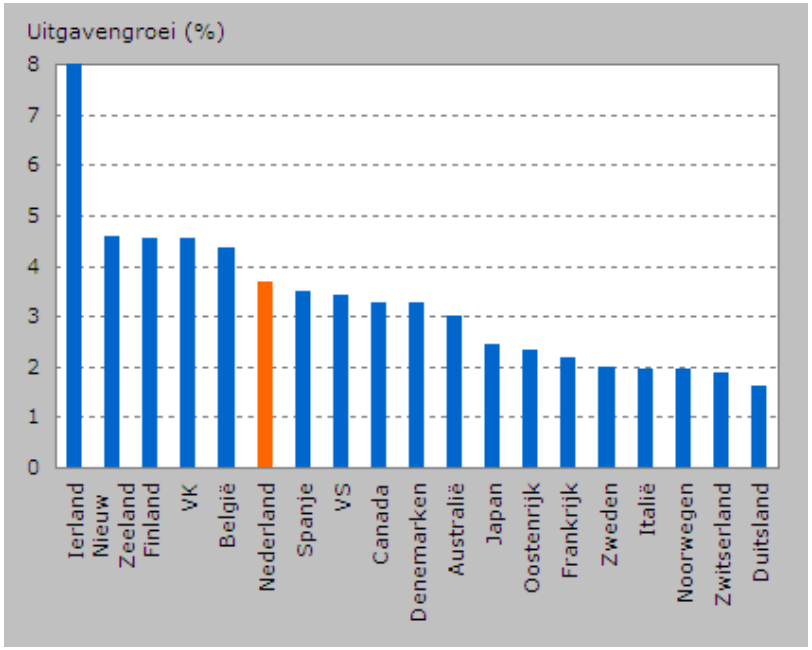
Healthcare Costs

Total Health Expenditure per Capita and GDP per Capita 2008

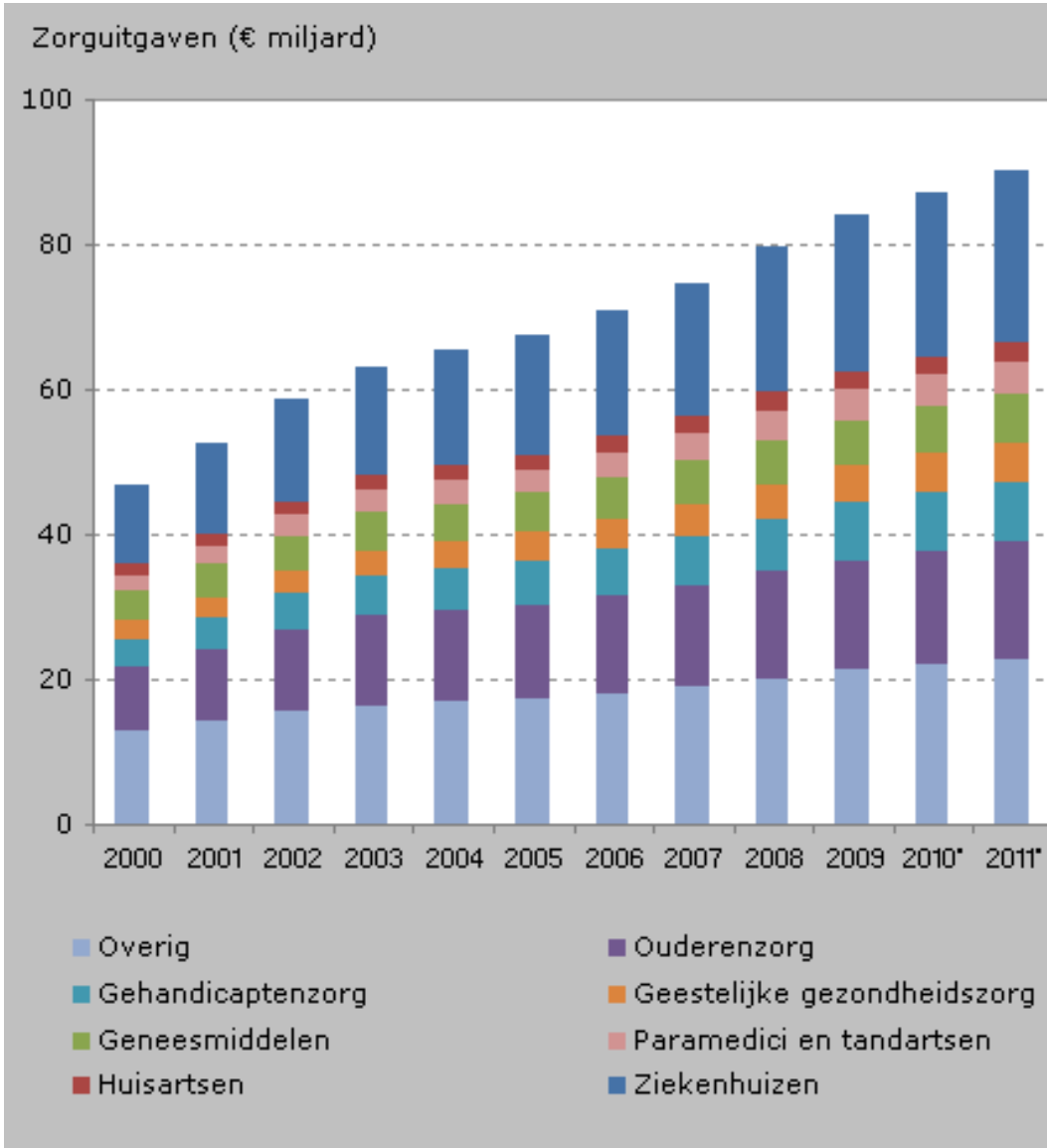


Source: Organisation for Economic Co-operation and Development (2010), "OECD Health Data", *OECD Health Statistics* (database). doi: 10.1787/data-00350-en

Costs are Rising!!

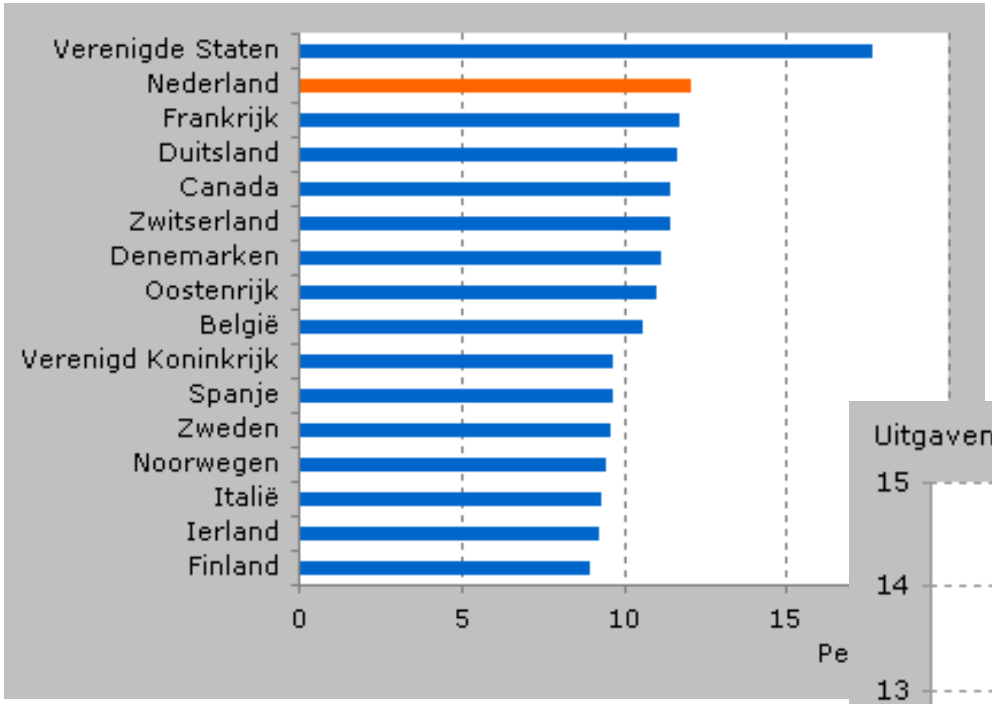


Gemiddelde jaarlijkse reële uitgavengroei per inwoner (%), 2000-2008 (Bron: OECD Health Data, 2010)a



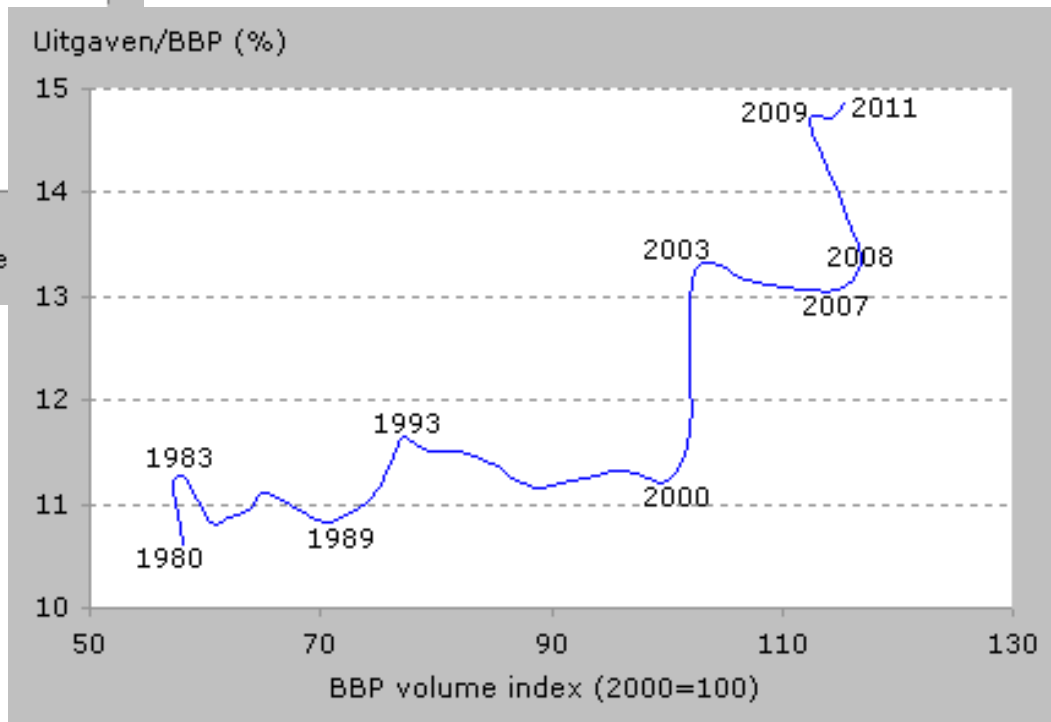
Zorguitgaven per sector, € miljard, 2000-2011 (Bron: CBS Statline, 2011ba; CBS, 2012).

Healthcare costs as a percentage of the Gross Domestic Product (GDP)



Aandeel zorguitgaven in het bruto binnenlands product, 2010 (Bron: OECD Health Data, 2012).

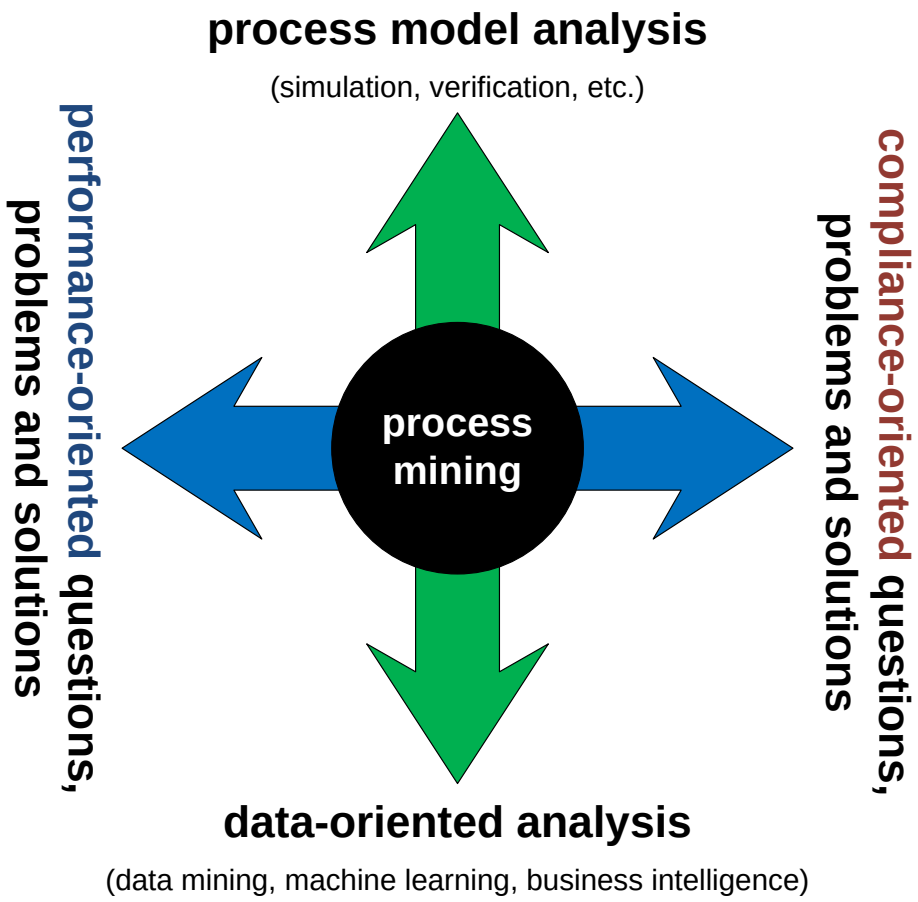
Aandeel zorguitgaven in het bruto binnenlands product afgezet tegen het bbp volume (2000=100) (%), 1980-2011 (Bron: CBS Statline, 2009c; CBS Statline, 2011b; OECD Health Data, 2009; databewerking RIVM).



Process Mining in Healthcare

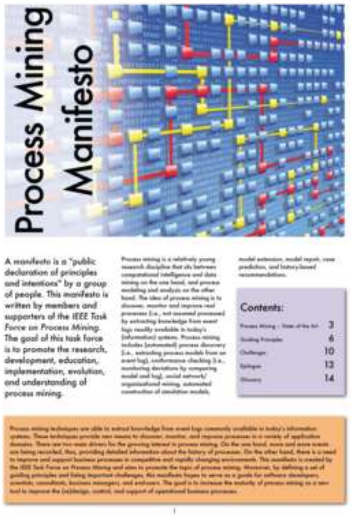
- Show the actual care processes (rather than idealized or assumed ones) and provide insights
- Uncover bottlenecks in care processes
- Show deviations from the “happy path”
- Performance and compliance analyzed in a unified, evidence-based, manner
- Provide operational support: predicting problems and recommending actions
- From “politics” to “analytics” to avoid “management by PowerPoint” and the usual “IT disasters”
- Improve service and reduce costs in healthcare

Positioning Process Mining



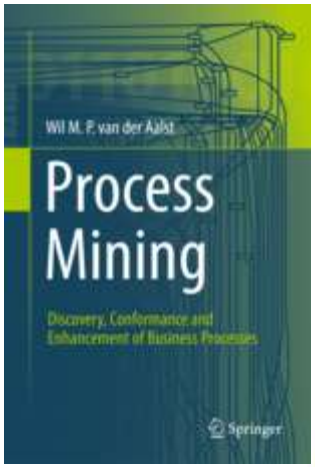
Advances in Process Mining

- **Many process discovery and conformance checking algorithms and tools are available (cf. the various ProM packages).**
- **Also commercial software based on these ideas:**
  Disco (Fluxicon), Reflect (Futura/Perceptive), BPMOne (Pallas Athena/Perceptive), ARIS Process Performance Manager (Software AG), Interstage Automated Process Discovery (Fujitsu), QPR ProcessAnalyzer/Analysis (QPR Software), flow (fourspark), Discovery Analyst (StereoLOGIC), etc.
- **We applied process mining in over 100 organizations.**



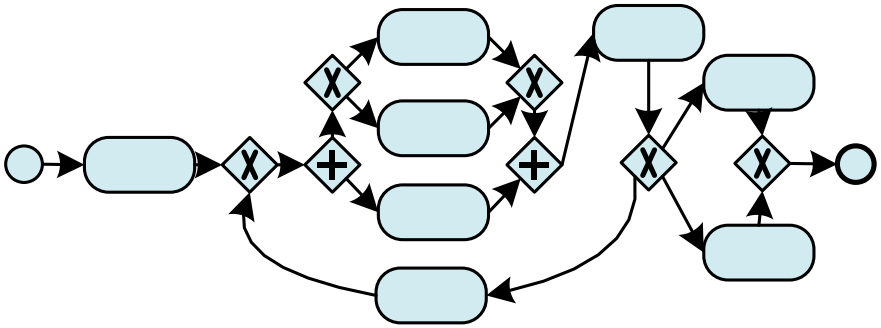
More than 75 people involving more than 50 organizations created the Process Mining Manifesto in the context of the IEEE Task Force on Process Mining.

Available in 13 languages

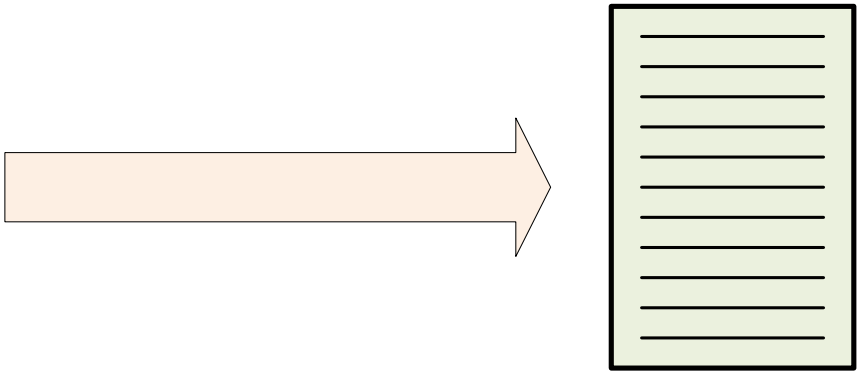


On the different roles of (process) models …

Play-Out

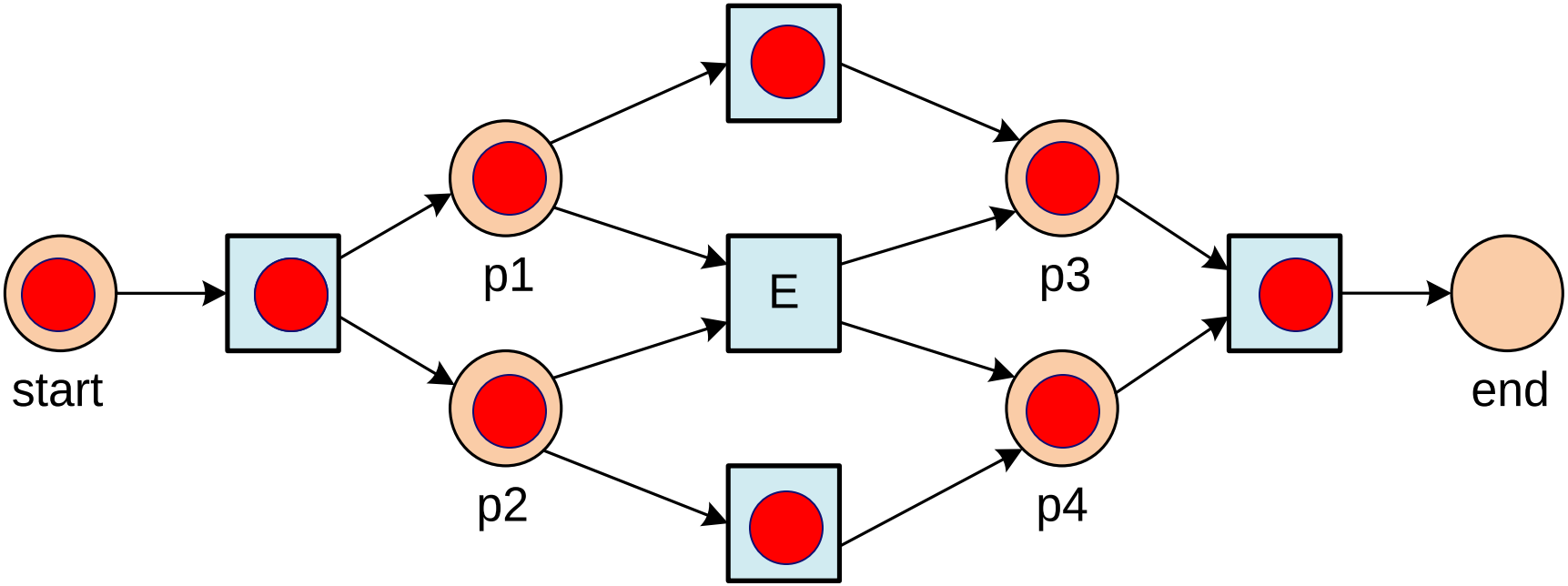


process model



event log

Play-Out (Classical use of models)

