UNIVERSITY OF TARTU

apromore

erc

AI for Business Process Management

From Descriptive Process Mining to Automated Process Improvement

Marlon Dumas

Professor of Information Systems @ **University of Tartu**

Co-founder @ **Apromore**

Guest Lecture, Virtual Lecture Series in BPM, U. Wuerzburg, 2020

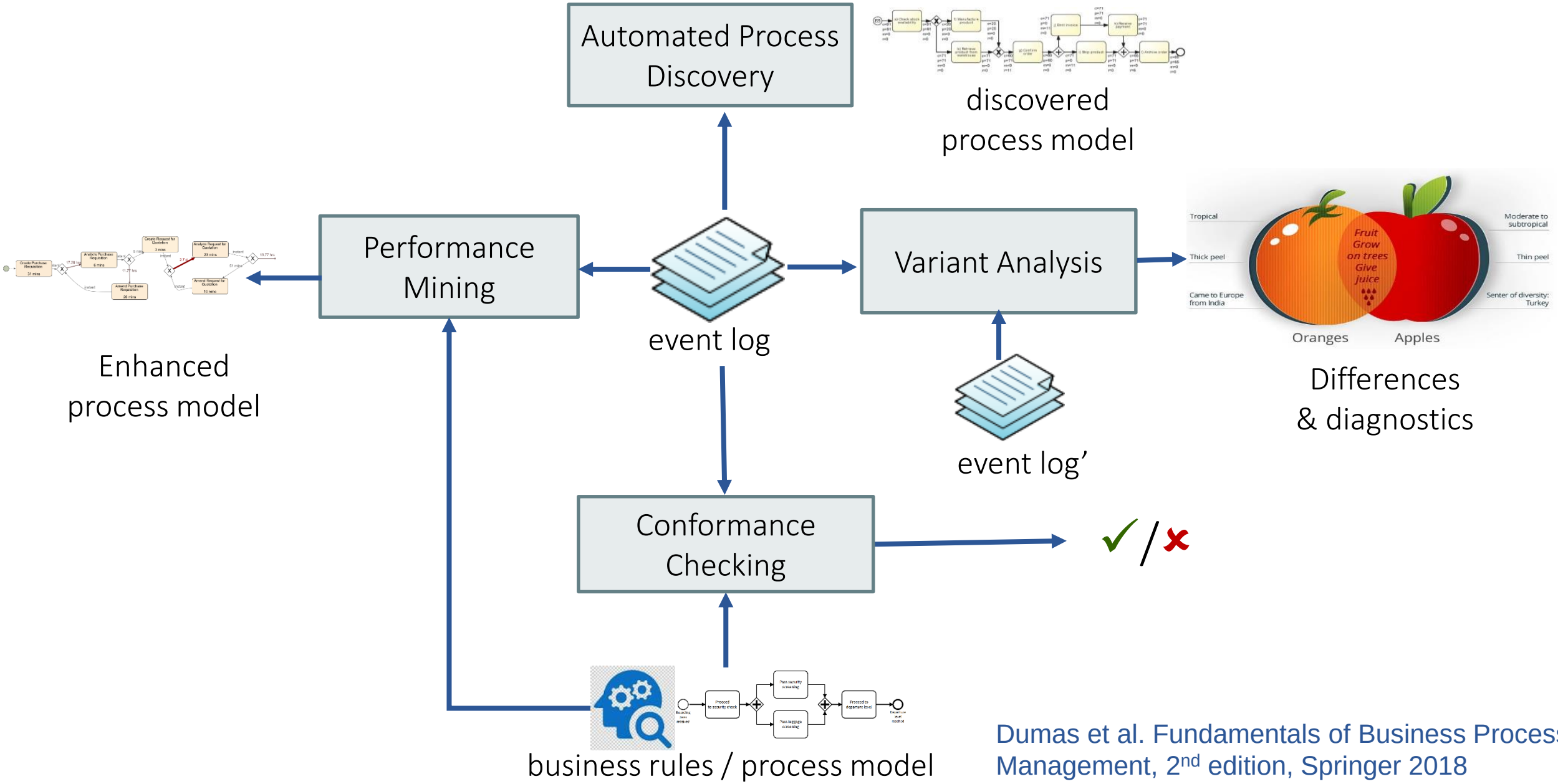
Process Mining 1.0

event log

Event Log – Incident Management Process Extracted From HP Service Manager @ Rabobank

Incident ID	DateStamp	IncidentActivity_Number	IncidentActivity_Type	Assignment Group	KM number	Interaction
Case ID	End timestamp	Event Attribute	Activity	Resource	Event Attribute	Event Attribute
IM0000004	07-01-2013 08:17:17	001A3689763	Reassignment	TEAM0001	KM0000553	SD0000007
IM0000004	04-11-2013 13:41:30	001A5852941	Reassignment	TEAM0002	KM0000553	SD0000007
IM0000004	04-11-2013 13:41:30	001A5852943	Update from customer	TEAM0002	KM0000553	SD0000007
IM0000004	04-11-2013 12:09:37	001A5849980	Operator Update	TEAM0003	KM0000553	SD0000007
IM0000004	04-11-2013 12:09:37	001A5849979	Assignment	TEAM0003	KM0000553	SD0000007
IM0000004	04-11-2013 13:41:30	001A5852942	Assignment	TEAM0002	KM0000553	SD0000007
IM0000004	04-11-2013 13:51:18	001A5852172	Closed	TEAM0003	KM0000553	SD0000007
IM0000004	04-11-2013 13:51:18	001A5852173	Caused By CI	TEAM0003	KM0000553	SD0000007
IM0000004	04-11-2013 12:09:37	001A5849978	Reassignment	TEAM0003	KM0000553	SD0000007
IM0000004	25-09-2013 08:27:40	001A5544096	Operator Update	TEAM0003	KM0000553	SD0000007
IM0000005	03-06-2013 11:15:43	001A4725475	Update	TEAM9999	KM0000611	SD0000011
IM0000005	03-04-2013 11:29:46	001A4327777	Operator Update	TEAM0003	KM0000611	SD0000011
IM0000005	07-01-2013 08:17:54	001A3689771	Reassignment	TEAM0001	KM0000611	SD0000011
IM0000005	05-09-2013 08:58