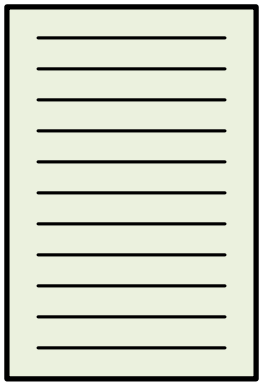


A B C D A E D A E D

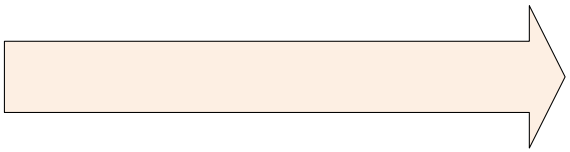
A B C D A C B D

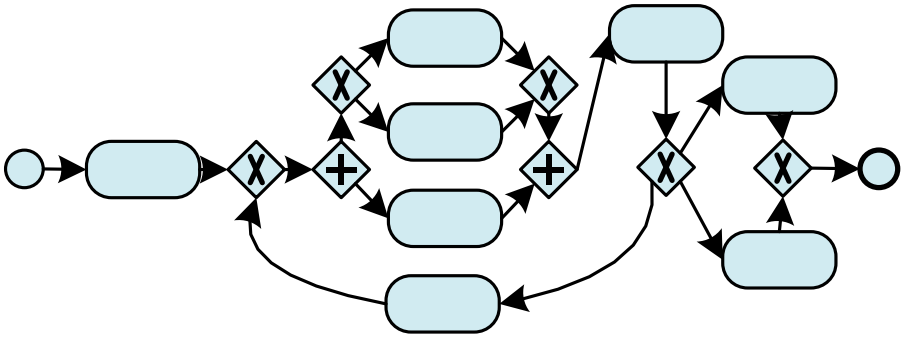
A C B D A E D A C B D

Play-In



event log





process model

Play-In

A B C D

A E D

A E D

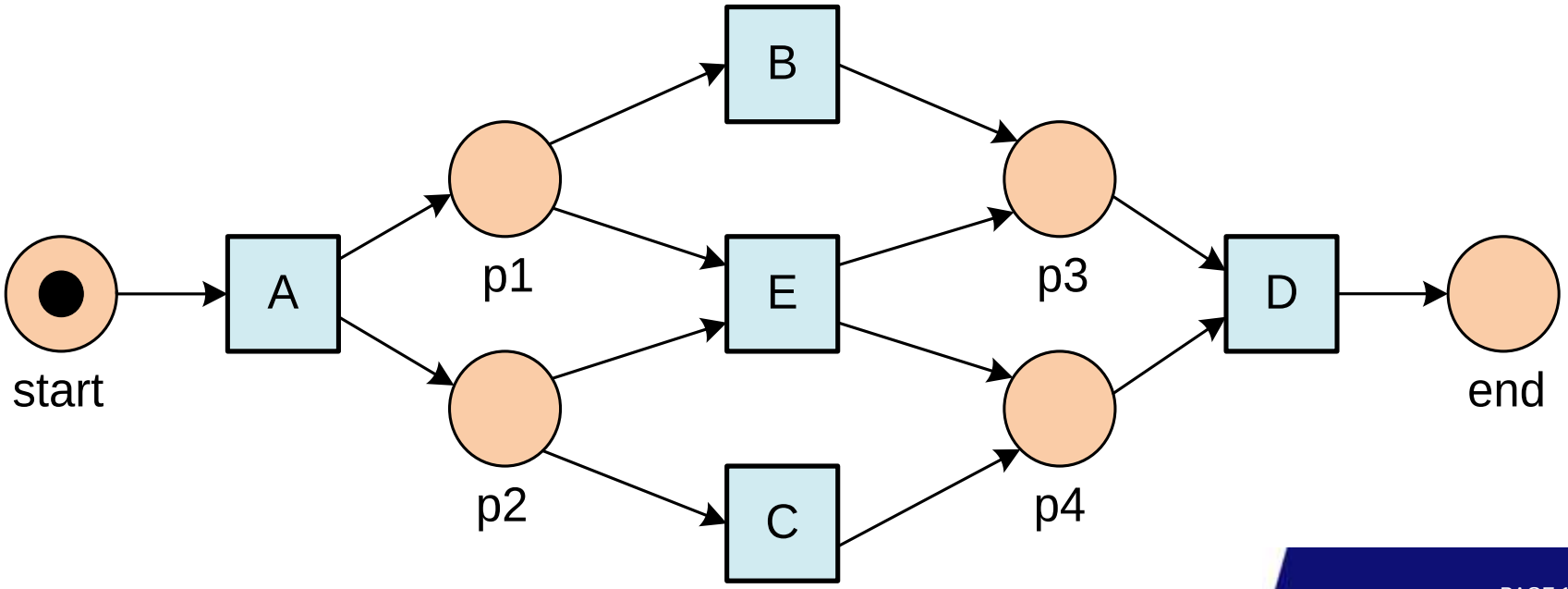
A B C D

A C B D

A C B D

A E D

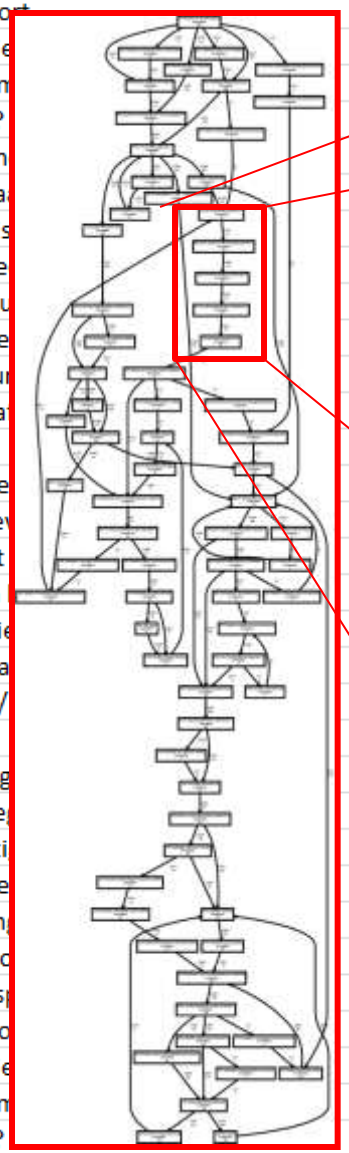
A C B D

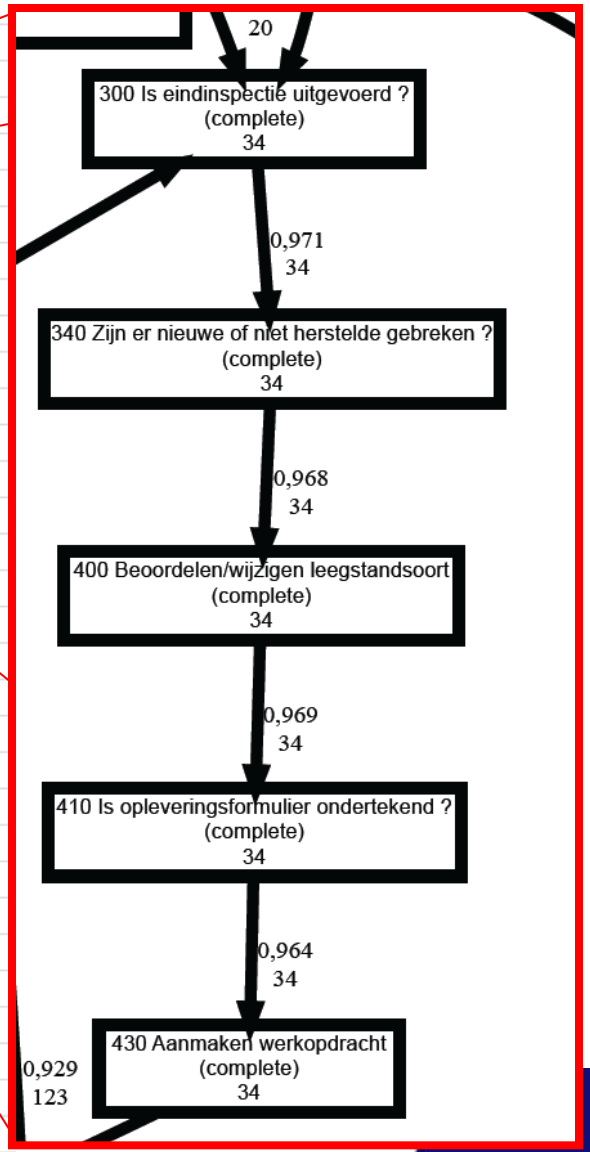


Example Process Discovery

(Vestia, Dutch housing agency, 208 cases, 5987 events)

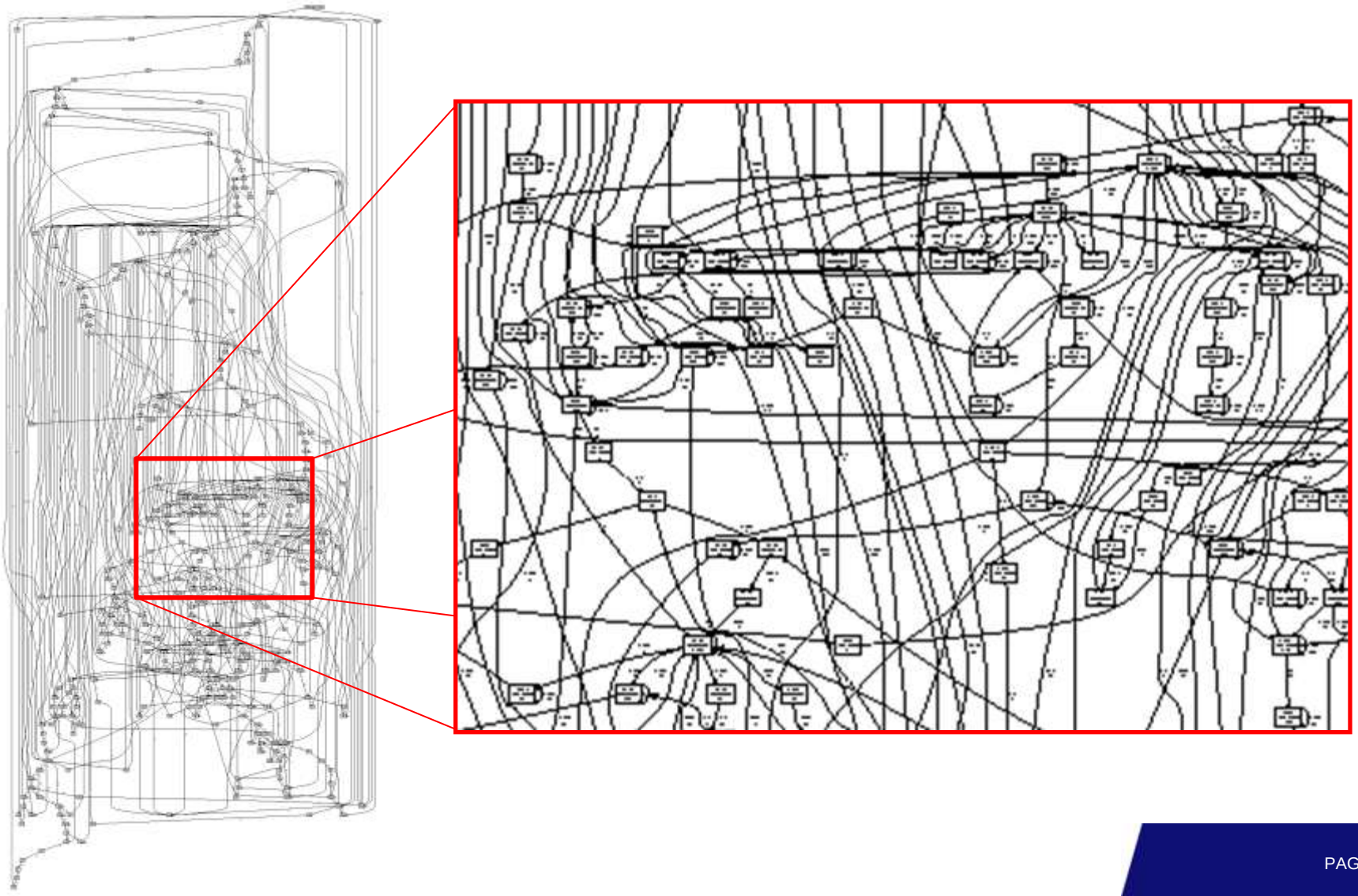
117315	110 Bepalen leegstandsoo	16.05.2007 14:06:23
117315	120 Plannen eindinspectie	16.05.2007 14:36:01
117315	130 Is het opleveringsform	23.05.2007 09:41:40
117315	150 Is er sprake van ZAV ?	23.05.2007 09:41:51
117315	170 Aanpassen plattegron	23.05.2007 11:57:18
117315	180 Aanpassen woningwa	23.05.2007 09:42:37
117315	190 Actualiseren huurprijs	23.05.2007 09:48:23
117315	200 Toewijzen woning/be	23.05.2007 09:48:29
117315	210 Registreren voorl. huu	10.09.2007 16:24:36
117315	220 Is contract getekend e	11.09.2007 14:56:18
117315	240 Definitief maken Huur	31.03.2008 16:17:12
117315	250 Aanpassen factureera	09.09.2008 15:39:59
117315	260 After sales	09.09.2008 16:51:24
117315	270 Archiveren nieuwe ve	10.09.2008 07:52:08
117315	300 Is eindinspectie uitgev	07.06.2007 14:47:04
117315	340 Zijn er nieuwe of niet	07.06.2007 14:47:06
117315	400 Beoordelen/wijzigen l	07.06.2007 14:51:16
117315	410 Is opleveringsformulie	07.06.2007 14:51:26
117315	430 Aanmaken werkopdra	11.06.2007 09:21:39
117315	440 Worden er bonussen/	11.06.2007 09:21:49
117315	460 Opstellen eindnota	08.08.2007 16:18:26
117315	470 Archiveren huuropzeg	09.08.2007 14:42:23
119763	010 Registreren huuropze	09.05.2007 11:19:14
119763	030 Vastleggen toekomsti	09.05.2007 12:25:01
119763	050 Inplannen afspraak 1e	09.05.2007 11:59:52
119763	060 Aanmaken bevestigin	09.05.2007 12:31:57
119763	070 Is 1e inspectie uitgevo	16.05.2007 13:04:26
119763	100 Gereedmelden 1e insp	16.05.2007 13:43:39
119763	110 Bepalen leegstandsoo	16.05.2007 13:43:28
119763	120 Plannen eindinspectie	16.05.2007 13:42:58
119763	130 Is het opleveringsform	16.05.2007 13:34:49
119763	150 Is er sprake van ZAV ?	16.05.2007 13:34:56





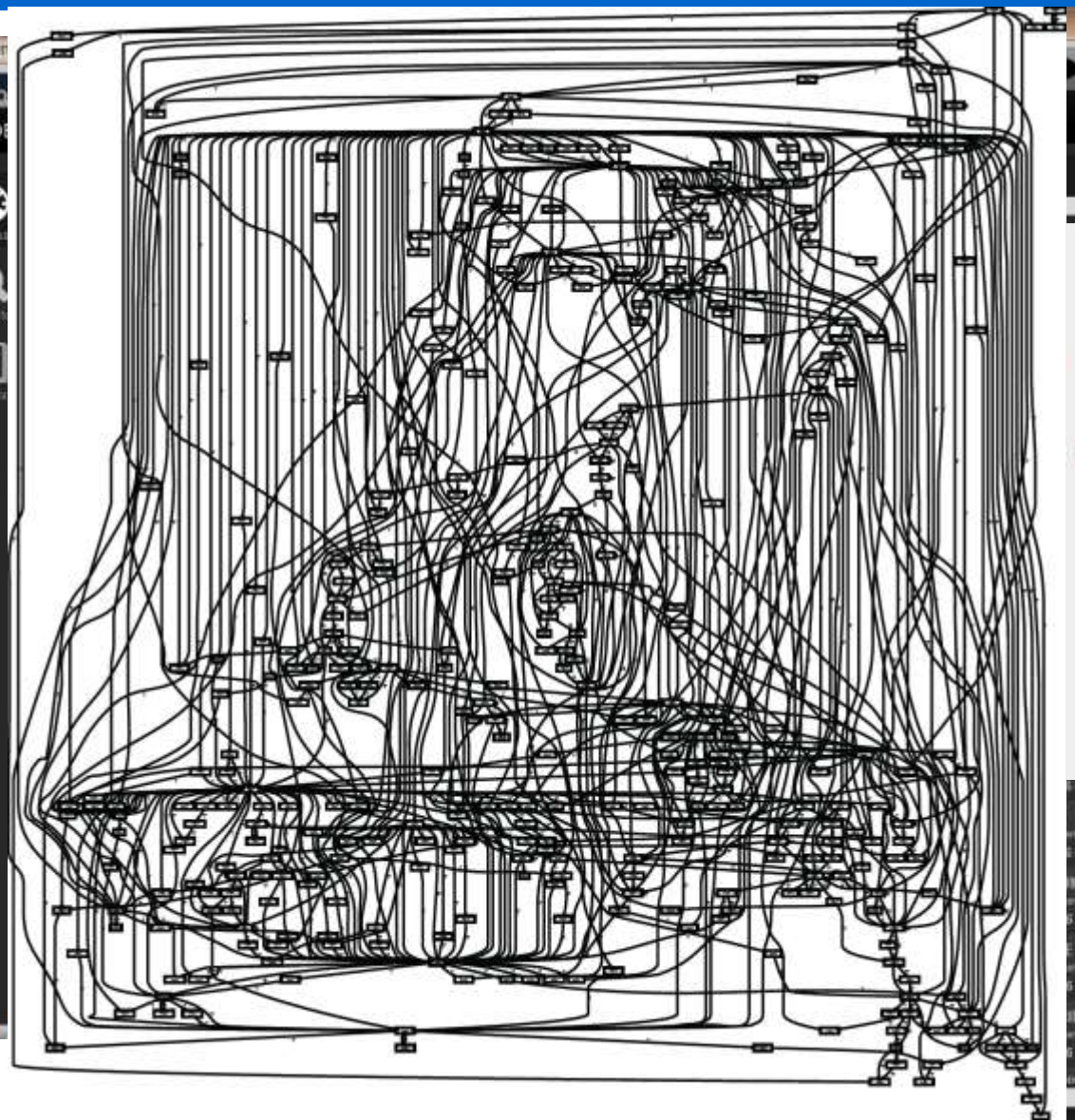
Example Process Discovery

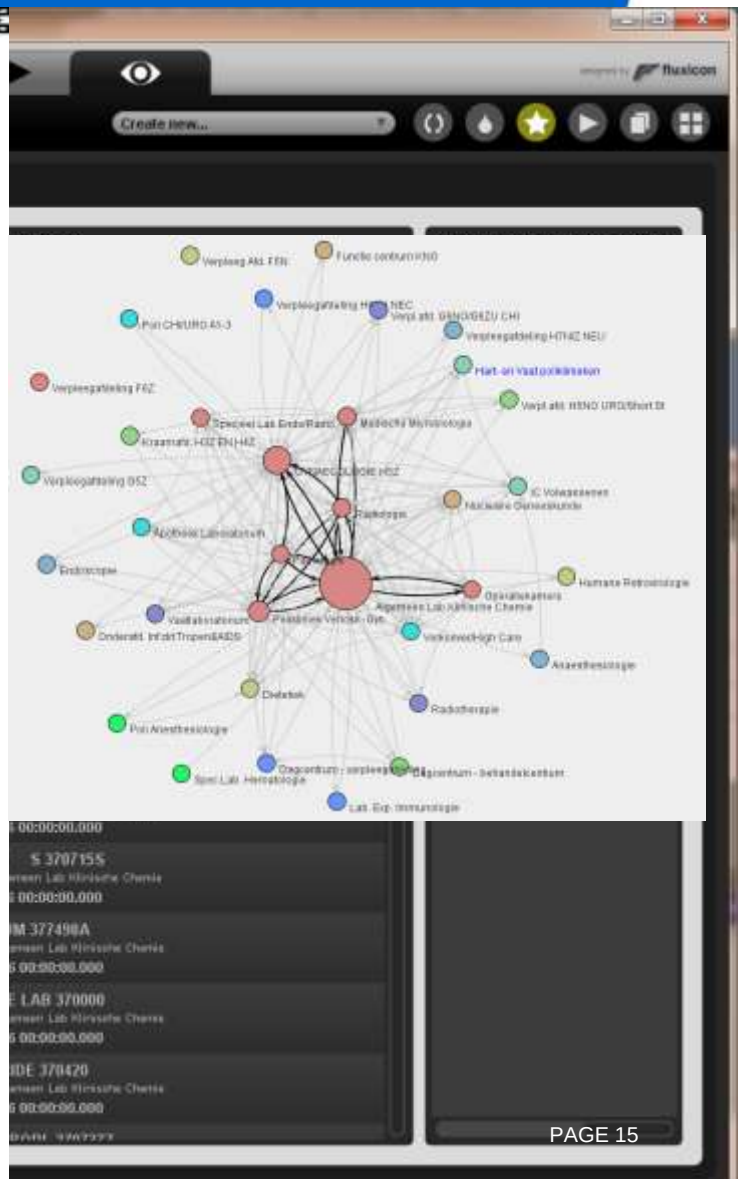
(ASML, test process lithography systems, 154966 events)



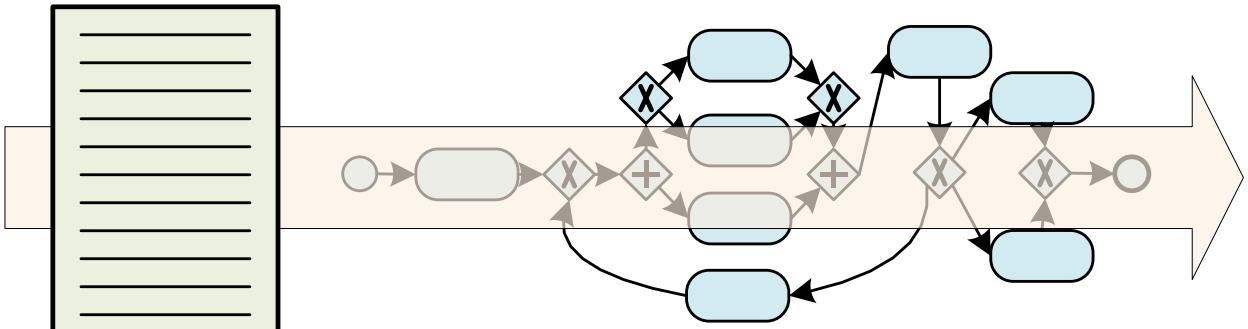
Example Process Discovery

(AMC, 627 gynecological oncology patients, 24331 events)





Replay



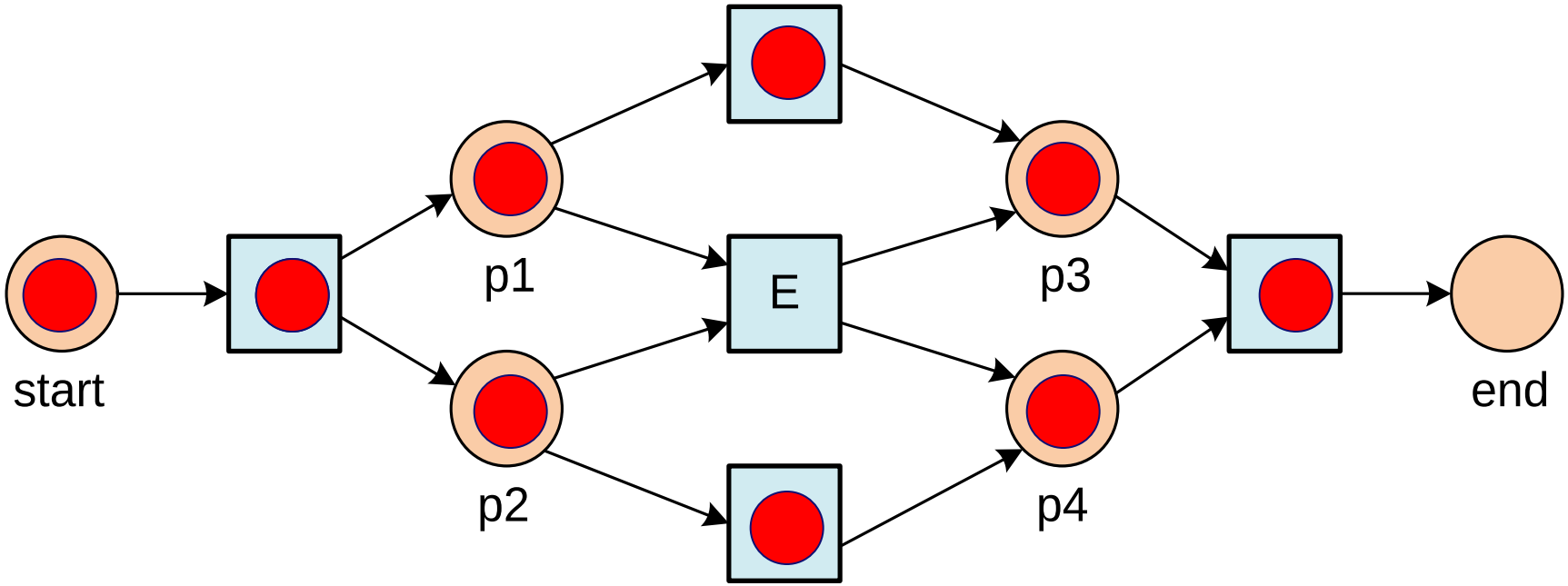
event log

process model

- extended model showing times, frequencies, etc.
- diagnostics
- predictions
- recommendations

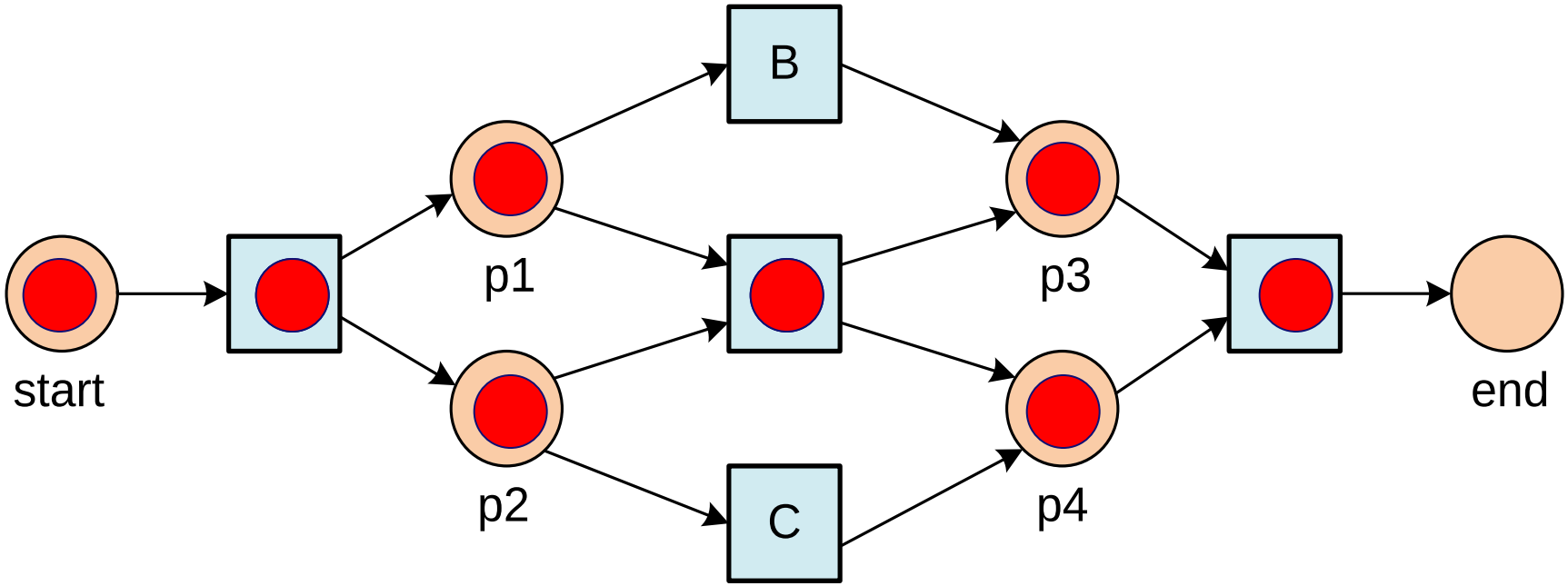
Replay

A B C D



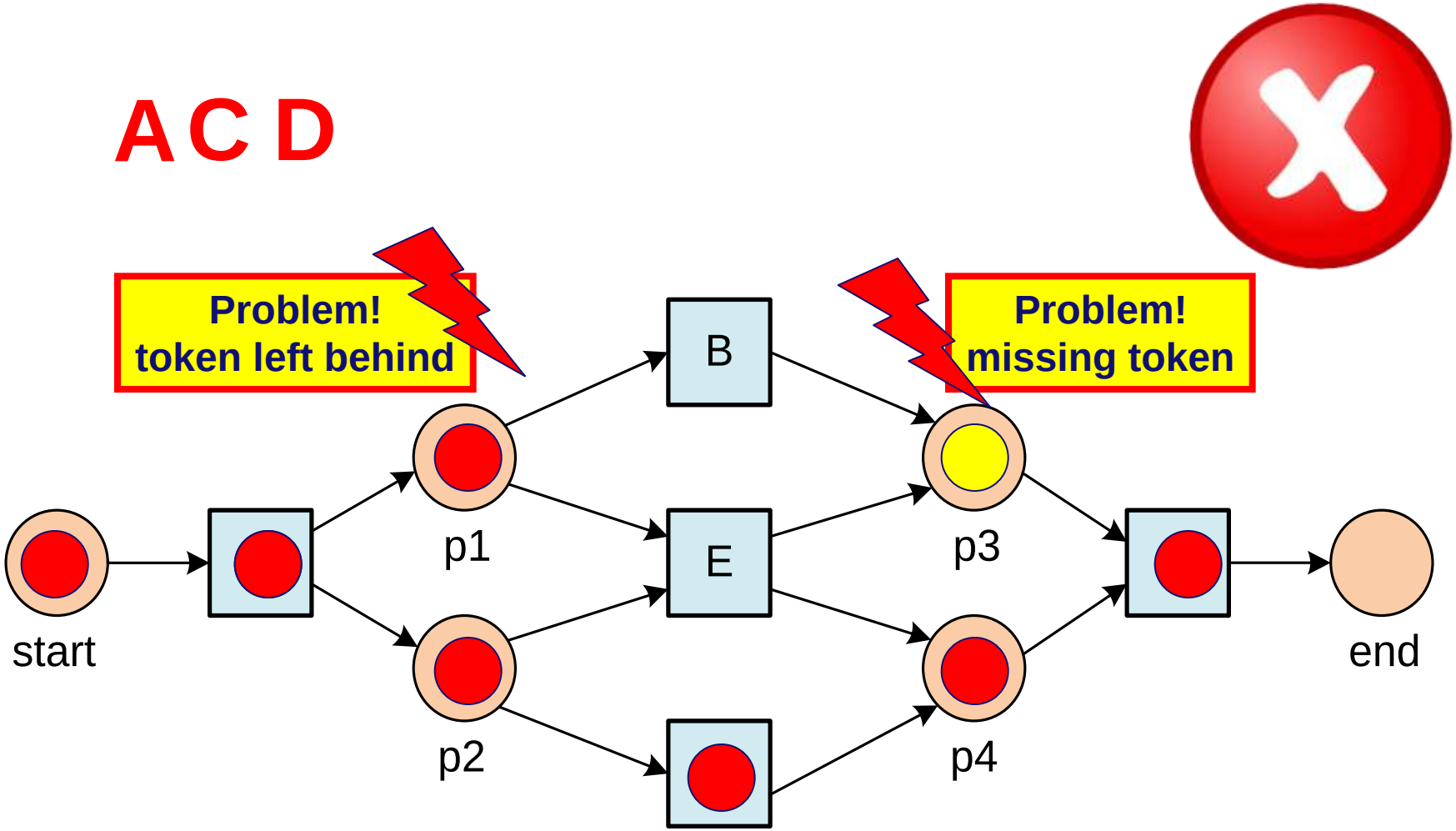
Replay

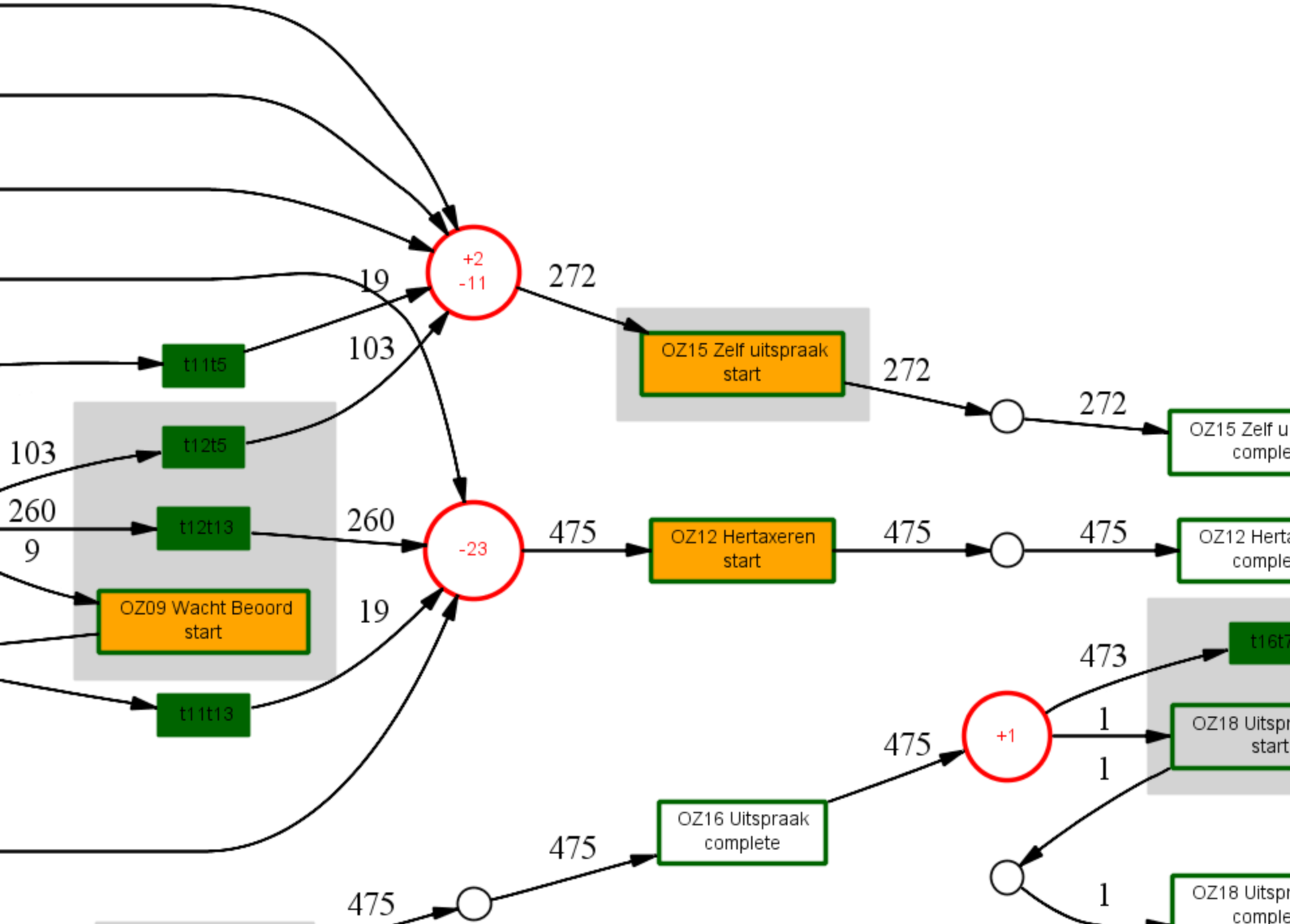
A E D



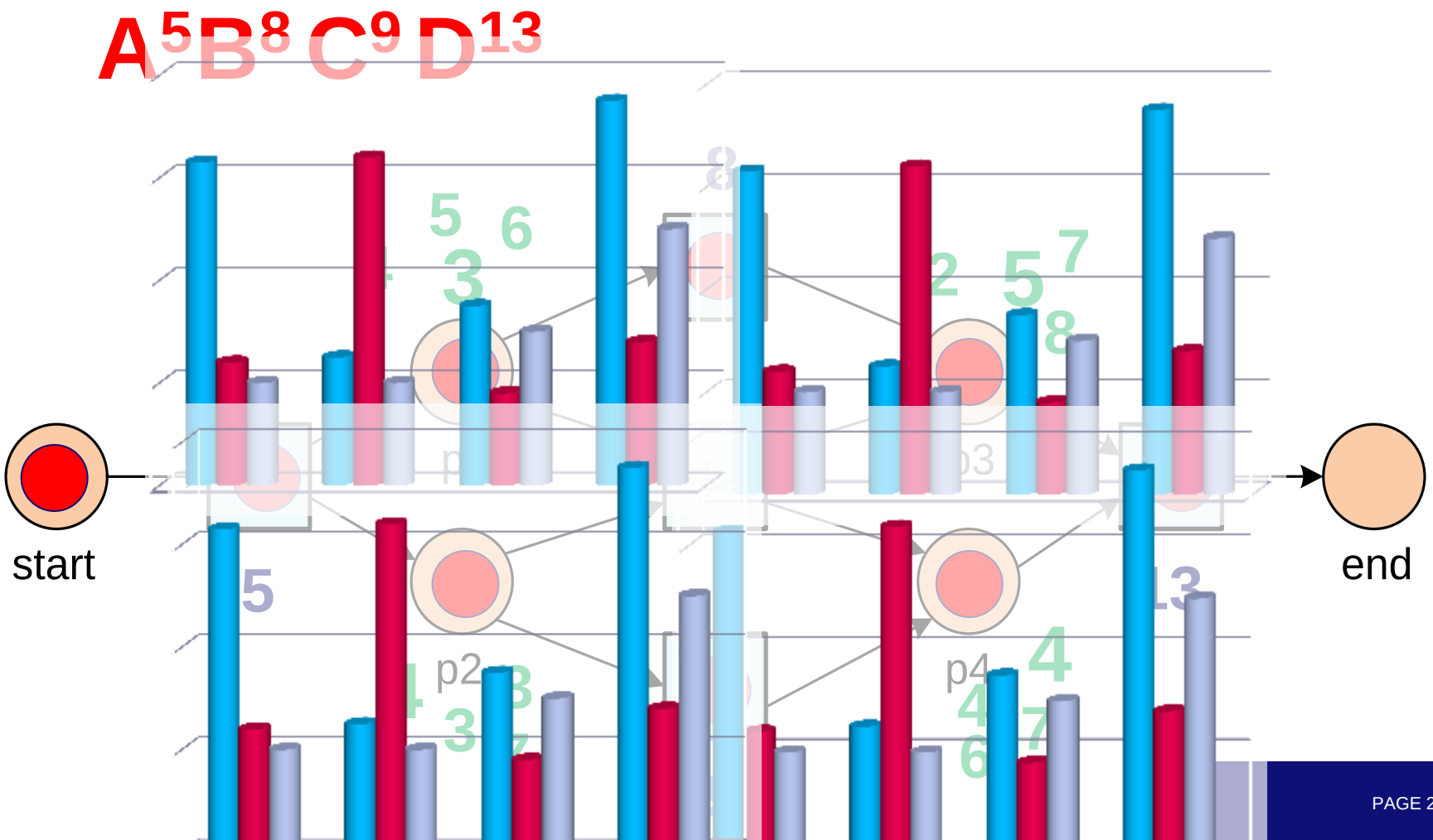
Replay can detect problems

A C D



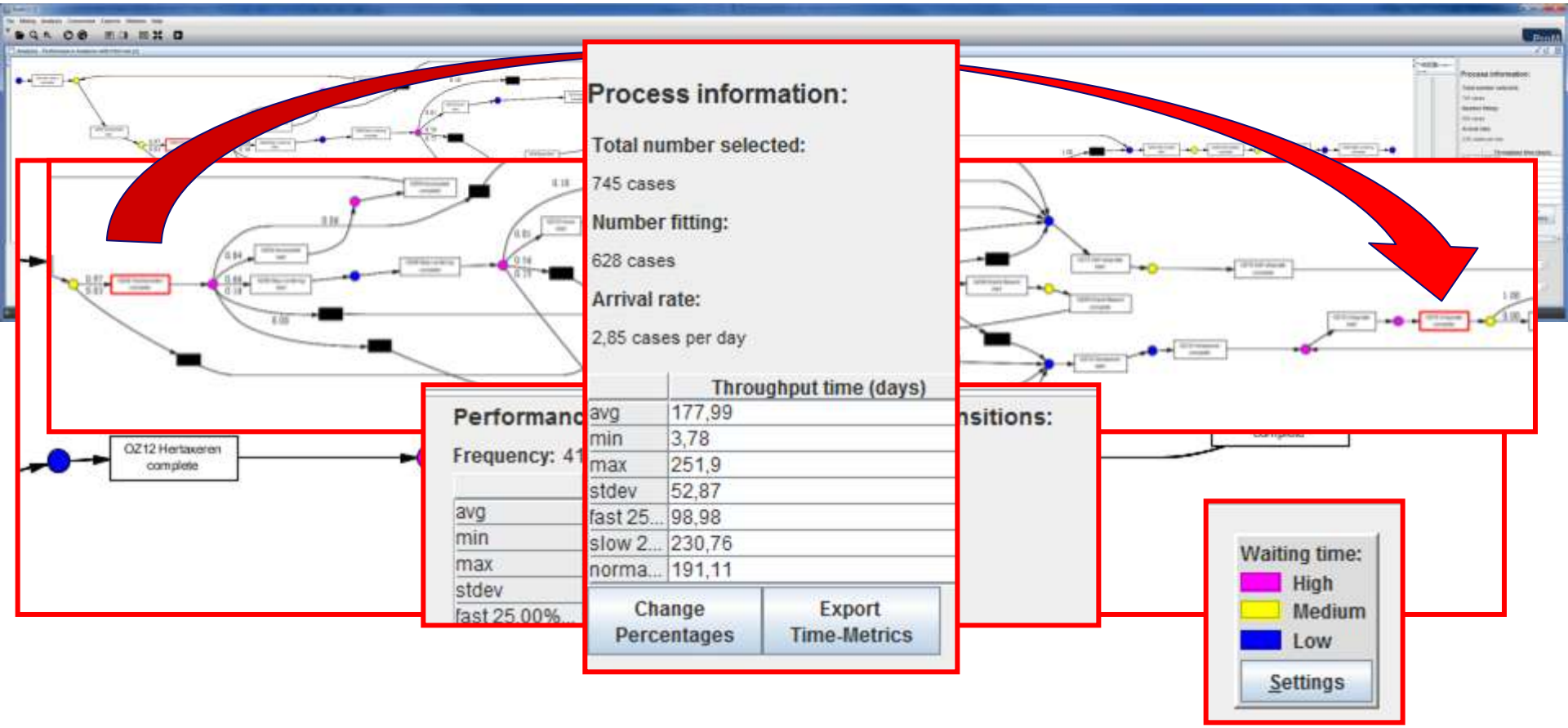

+2
-11
19
103
272
t11t5
t12t5
103
260
9
t12t13
OZ09 Wacht Beoord start
t11t13
260
-23
19
475
OZ12 Hertaxeren start
OZ15 Zelf uitspraak start
272
272
272
OZ15 Zelf u
comple
475
475
OZ12 Herta
comple
473
t16t7
1
OZ18 Uitspr
start
1
475
+1
OZ16 Uitspraak complete
475
475
1
OZ18 Uitspr
comple

Replay can extract timing information



Performance Analysis Using Replay

(WOZ objections Dutch municipality, 745 objections, 9583 event, f= 0.988)



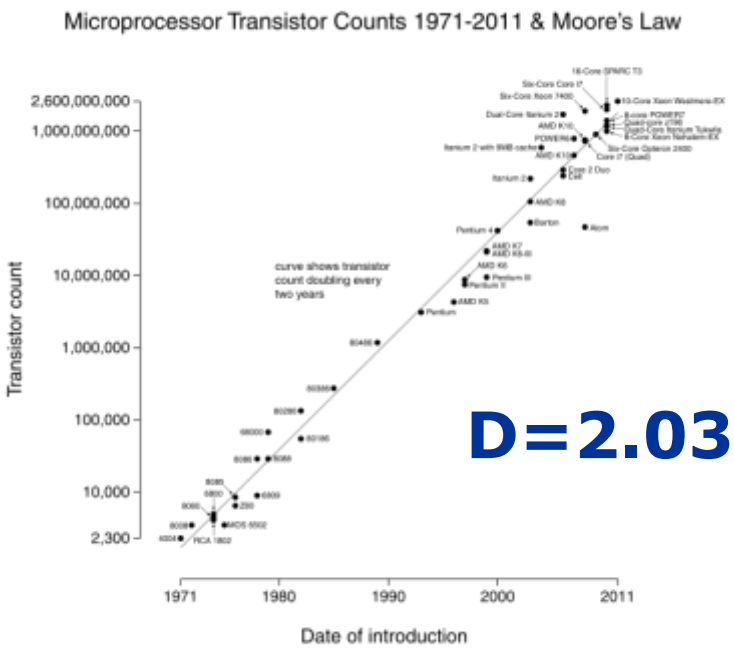
Desire Lines in Big Data

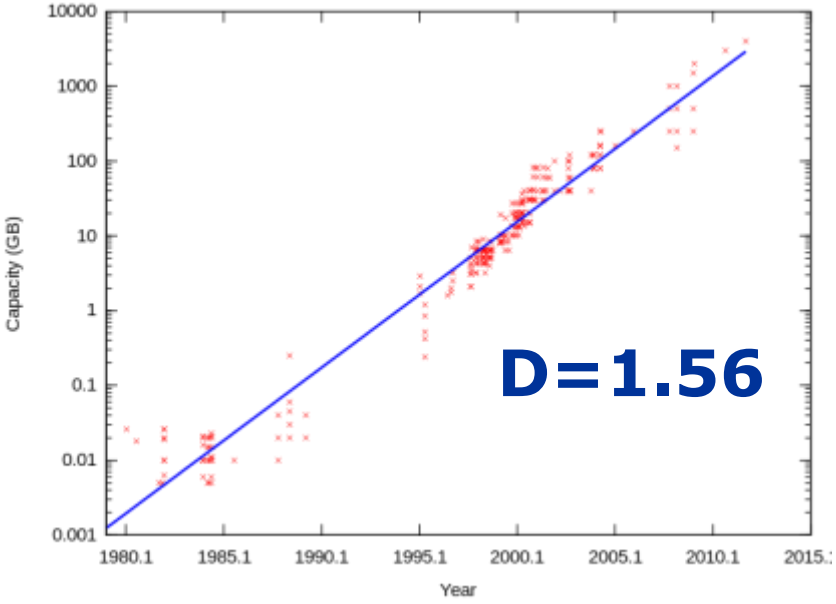
www.olifantenpaadjes.nl
60

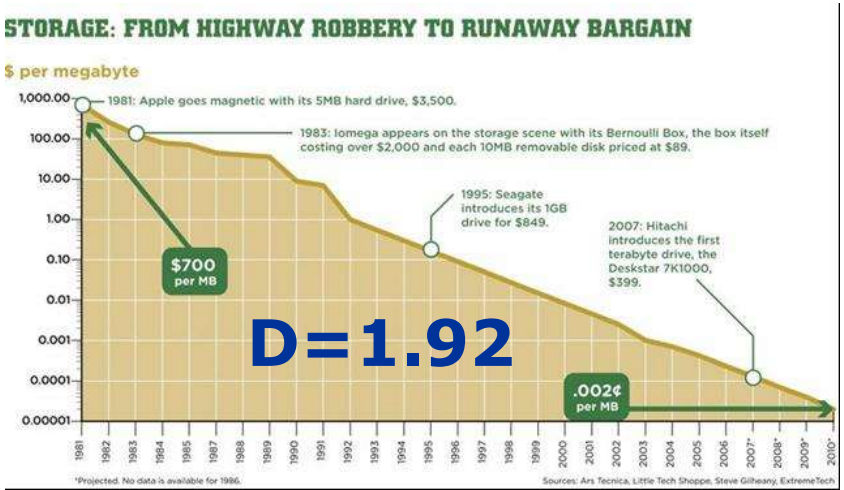
0100110101010

0100110011010101010

Moore's Law


Microprocessor Transistor Counts 1971-2011 & Moore's Law
Transistor count
2,600,000,000
1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
10,000
2,300
curve shows transistor count doubling every two years
1971
1980
1990
2000
2011
Date of introduction
D=2.03

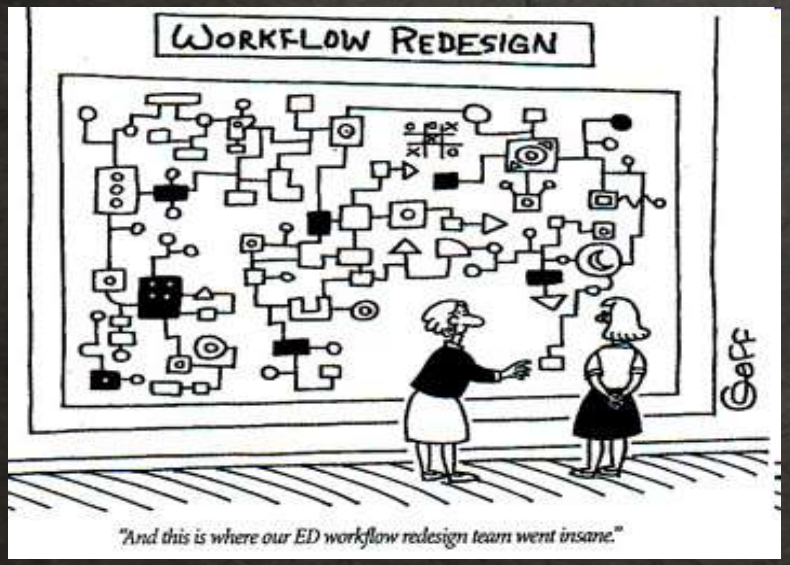

Capacity (GB)
10000
1000
100
10
1
0.1
0.01
0.001
1980.1
1985.1
1990.1
1995.1
2000.1
2005.1
2010.1
2015.
Year
D=1.56


STORAGE: FROM HIGHWAY ROBBERY TO RUNAWAY BARGAIN
$ per megabyte
1,000.00
100.00
10.00
1.00
0.10
0.01
0.001
0.0001
0.00001
1981: Apple goes magnetic with its 5MB hard drive, $3,500.
1983: Iomega appears on the storage scene with its Bernoulli Box, the box itself costing over $2,000 and each 10MB removable disk priced at $89.
1995: Seagate introduces its 1GB drive for $849.
2007: Hitachi introduces the first terabyte drive, the Deskstar 7K1000, $399.
$700 per MB
.002¢ per MB
D=1.92
1981 1982 1983 1984 1985 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007* 2008* 2009* 2010*
*Projected. No data is available for 1986.
Sources: Ars Tecnica, Little Tech Shoppe, Steve Gilheany, ExtremeTech

A simple calculation

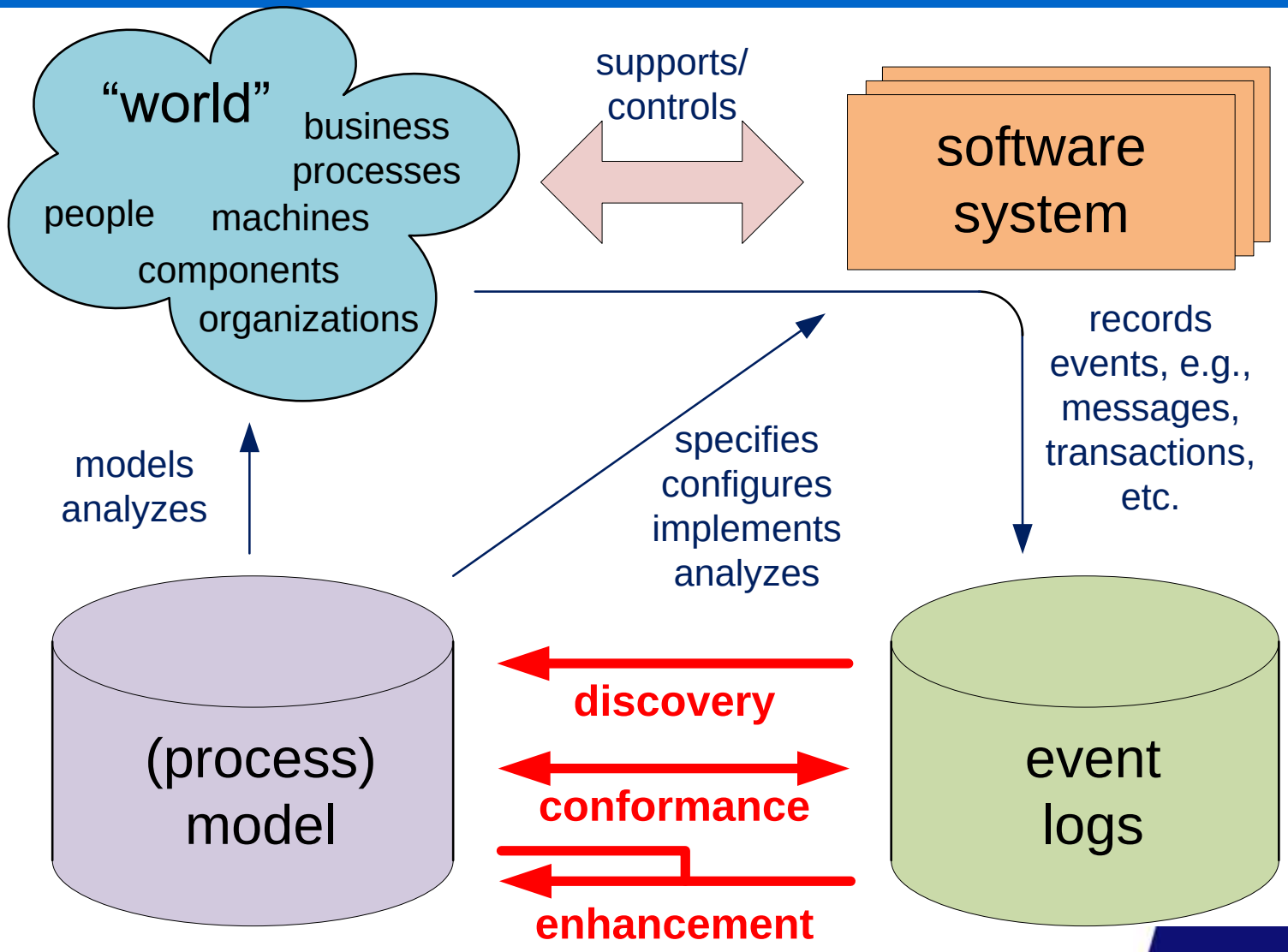
- **Starting point 2010:**
  - **Harddisk 1 Terabyte = 10^{12} bytes**
  - **Digital Universe 1.2 Zettabyte = $1.2*10^{21}$ bytes** (estimate in IDC's annual report, "The Digital Universe Decade – Are You Ready?" May 2010)
- **Disk needs to grow $2^{30.16} = 1.2* 10^{9} = 1.2*10^{21}/ 10^{12}$ times its current size.**
- **Assuming D=1.56 this takes 30.16*1.56 = 47.05 years.**
- **Hence, in 2060 your laptop can contain all of today's digital universe (internet, computer files, transaction logs, movies, photos, music, books, databases, etc.)!**

Evidence-Based Business Process Management



Process Mining

Process Mining



Starting point: event log

case id	event id	properties				
		timestamp	activity	resource	cost	...
1	35654423	30-12-2010:11.02	register request	Pete	50	...
	35654424	31-12-2010:10.06	examine thoroughly	Sue	400	...
	35654425	05-01-2011:15.12	check ticket	Mike	100	...
	35654426	06-01-2011:11.18	decide	Sara	200	...
	35654427	07-01-2011:14.24	reject request	Pete	200	...
2	35654483	30-12-2010:11.32	register request	Mike	50	...
	35654485	30-12-2010:12.12	check ticket	Mike	100	...
	35654487	30-12-2010:14.16	examine casually	Pete	400	...
	35654488	05-01-2011:11.22	decide	Sara	200	...
	35654489	08-01-2011:12.05	pay compensation	Ellen	200	...
3	35654521	30-12-2010:14.32	register request			
	35654522	30-12-2010:15.06	examine casually			
	35654524	30-12-2010:16.34	check ticket			
	35654525	06-01-2011:09.18	decide			
	35654526	06-01-2011:12.18	reinitiate request			
	35654527	06-01-2011:13.06	examine thoroughly			
	35654530	08-01-2011:11.43	check ticket			
	35654531	09-01-2011:09.55	decide			
	35654533	15-01-2011:10.45	pay compensation			
4	35654641	06-01-2011:15.02	register request			
	35654643	07-01-2011:12.06	check ticket			
	35654644	08-01-2011:14.43	examine thoroughly			
	35654645	09-01-2011:12.02	decide			
	35654647	12-01-2011:15.44	reject request			
5	35654711	06-01-2011:09.02	register request			
	35654712	07-01-2011:10.16	examine casually			
	35654714	08-01-2011:11.22	check ticket			
	35654715	10-01-2011:13.28	decide			
	35654716	11-01-2011:16.18	reinitiate request			
	35654718	14-01-2011:14.33	check ticket			
	35654719	16-01-2011:15.50	examine casually			
	35654720	19-01-2011:11.18	decide	Sara	200	...
	35654721	20-01-2011:12.48	reinitiate request	Sara	200	...
	35654722	21-01-2011:09.06	examine casually	Sue	400	...
	35654724	21-01-2011:11.34	check ticket	Pete	100	...
	35654725	23-01-2011:13.12	decide	Sara	200	...
	35654726	24-01-2011:14.56	reject request	Mike	200	...
6	35654871	06-01-2011:15.02	register request	Mike	50	...
	35654873	06-01-2011:16.06	examine casually	Ellen	400	...
	35654874	07-01-2011:16.22	check ticket	Mike	100	...
	35654875	07-01-2011:16.52	decide	Sara	200	...
	35654877	16-01-2011:11.47	pay compensation	Mike	200	...
...	...	...	...	...	...	...

case id	event id	properties				
		timestamp	activity	resource	cost	...
1	35654423	30-12-2010:11.02	register request	Pete	50	...
	35654424	31-12-2010:10.06	examine thoroughly	Sue	400	...
	35654425	05-01-2011:15.12	check ticket	Mike	100	...
	35654426	06-01-2011:11.18	decide	Sara	200	...
	35654427	07-01-2011:14.24	reject request	Pete	200	...
2	35654483	30-12-2010:11.32	register request	Mike	50	...
	35654485	30-12-2010:12.12	check ticket	Mike	100	...
	35654487	30-12-2010:14.16	examine casually	Pete	400	...
	35654488	05-01-2011:11.22	decide	Sara	200	...
	35654489	08-01-2011:12.05	pay compensation	Ellen	200	...

XES, MXML, SA-MXML, CSV, etc.

Simplified event log

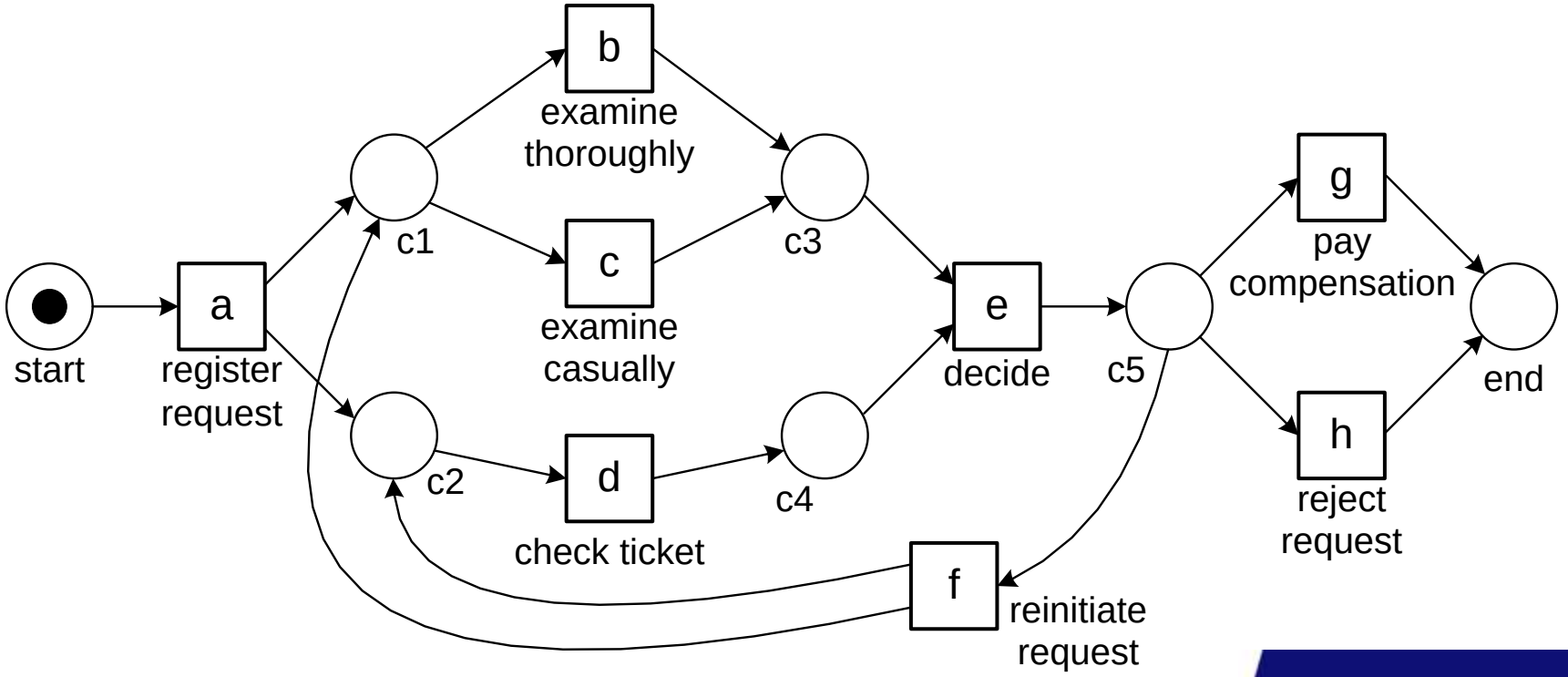
case id	event id	properties				
		timestamp	activity	resource		
1	35654423	30-12-2010:11.02	register request	Pete		
	35654424	31-12-2010:10.06	examine thoroughly	Sue		
	35654425	05-01-2011:15.12	check ticket	Mike		
	35654426	06-01-2011:11.18	decide	Sara		
	35654427	07-01-2011:14.24	reject request	Pete		
2	35654483	30-12-2010:11.32	register request	Mike		
	35654485	30-12-2010:12.12	check ticket	Mike		
	35654487	30-12-2010:14.16	examine casually	Pete		
	35654488	05-01-2011:11.22	decide	Sara		
	35654489	08-01-2011:12.05	pay compensation	Ellen		
3	35654521	30-12-2010:14.32	register request	Pete		
	35654522	30-12-2010:15.06	examine casually	Mike		
	35654524	30-12-2010:16.34	check ticket	Ellen		
	35654525	06-01-2011:09.18	decide	Sara		
	35654526	06-01-2011:12.18	reinitiate request	Sara		
	35654527	06-01-2011:13.06	examine thoroughly	Sean		
	35654530	08-01-2011:11.43	check ticket	Pete		
	35654531	09-01-2011:09.55	decide	Sara		
	35654533	15-01-2011:10.45	pay compensation	Ellen		
4	35654641	06-01-2011:15.02	register request	Pete	50	...
	35654643	07-01-2011:12.06	check ticket	Mike	100	...
	35654644	08-01-2011:14.43	examine thoroughly	Sean	400	...
	35654645	09-01-2011:12.02	decide	Sara	200	...
	35654647	12-01-2011:15.44	reject request	Ellen	200	...
5	35654711	06-01-2011:09.02	register request	Ellen	50	...
	35654712	07-01-2011:10.16	examine casually	Mike	400	...
	35654714	08-01-2011:11.22	check ticket	Pete	100	...
	35654715	10-01-2011:13.28	decide	Sara	200	...
	35654716	11-01-2011:16.18	reinitiate request	Sara	200	...
	35654718	14-01-2011:14.33	check ticket	Ellen	100	...
	35654719	16-01-2011:15.50	examine casually	Mike	400	...
	35654720	19-01-2011:11.18	decide	Sara	200	...
	35654721	20-01-2011:12.48	reinitiate request	Sara	200	...
	35654722	21-01-2011:09.06	examine casually	Sue	400	...
	35654724	21-01-2011:11.34	check ticket	Pete	100	...
	35654725	23-01-2011:13.12	decide	Sara	200	...
	35654726	24-01-2011:14.56	reject request	Mike	200	...
6	35654871	06-01-2011:15.02	register request	Mike	50	...
	35654873	06-01-2011:16.06	examine casually	Ellen	400	...
	35654874	07-01-2011:16.22	check ticket	Mike	100	...
	35654875	07-01-2011:16.52	decide	Sara	200	...
	35654877	16-01-2011:11.47	pay compensation	Mike	200	...
...	...	...	...	...	...	...

case id	trace
1	$\langle a,b,d,e,h \rangle$
2	$\langle a,d,c,e,g \rangle$
3	$\langle a,c,d,e,f,b,d,e,g \rangle$
4	$\langle a,d,b,e,h \rangle$
5	$\langle a,c,d,e,f,d,c,e,f,c,d,e,h \rangle$
6	$\langle a,c,d,e,g \rangle$
...	...

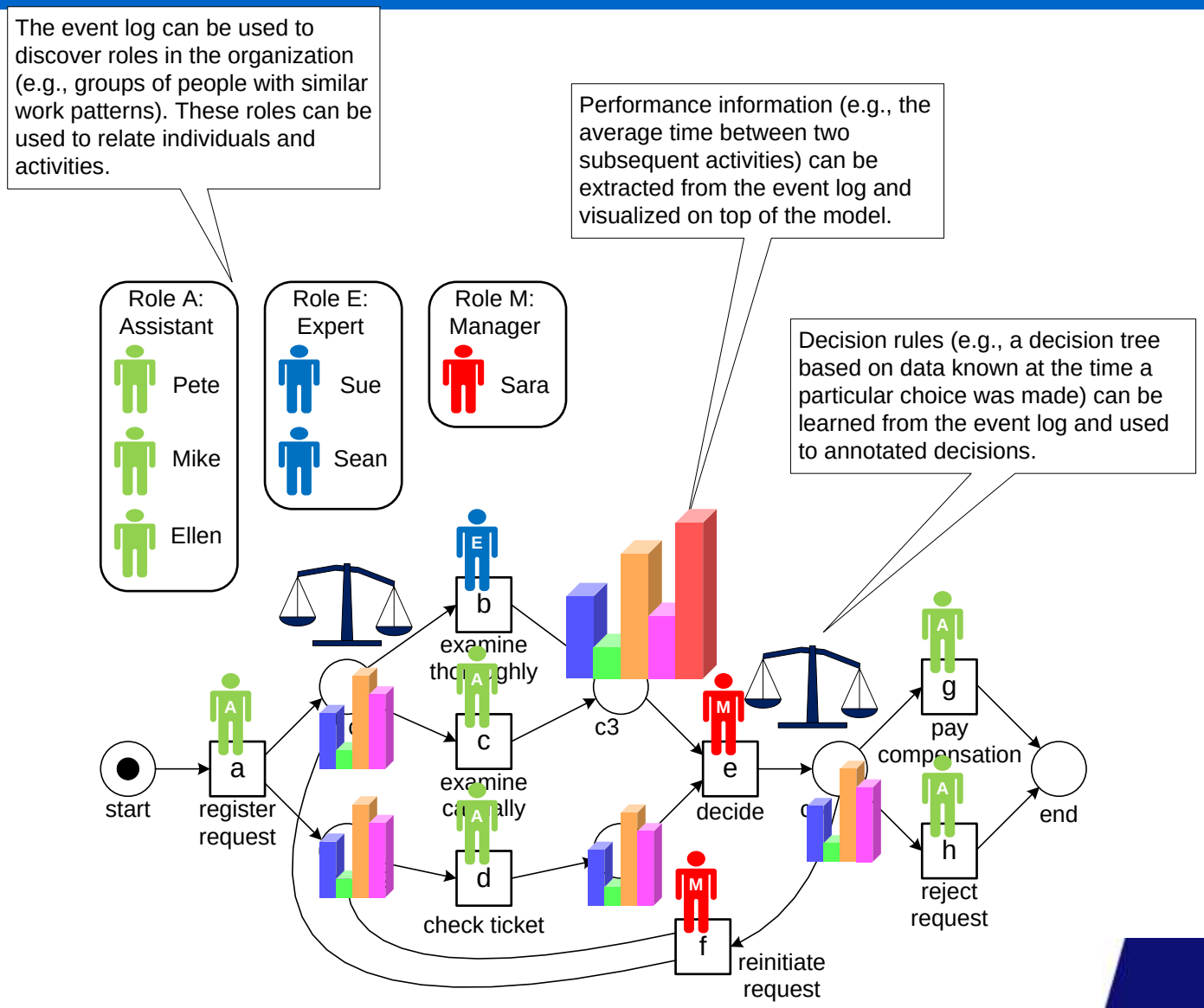
a = register request,
b = examine thoroughly,
c = examine casually,
d = check ticket,
e = decide,
f = reinitiate request,
g = pay compensation,
and h = reject request

Process discovery

case id	trace
1	$\langle a,b,d,e,h \rangle$
2	$\langle a,d,c,e,g \rangle$
3	$\langle a,c,d,e,f,b,d,e,g \rangle$
4	$\langle a,d,b,e,h \rangle$
5	$\langle a,c,d,e,f,d,c,e,f,c,d,e,h \rangle$
6	$\langle a,c,d,e,g \rangle$
...	...

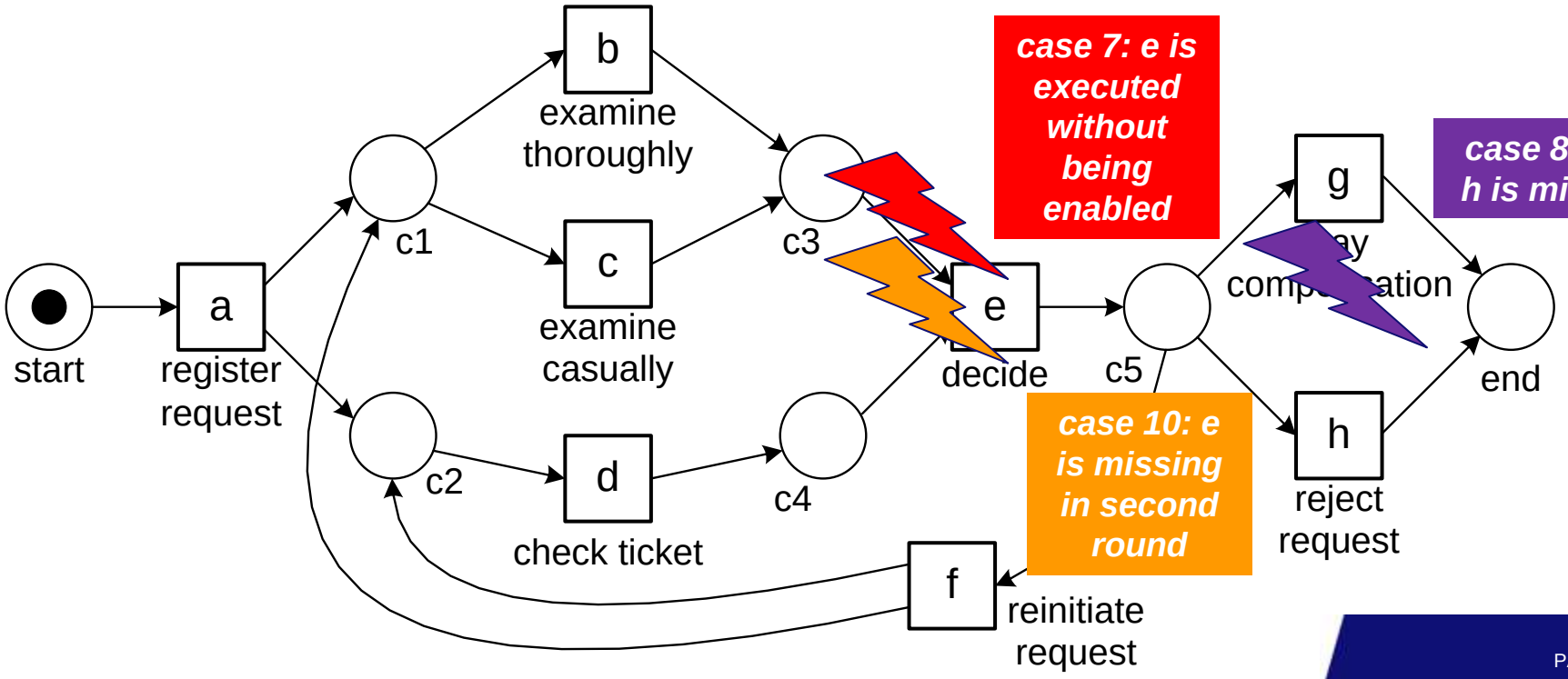


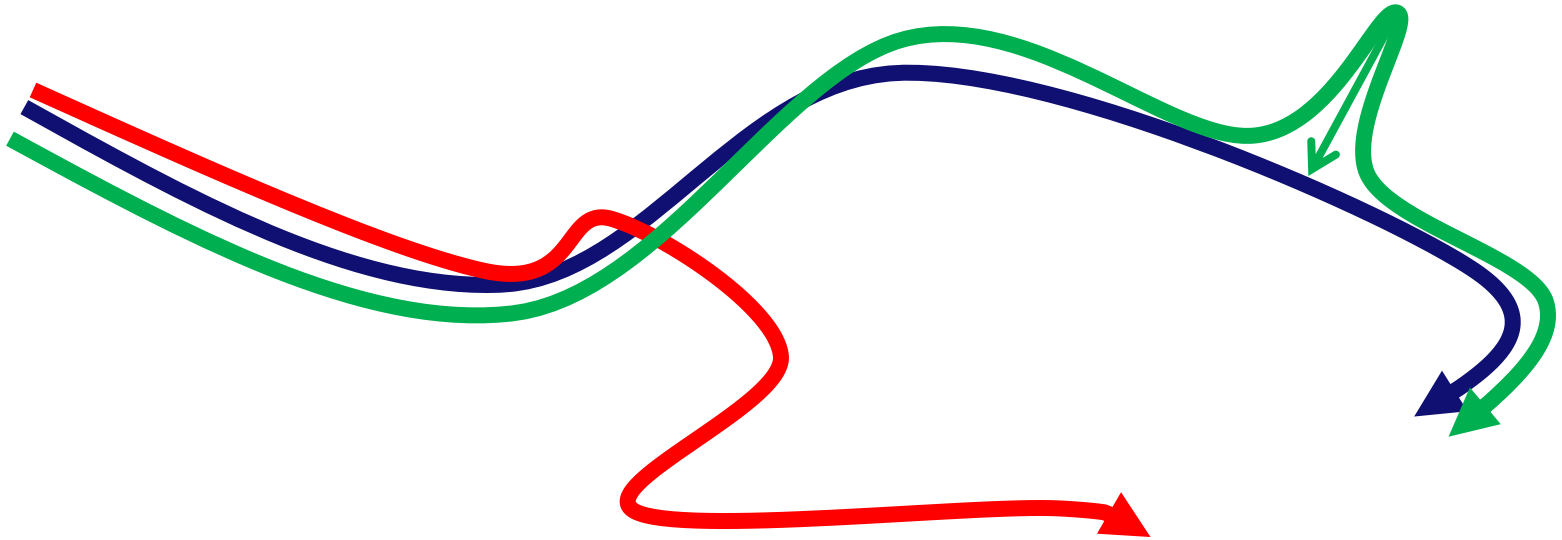
Extension: Adding perspectives to model based on event log



Conformance checking

case id	trace
1	$\langle a,b,d,e,h\rangle$
2	$\langle a,d,c,e,g\rangle$
3	$\langle a,c,d,e,f,b,d,e,g\rangle$
4	$\langle a,d,b,e,h\rangle$
5	$\langle a,c,d,e,f,d,c,e,f,c,d,e,h\rangle$
6	$\langle a,c,d,e,g\rangle$
7	$\langle \mathbf{a},\mathbf{b},\mathbf{e},\mathbf{g}\rangle$
8	$\langle \mathbf{a},\mathbf{b},\mathbf{d},\mathbf{e}\rangle$
9	$\langle a,d,c,e,f,d,c,e,f,b,d,e,h\rangle$
10	$\langle \mathbf{a},\mathbf{c},\mathbf{d},\mathbf{e},\mathbf{f},\mathbf{b},\mathbf{d},\mathbf{g}\rangle$

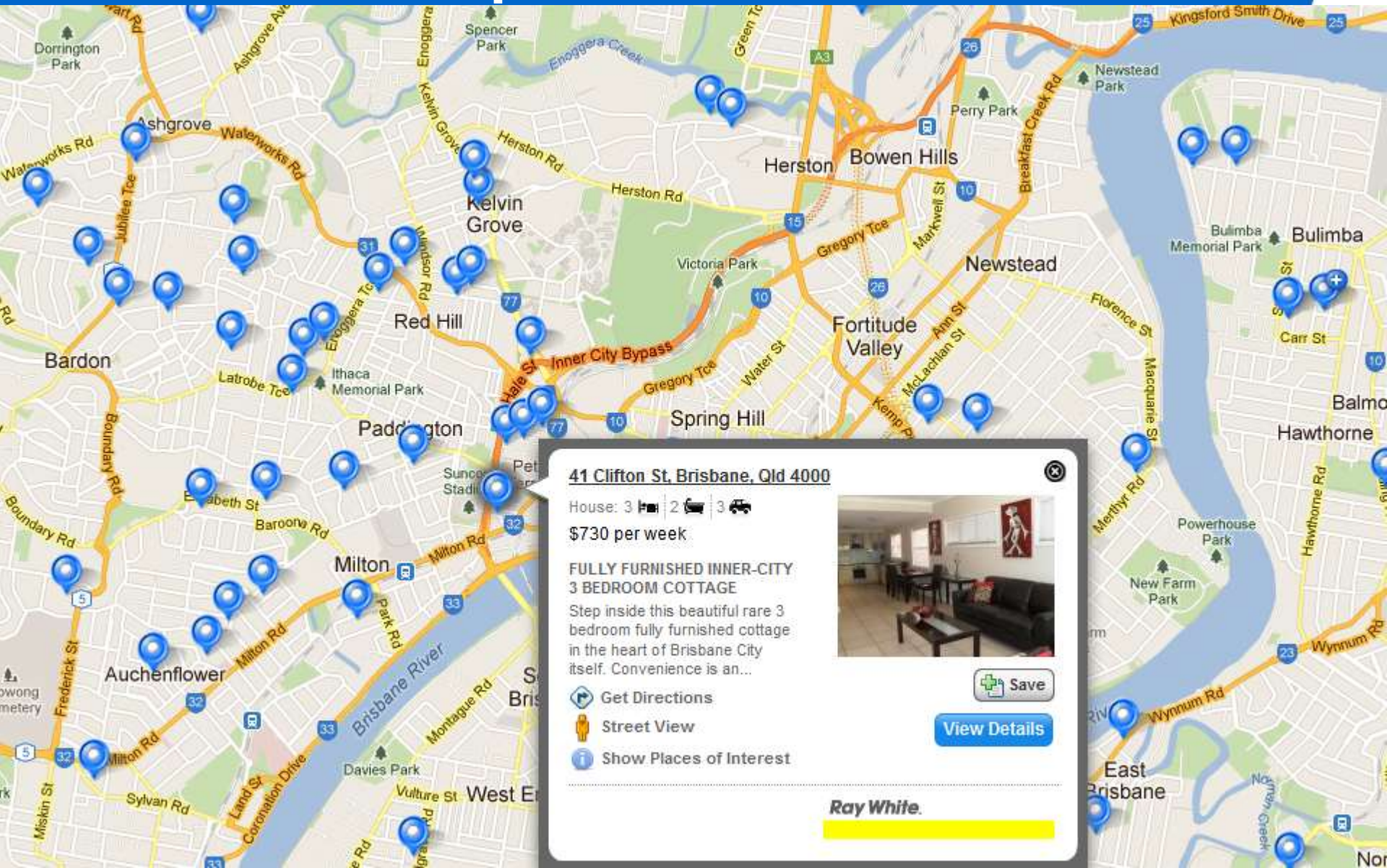




Alignments are essential!

- **conformance checking to diagnose deviations**
- **squeezing reality into the model to do model-based analysis**

Process models should be treated as electronic maps



Food for Thought

We applied ProM in >100 organizations

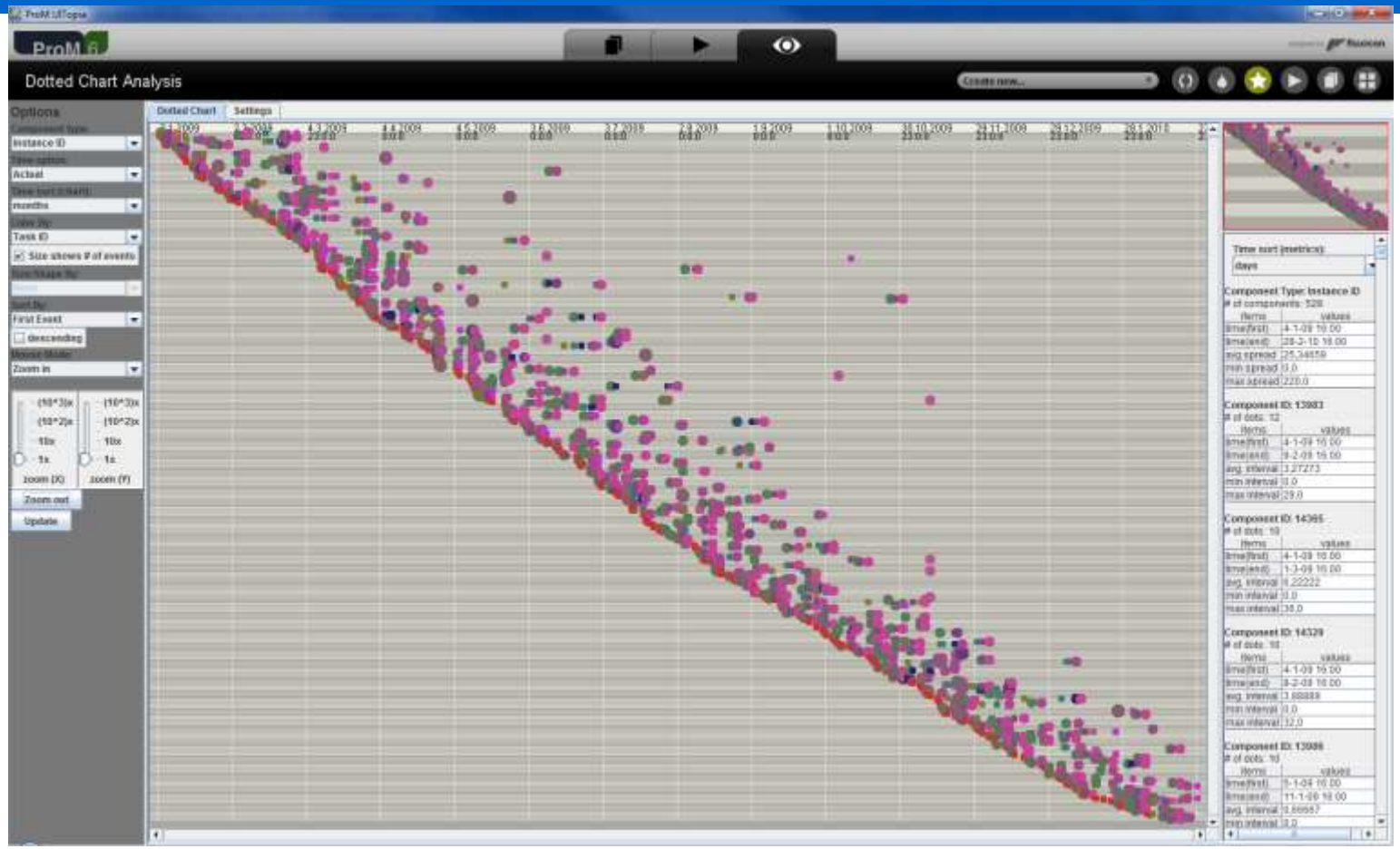
- **Municipalities** (e.g., Alkmaar, Heusden, Harderwijk, etc.)
- **Government agencies** (e.g., Rijkswaterstaat, Centraal Justitieel Incasso Bureau, Justice department)
- **Insurance related agencies** (e.g., UWV)
- **Banks** (e.g., ING Bank)
- **Hospitals** (e.g., AMC hospital, Catharina hospital, azM hospital, Isala clinics, GGzE)
- **Multinationals** (e.g., DSM, Deloitte)
- **High-tech system manufacturers and their customers** (e.g., Philips Healthcare, ASML, Ricoh, Thales)
- **Media companies** (e.g. Winkwaves)
- **...**

How can process mining help?

- Uncover bottlenecks
- Detect deviations
- Performance measurement
- Auditing/compliance
- Business Process Redesign (BPR)
- Continuous improvement (Six Sigma)
- Operational support (e.g., recommendation and prediction)

- Provide new insights
- Highlight important problems
- An organization's mirror (in two ways)
- Helps to avoid ICT failures
- Avoid "management by PowerPoint"
- From "politics" to "analytics"

Example of a Lasagna process: WMO process of a Dutch municipality

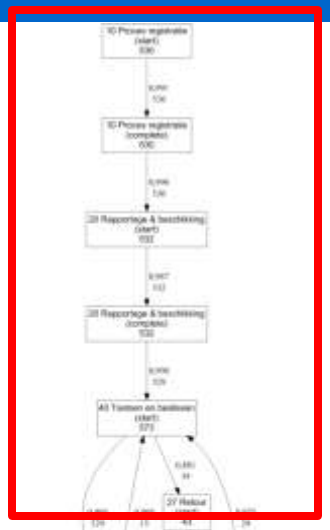


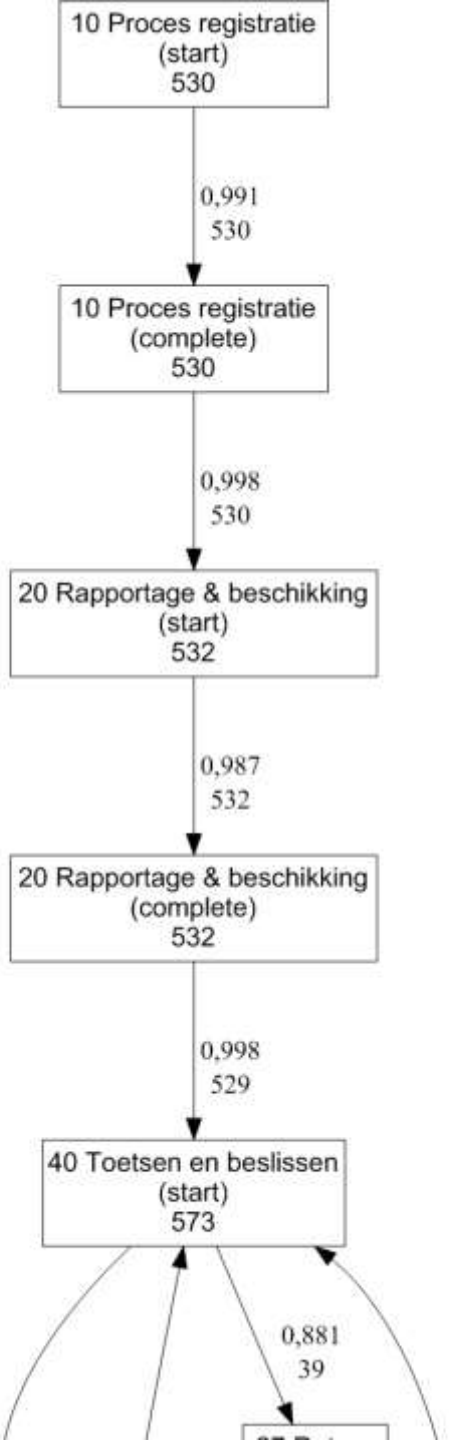
Each line corresponds to one of the 528 requests that were handled in the period from 4-1-2009 until 28-2-2010. In total there are 5498 events represented as dots. The mean time needed to handled a case is approximately 25 days.

WMO process
(Wet Maatschappelijke Ondersteuning)

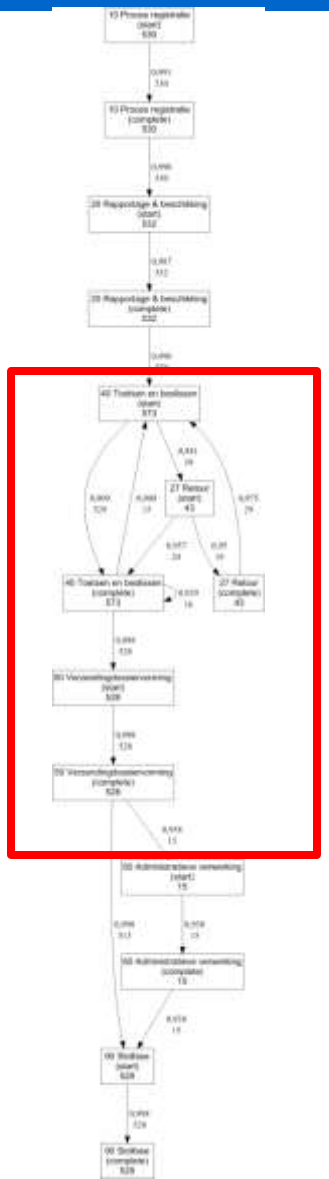
- **WMO refers to the social support act that came into force in The Netherlands on January 1st, 2007.**
- **The aim of this act is to assist people with disabilities and impairments. Under the act, local authorities are required to give support to those who need it, e.g., household help, providing wheelchairs and scootmobiles, and adaptations to homes.**
- **There are different processes for the different kinds of help. We focus on the process for handling requests for household help.**
- **In a period of about one year, 528 requests for household WMO support were received.**
- **These 528 requests generated 5498 events.**

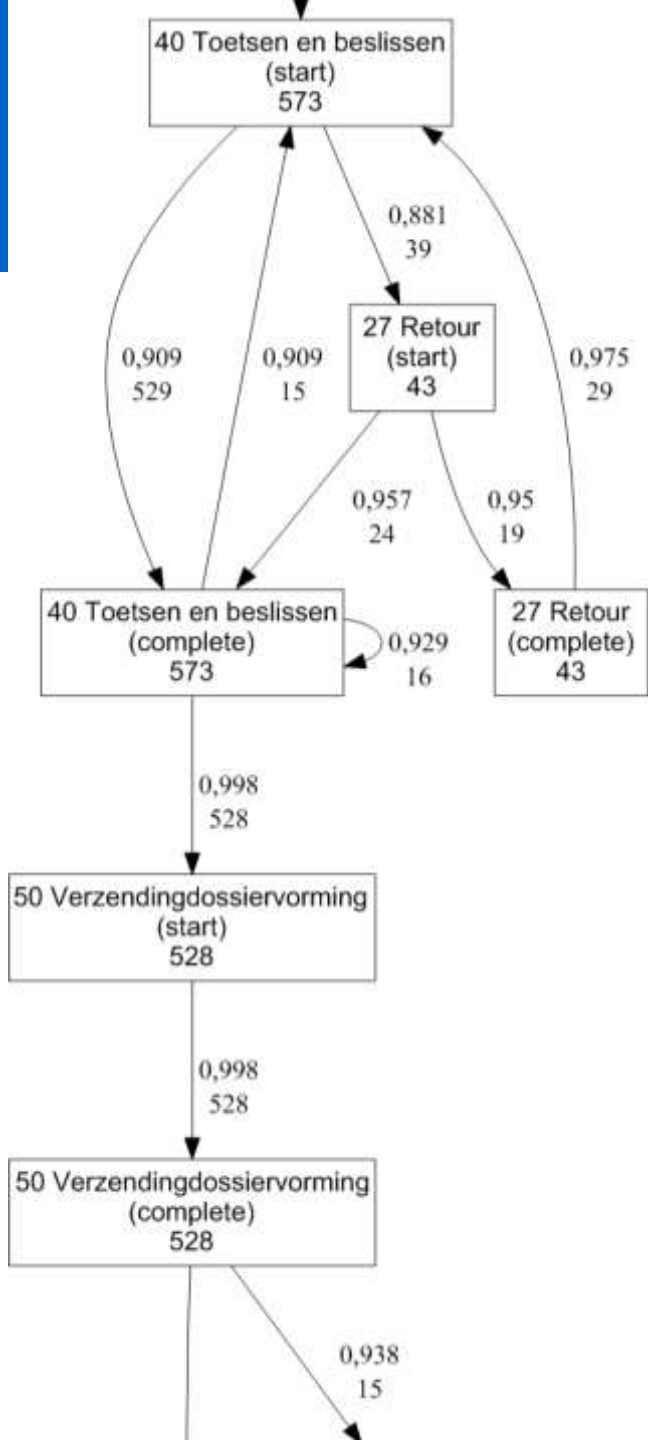
C-net discovered using heuristic miner (1/3)



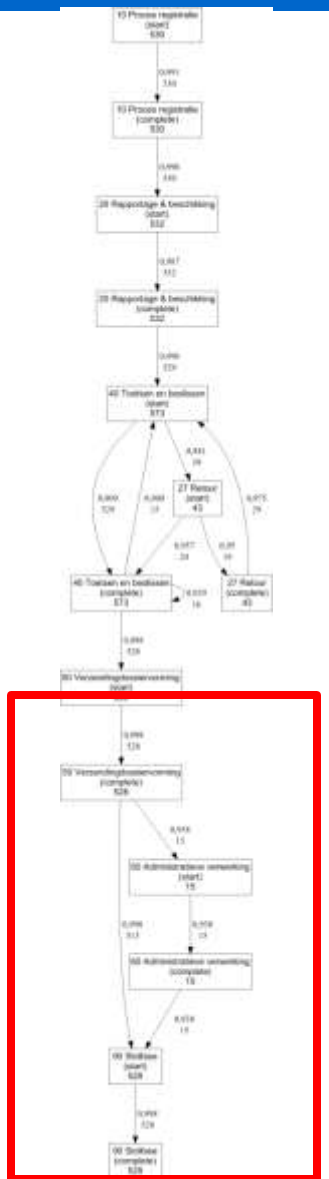


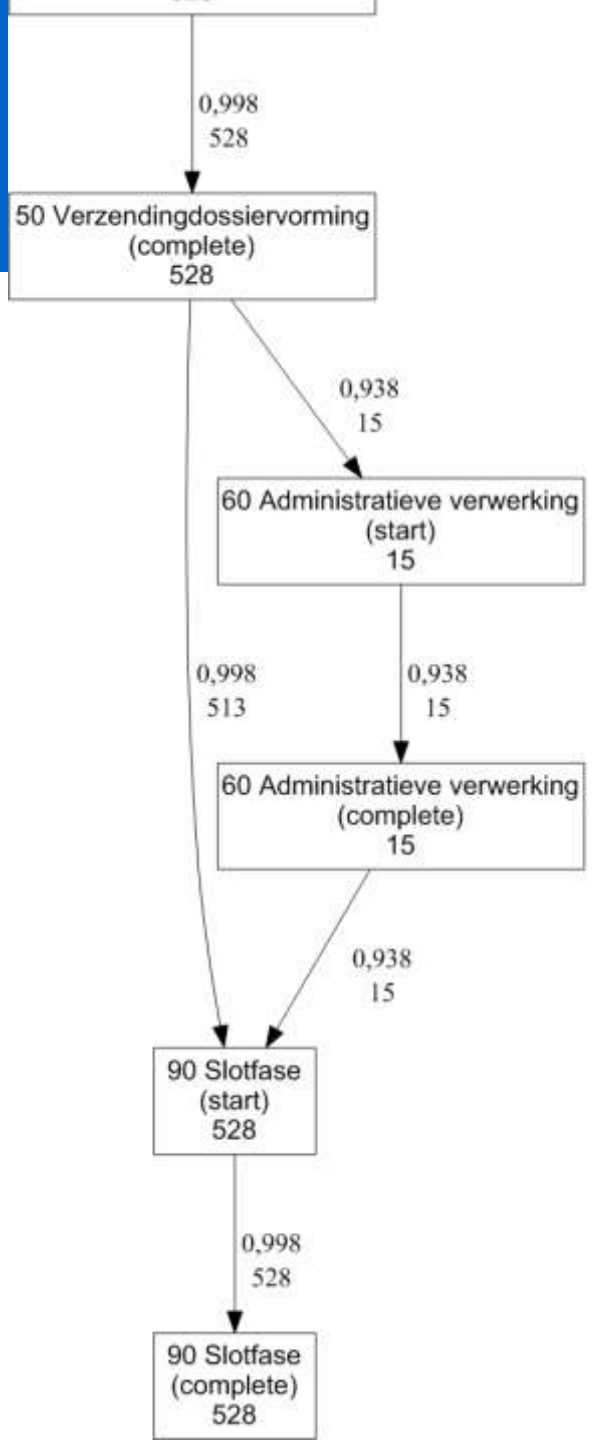
C-net discovered using heuristic miner (2/3)



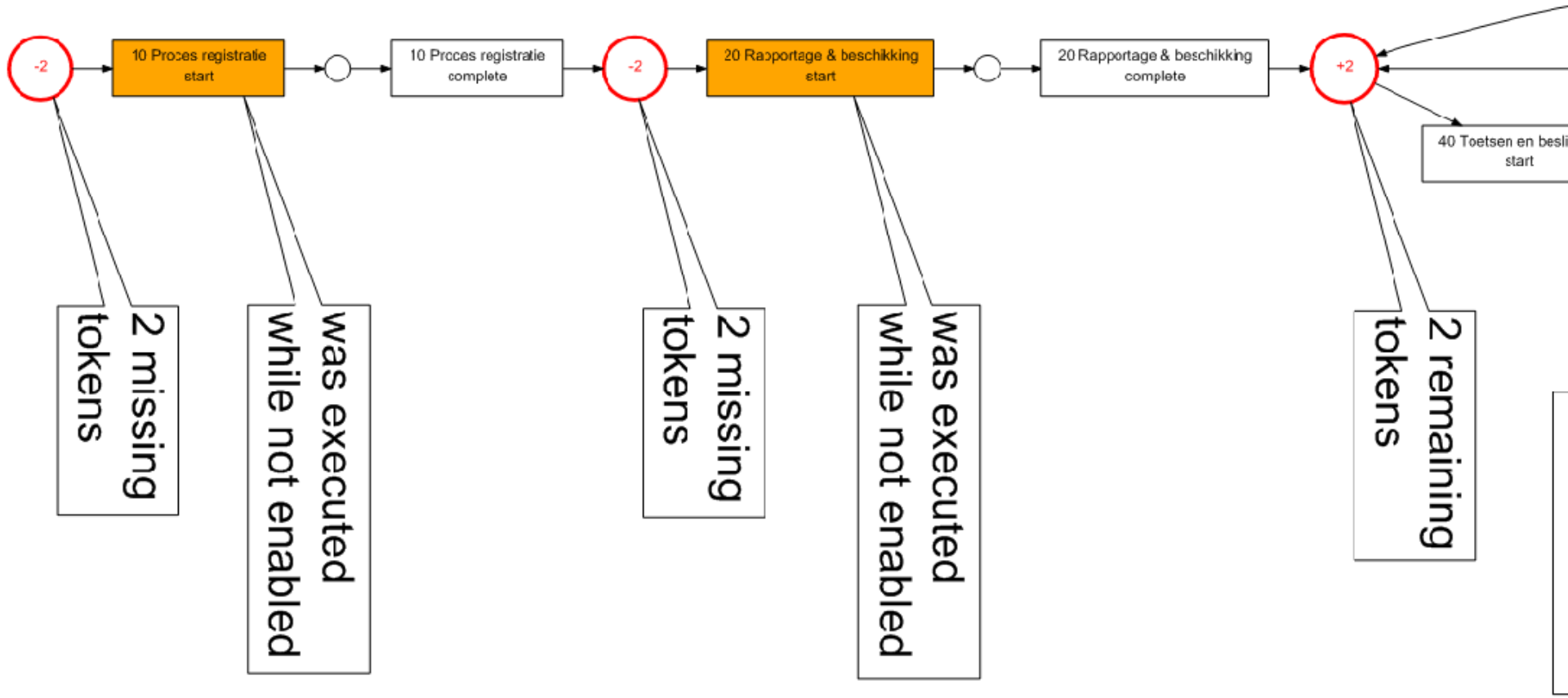


C-net discovered using heuristic miner (3/3)

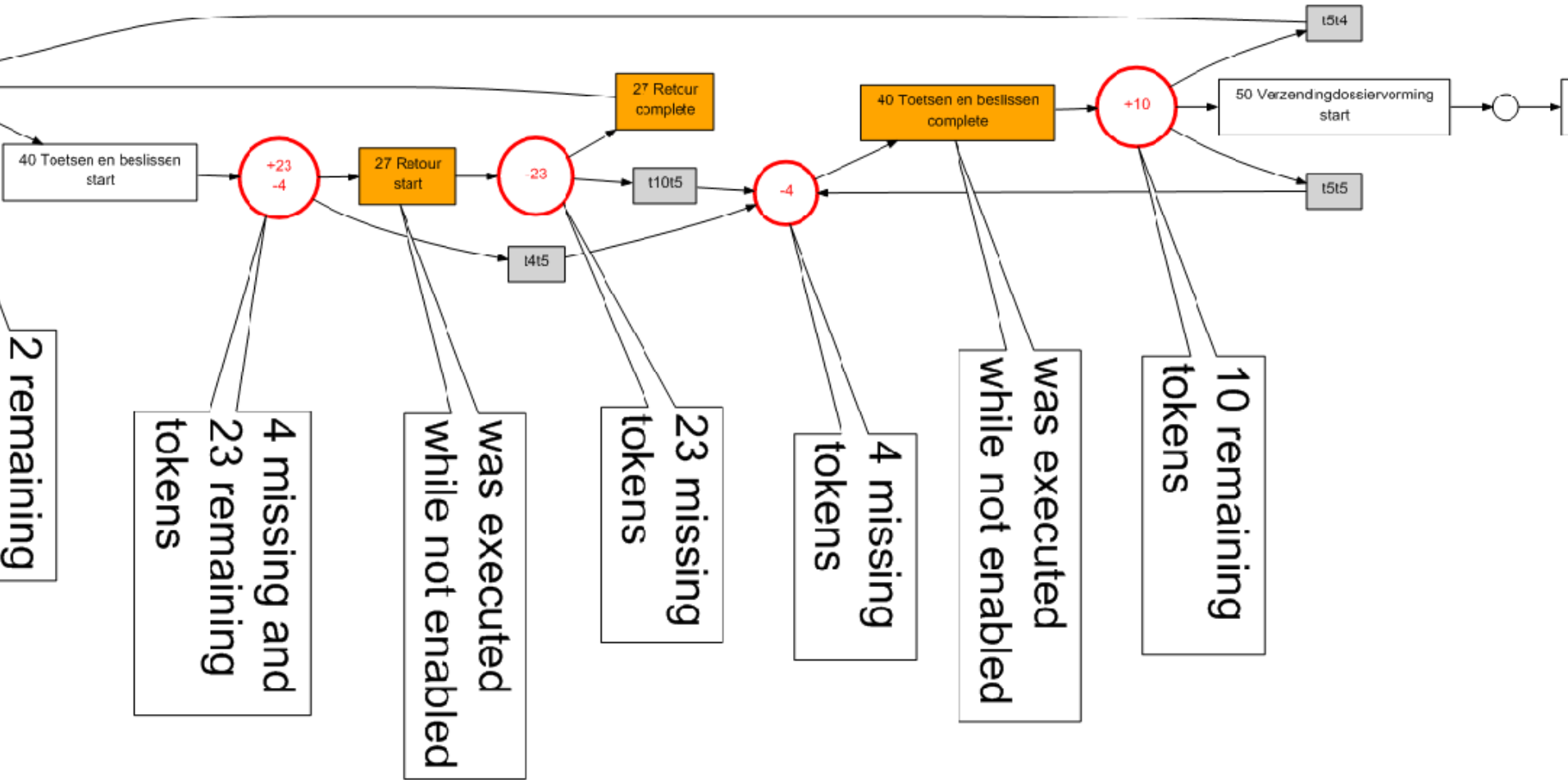




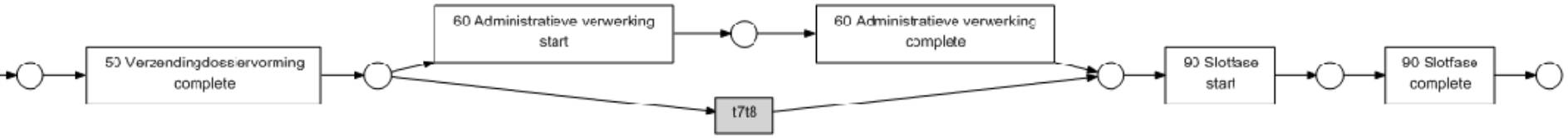
Conformance check WMO process (1/3)



Conformance check WMO process (2/3)

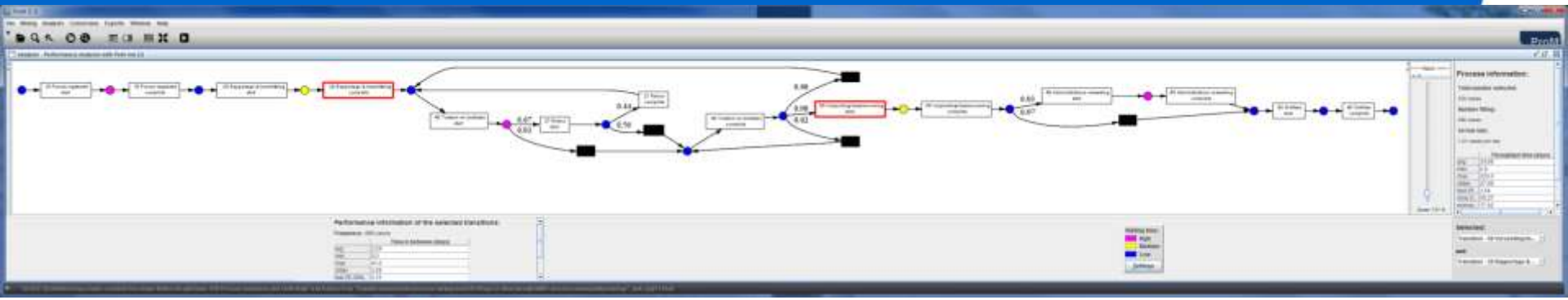


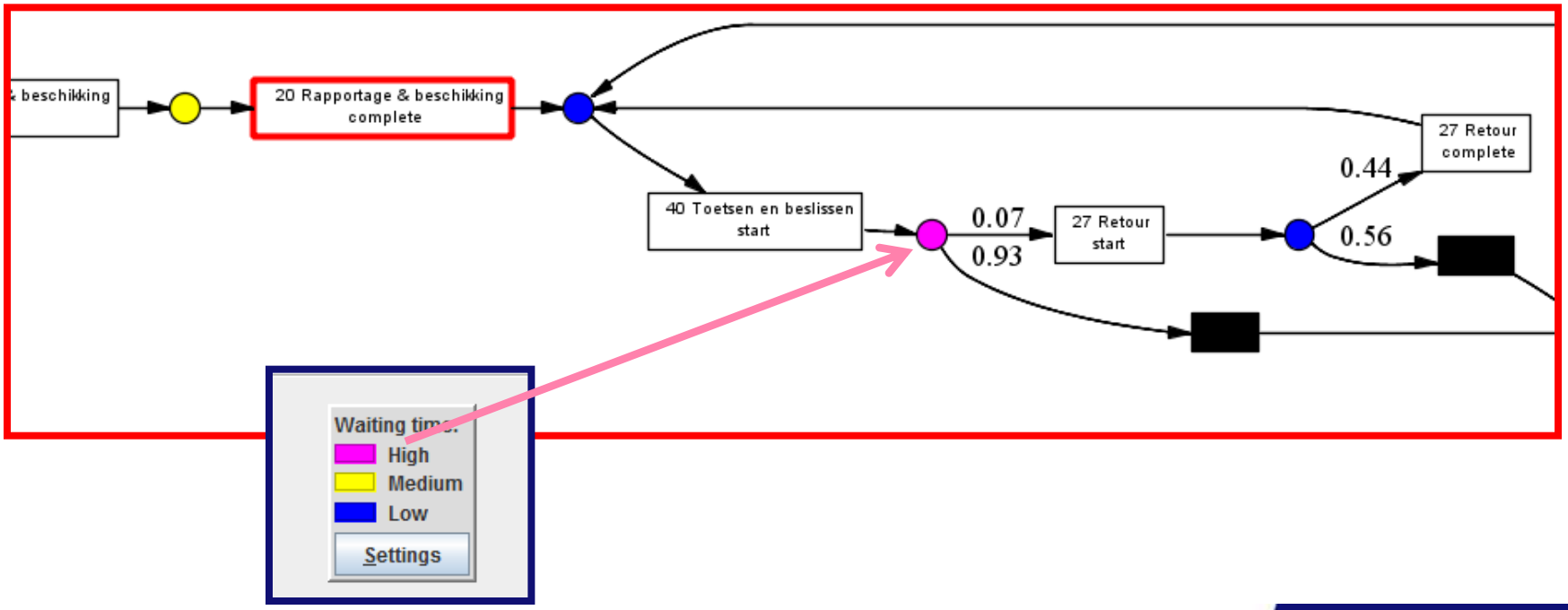
Conformance check WMO process (3/3)



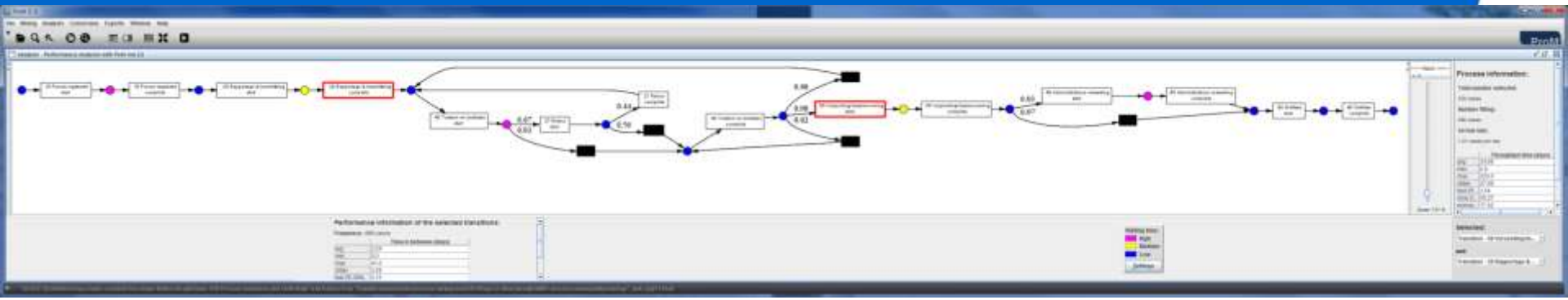
The fitness of the discovered process is 0.99521667. Of the 528 cases, 496 cases fit perfectly whereas for 32 cases there are missing or remaining tokens.

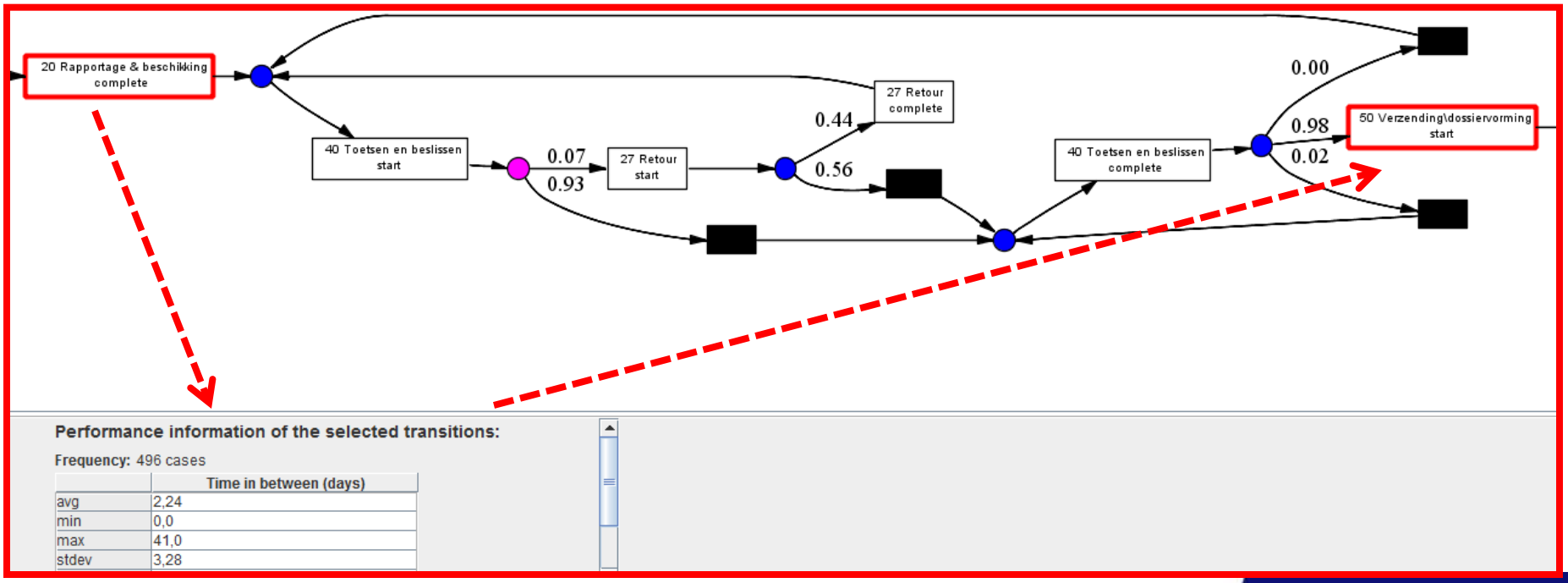
Bottleneck analysis WMO process (1/3)





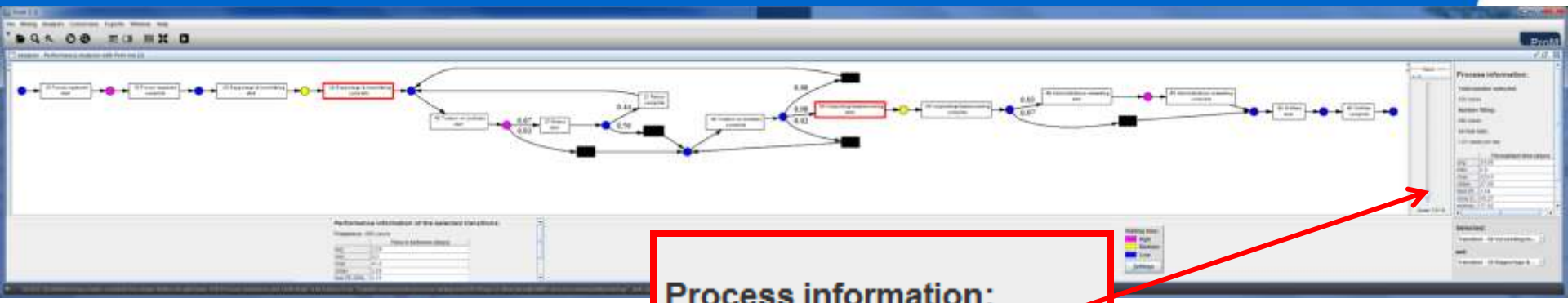
Bottleneck analysis WMO process (2/3)





	Time in between (days)
avg	2,24
min	0,0
max	41,0
stdev	3,28

Bottleneck analysis WMO process (3/3)



flow time of approx. 25 days with a standard deviation of approx. 28

Process information:

Total number selected:

528 cases

Number fitting:

496 cases

Arrival rate:

1,21 cases per day

	Throughput time (days)
avg	24,66
min	0,0
max	220,0
stdev	27,86
fast 25...	3,54
slow 2...	60,27
norma...	17,42

Academic Medical Center (AMC)

- University hospital, Amsterdam
  - >1000 beds
  - 25.000 patients admitted
  - 35.000 day admissions
  - 350.000 outpatient clinic visits
- Process surgery department
  - Diagnosis
  - Surgery
  - Aftercare
- Patient groups considered
  - General complaints stomach (algemene buikklachten n.n.o.)
  - Inguinal hernia (liesbreuk)
  - Varicose veins (spataderen)
  - Hemorroids (aambeien)
  - Lipoma and sebaceous cyst (lipoom (goedaardig gezwel van vetweefselcellen) en atheroom (verstopte talgklier))

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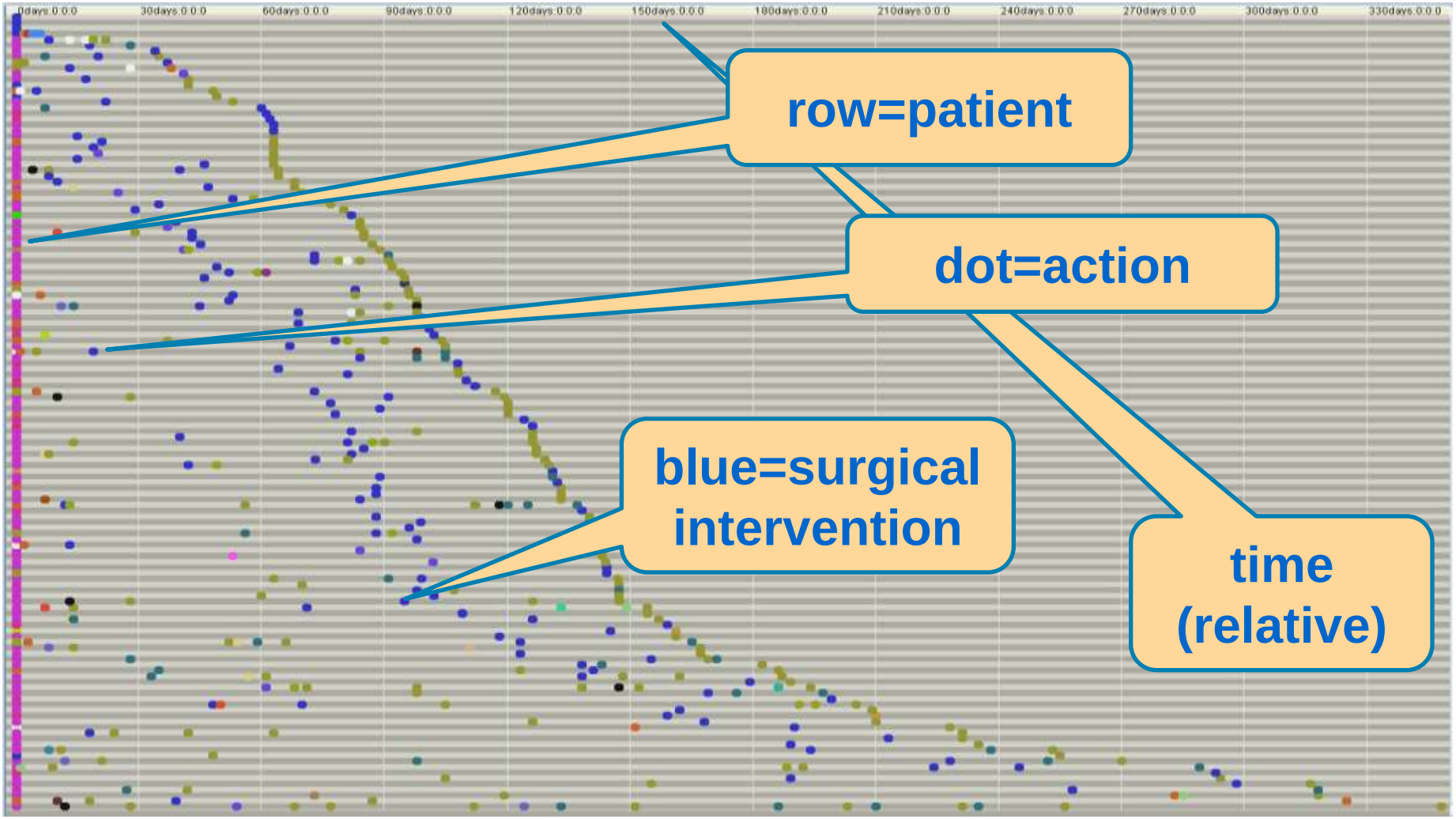
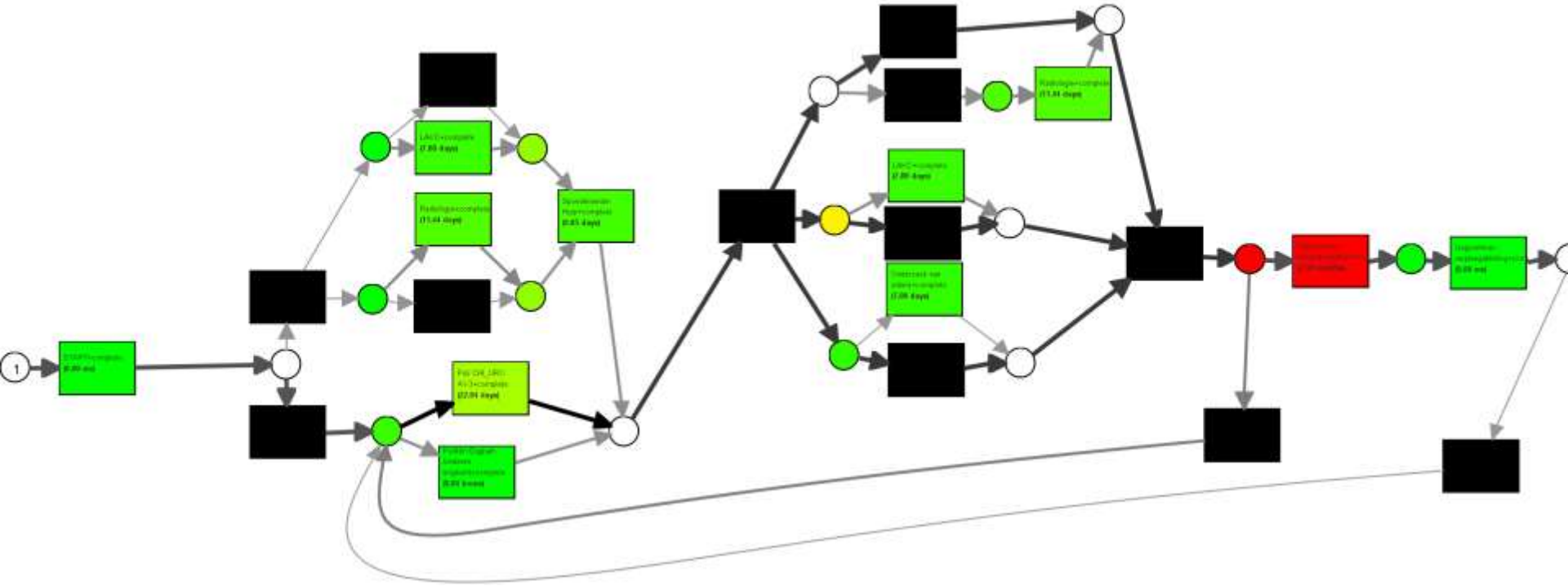
Dotted chart showing flow times

hernia inguinalis (liesbreuk) with day admission



Discovered process model with bottlenecks

hernia inguinalis (liesbreuk) with day admission

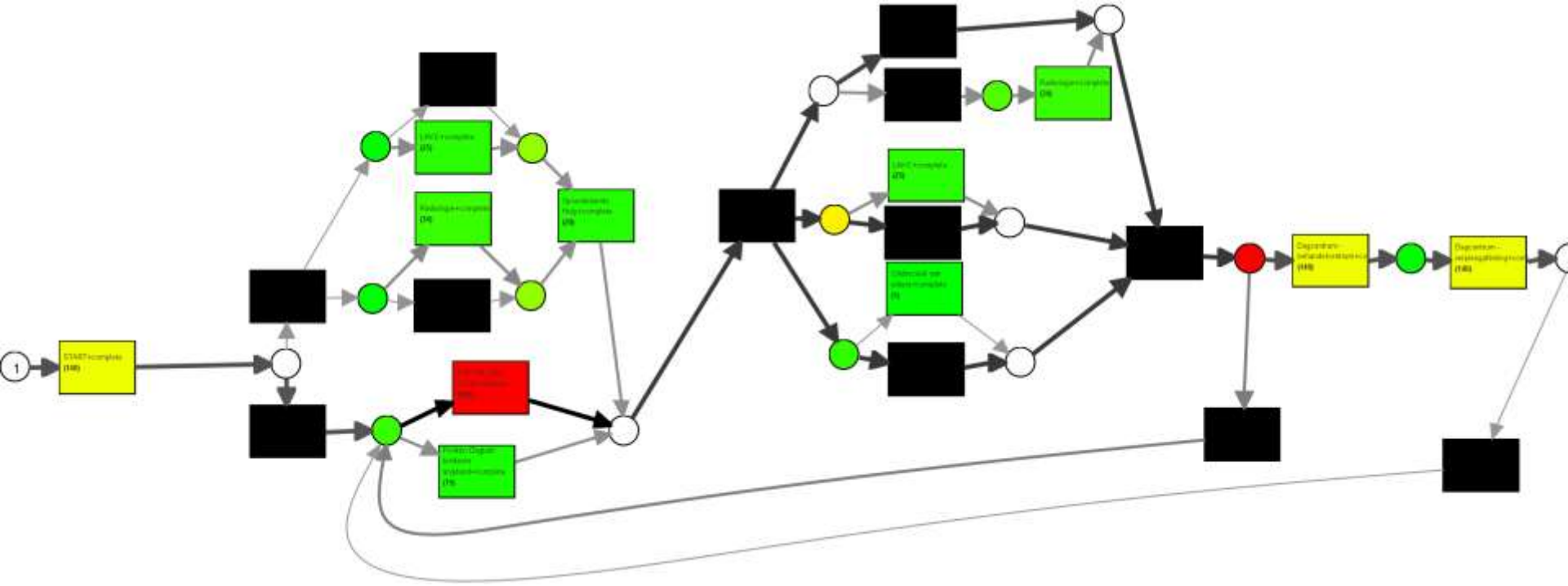


color indicates time

fitness=0.97

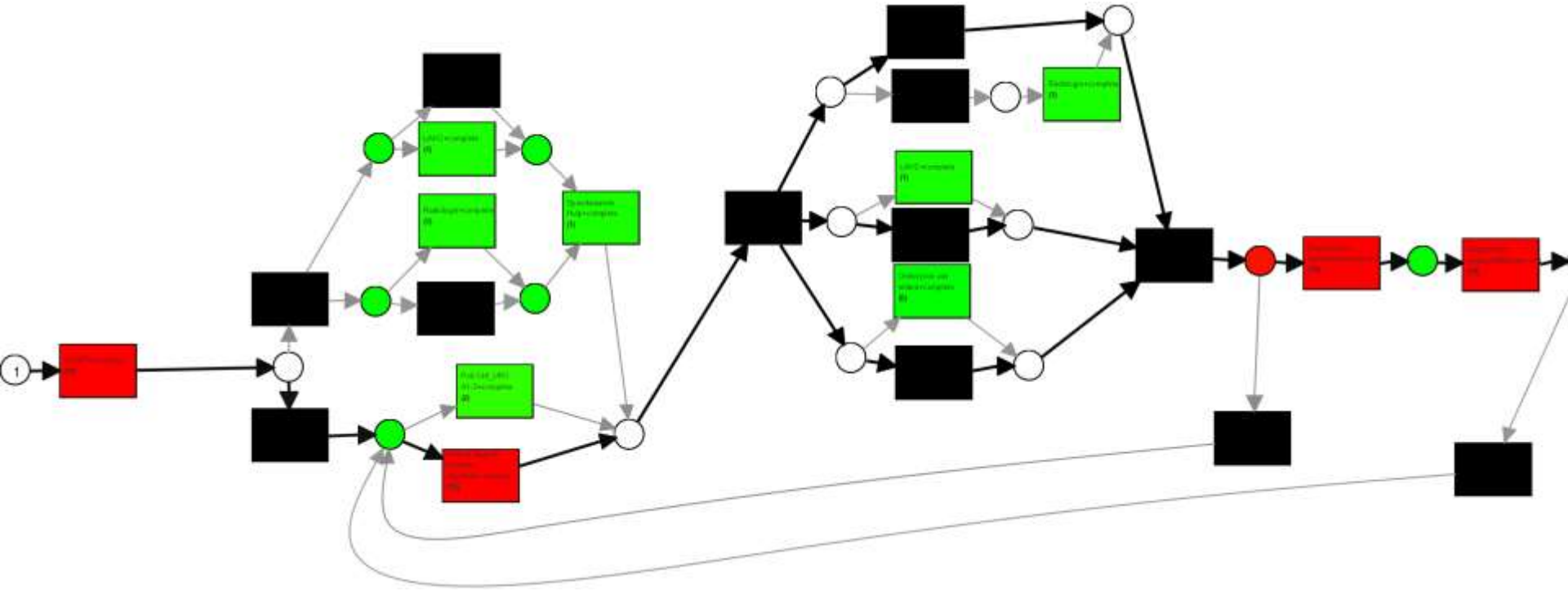
Discovered process model showing frequencies

hernia inguinalis (liesbreuk) with day admission

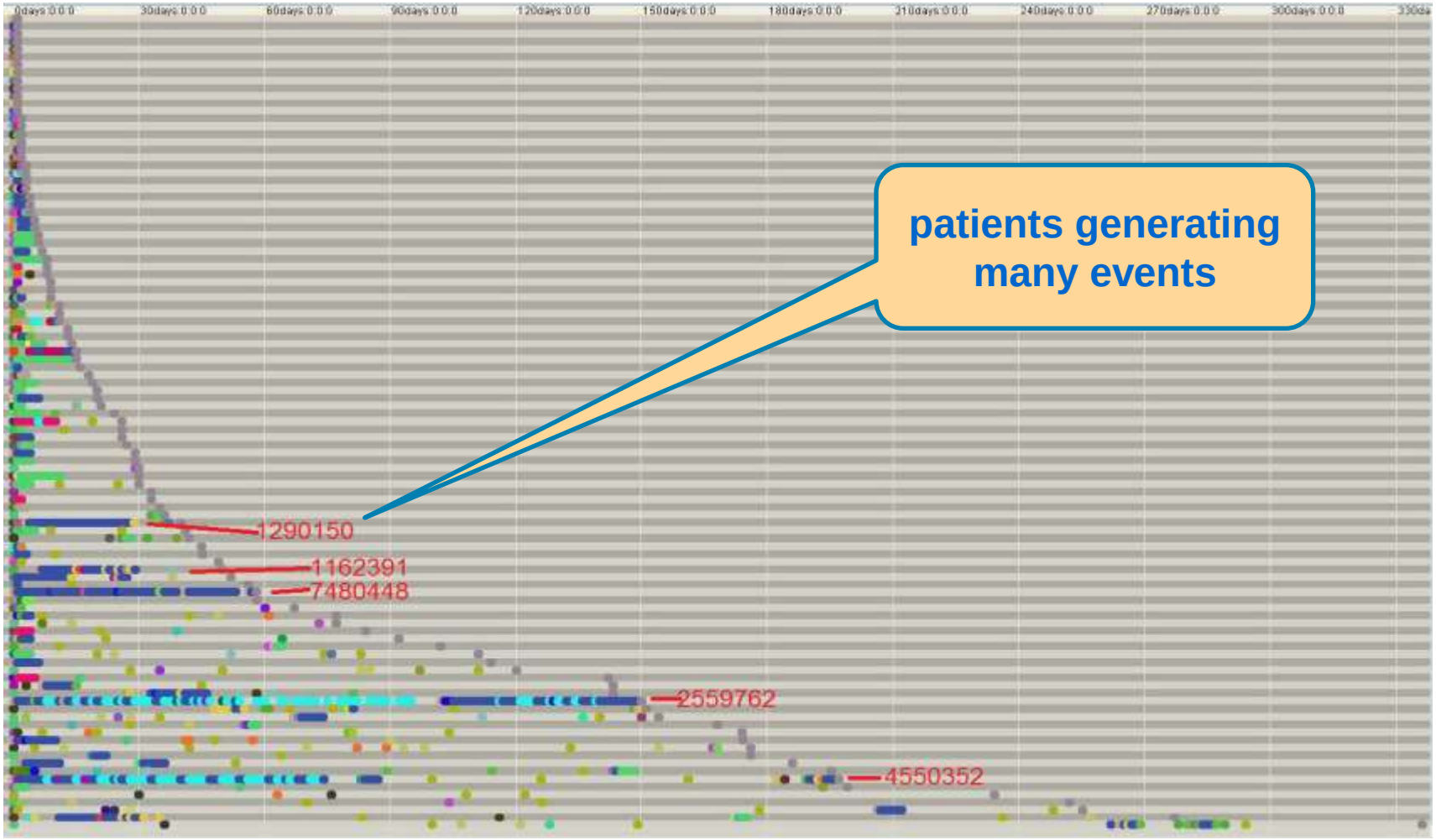


color indicates frequency

Same process but now for only children

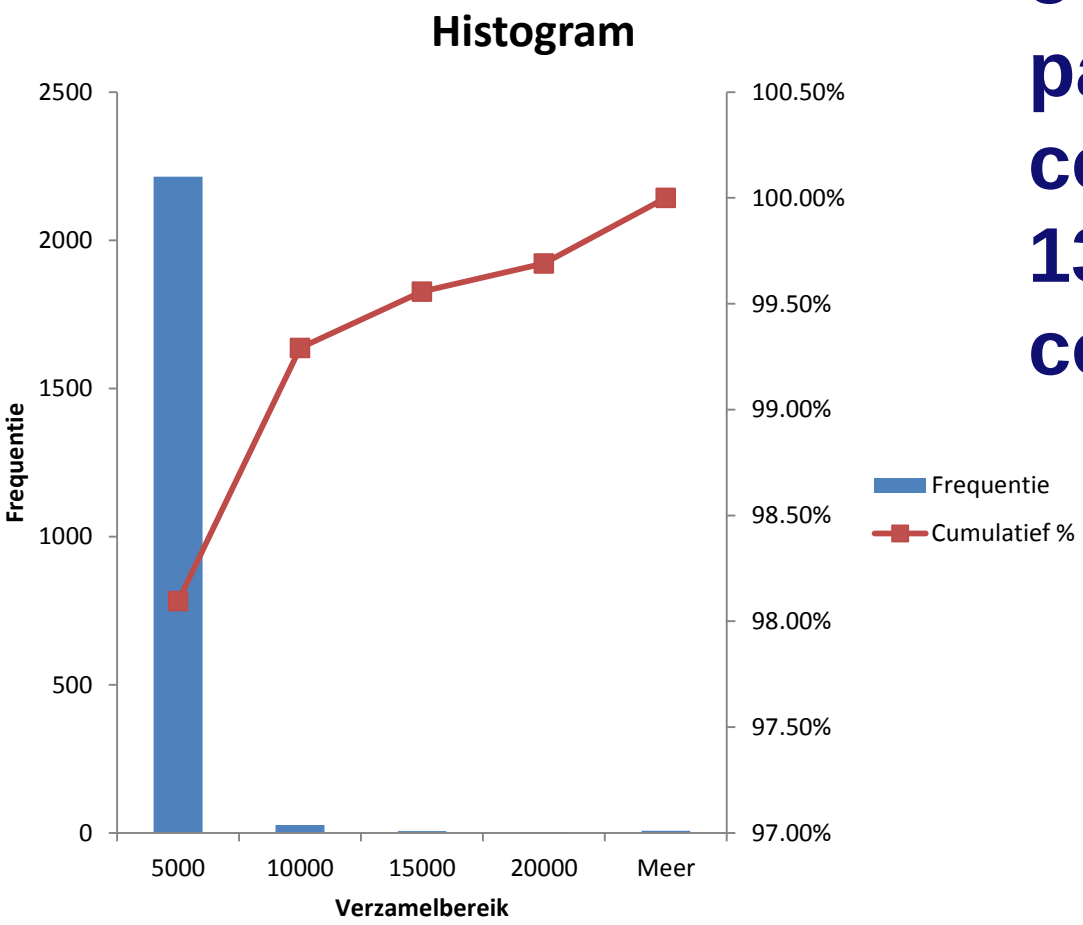


Uneven distribution in number of actions



Number of actions

- **Total costs (histogram)**



- **5 of the 2260 patients consume 13% of the costs!**

Isala Hospital

- **Top clinical care hospital Zwolle**
  - **>900 beds**
  - **> 5.000 employees**
- **Process urology department**
  - **Diagnosis**
  - **Surgery**
  - **Aftercare**
- **Patient groups considered**
  - **Phimosis (voorhuidsvernauwing)**
  - **Hydrocele (goedaardige zwelling uitgaande van de balzak)**
  - **Undescended testis (niet ingedaalde testikel)**
  - **Bladder cancer (blaastumor)**
  - **Ureter stones (steen in de urineleider)**

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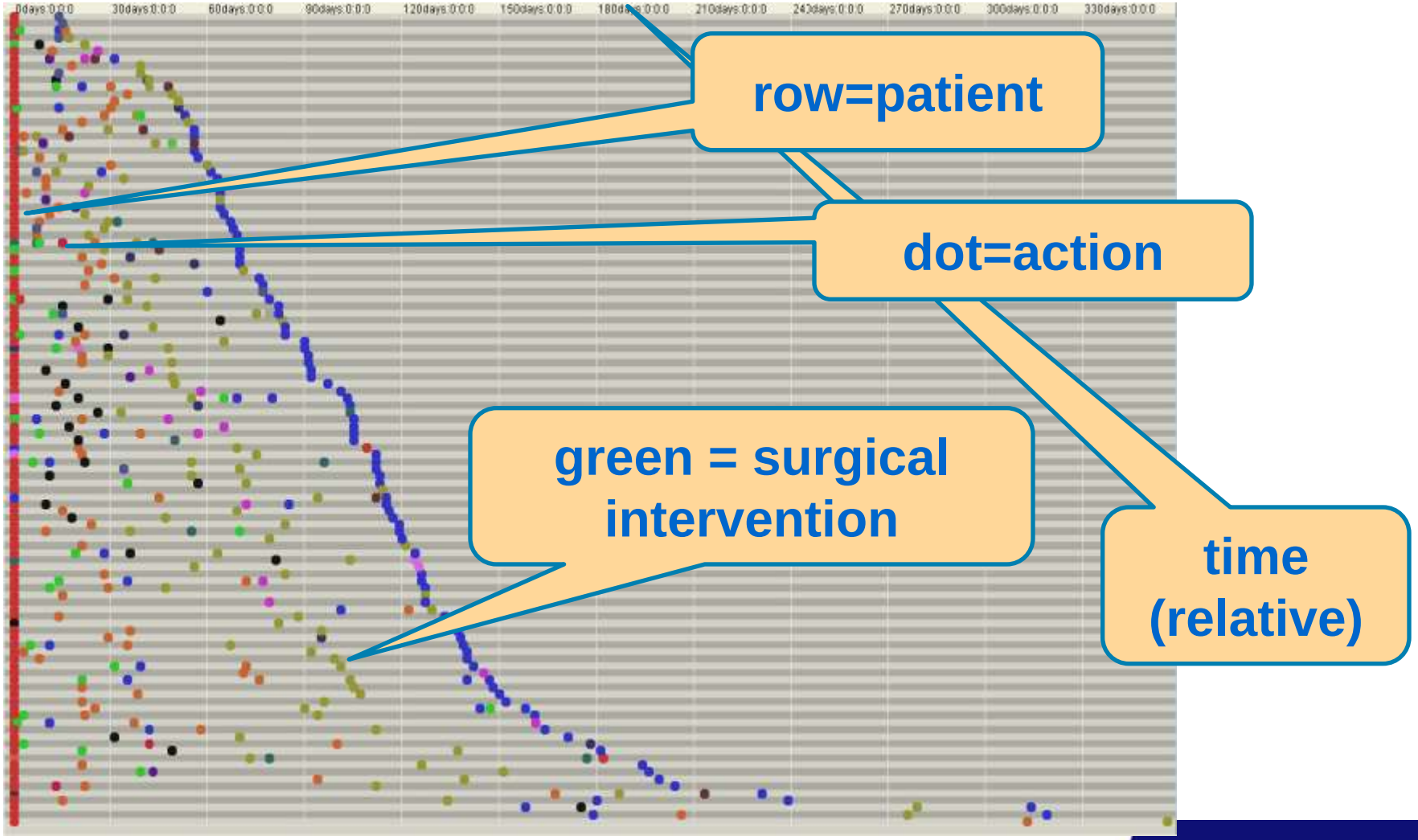
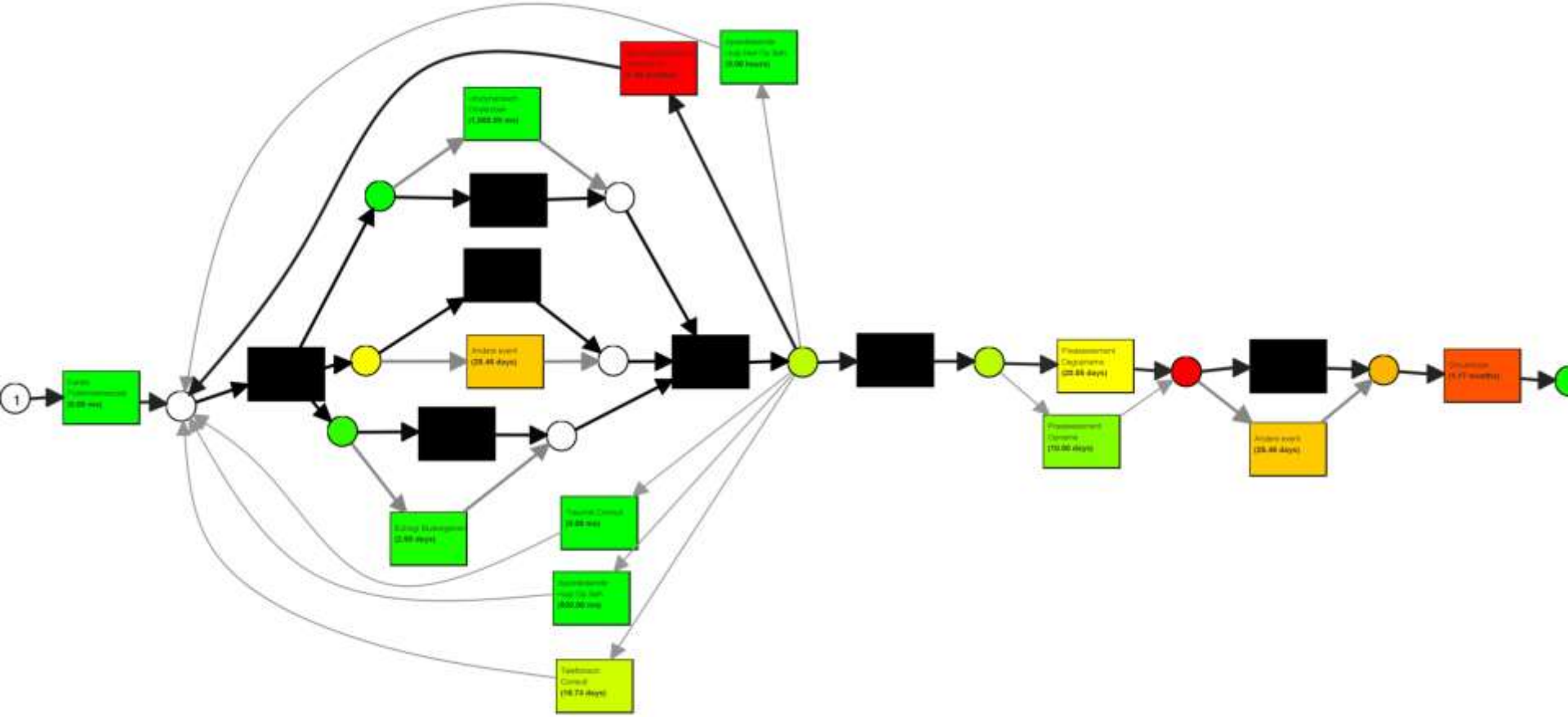
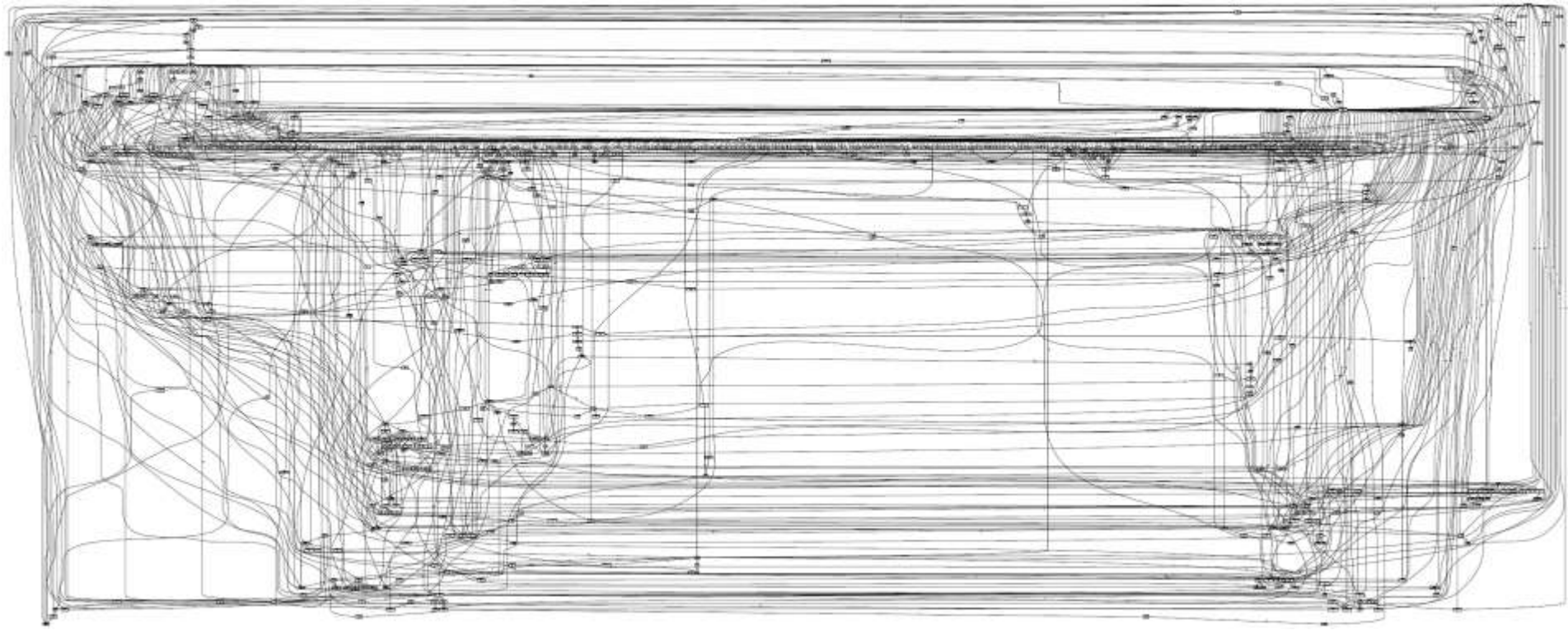
Dotted chart Phimosis



Process model showing where most time is spent by Phimosis patients



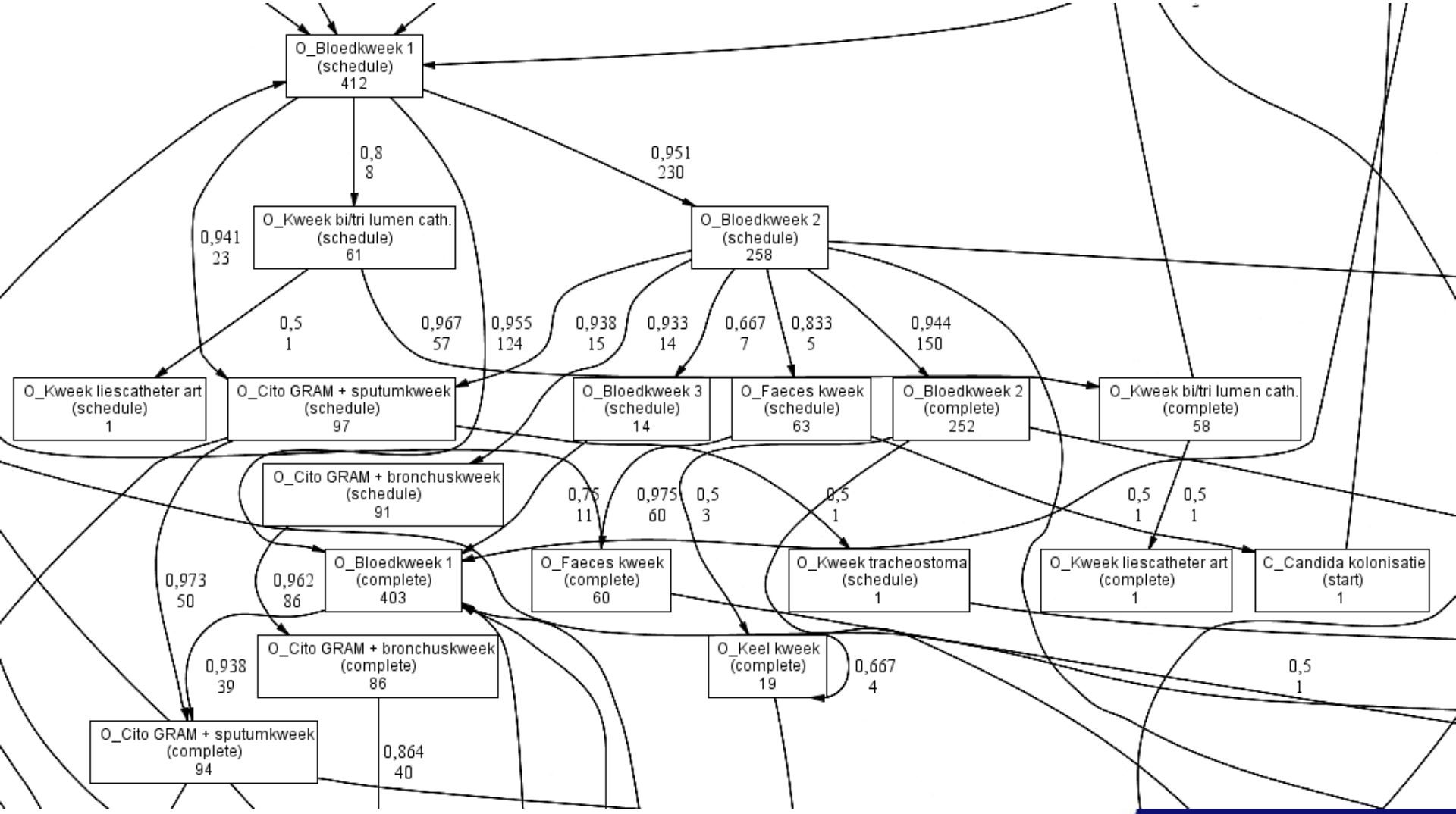
Example of a Spaghetti process



Spaghetti process describing the diagnosis and treatment of 2765 patients in a Dutch hospital. The process model was constructed based on an event log containing 114,592 events. There are 619 different activities (taking event types into account) executed by 266 different individuals (doctors, nurses, etc.).

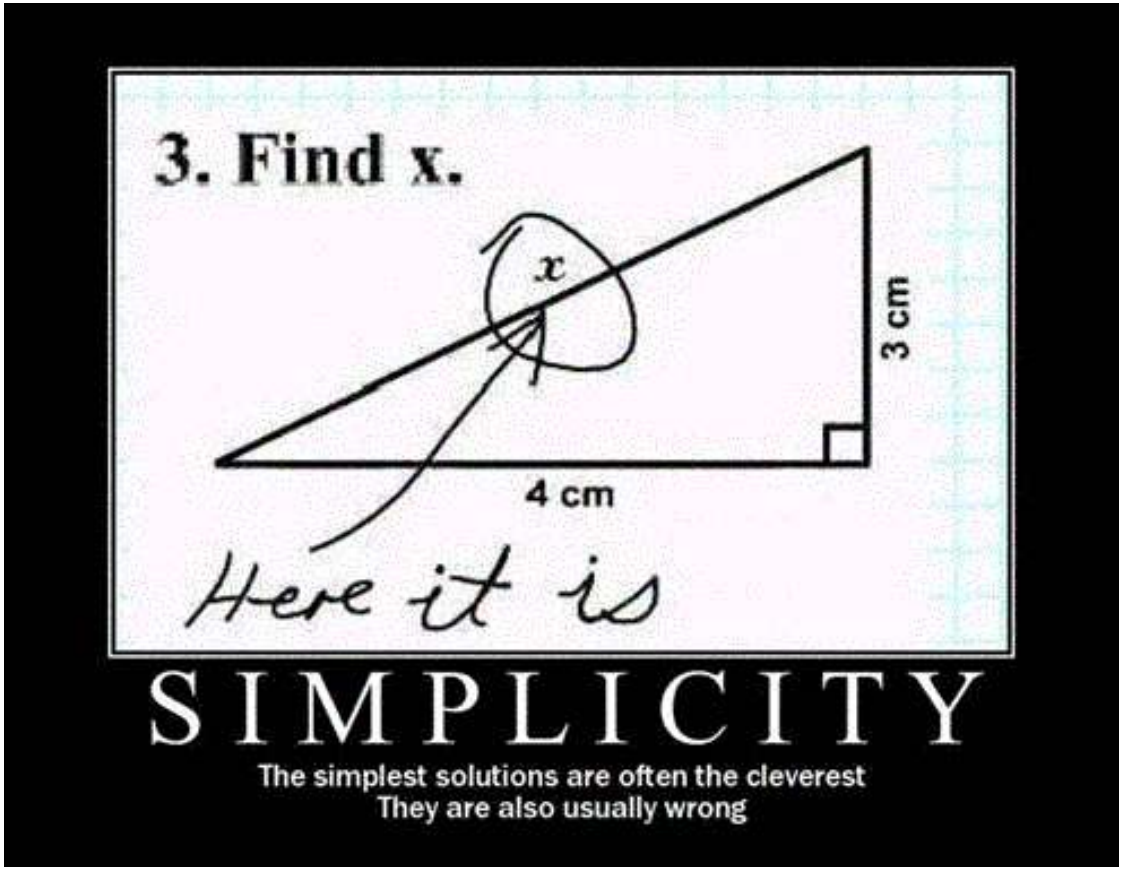
Fragment

18 activities of the 619 activities (2.9%)



Don't oversimplify

- **Reality cannot adequately be described using a simple PowerPoint**
- **Healthcare cannot be supported by simple logistical principles and mechanistic IT solutions**

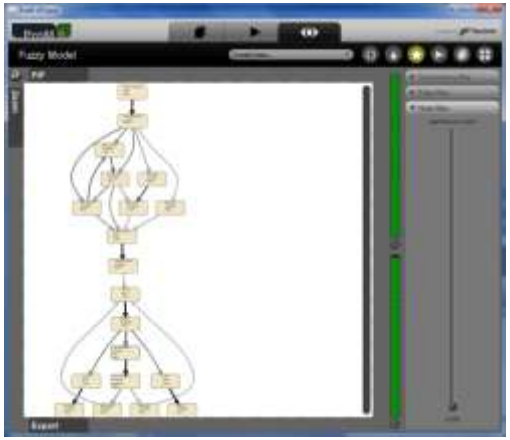


How to get started?

Hundreds of plug-ins available covering the whole process mining spectrum

ProM
process mining workbench

open-source (L-GPL)

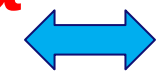


Download from: www.processmining.org

How to Get Started?

Collect event data

- Minimal requirement: events referring to an activity name and a process instance.
- Good to have: timestamps, resource information, additional data elements.
- Challenges: scoping and sometimes correlation.

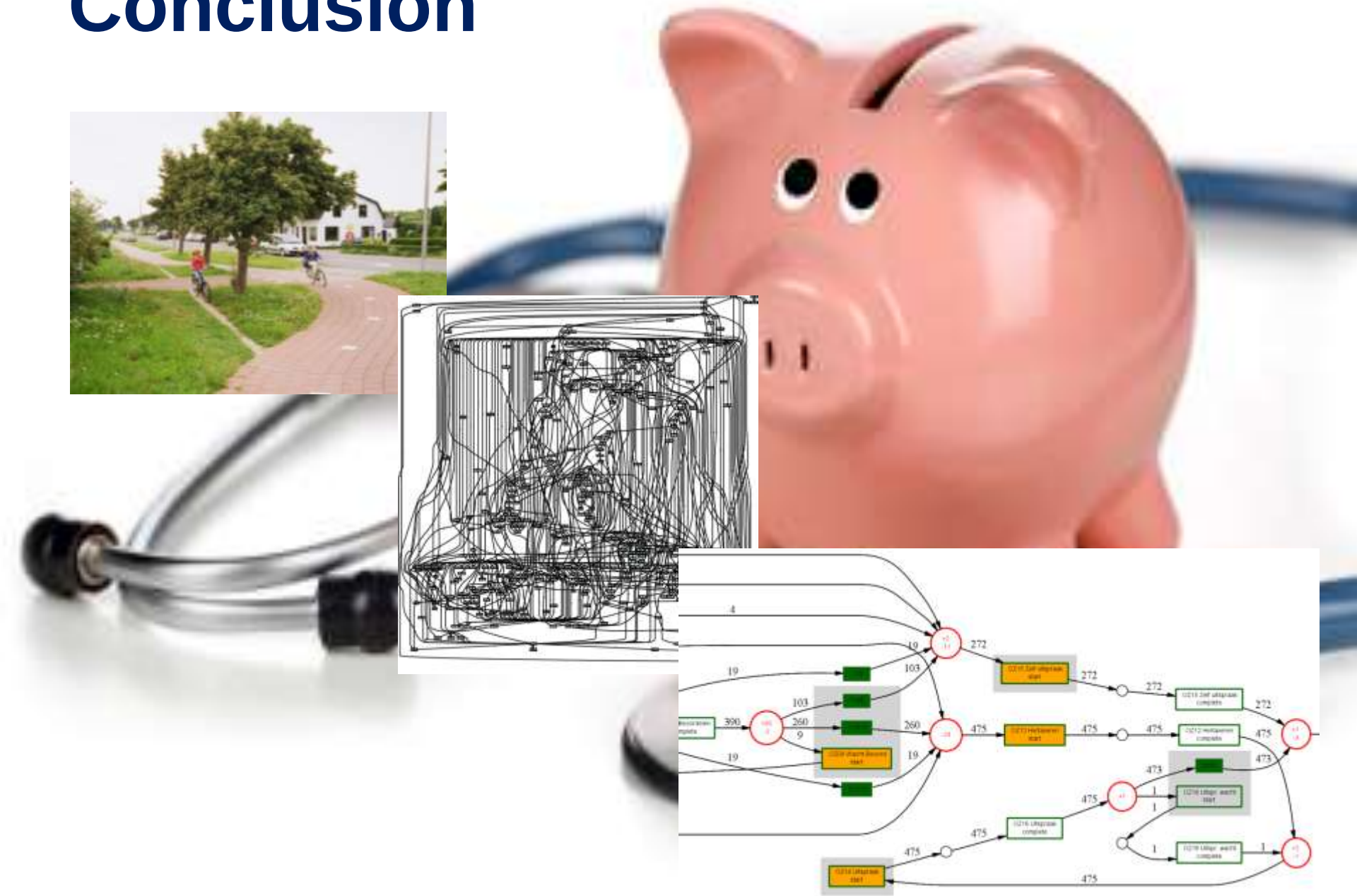


Collect questions

- What kind problems would you like to address (cost, time, risk, compliance, service, etc.)?
- Related to discovery, conformance, enhancement?
- Iterative process: can be “curiosity driven” initially.

Conclusion

Conclusion



Wil M. P. van der Aalst

Process Mining

Discovery, Conformance and Enhancement of Business Processes

More and more information about business processes is recorded by information systems in the form of so-called "event logs". Despite the omnipresence of such data, most organizations diagnose problems based on fiction rather than facts. Process mining is an emerging discipline based on process model-driven approaches and data mining. It not only allows organizations to fully benefit from the information stored in their systems, but it can also be used to check the conformance of processes, detect bottlenecks, and predict execution problems.

Wil van der Aalst delivers the first book on process mining. It aims to be self-contained while covering the entire process mining spectrum from process discovery to operational support. In Part I, the author provides the basics of business process modeling and data mining necessary to understand the remainder of the book. Part II focuses on process discovery as the most important process mining task. Part III moves beyond discovering the control flow of processes and highlights conformance checking, and organizational and time perspectives. Part IV guides the reader in successfully applying process mining in practice, including an introduction to the widely used open-source tool ProM. Finally, Part V takes a step back, reflecting on the material presented and the key open challenges.

Overall, this book provides a comprehensive overview of the state of the art in process mining. It is intended for business process analysts, business consultants, process managers, graduate students, and BPM researchers.

Features and Benefits:

- First book on process mining, bridging the gap between business process modeling and business intelligence.
- Written by one of the most influential and most-cited computer scientists and the best-known BPM researcher.
- Self-contained and comprehensive overview for a broad audience in academia and industry.
- The reader can put process mining into practice immediately due to the applicability of the techniques and the availability of the open-source process mining software ProM.

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van der Aalst

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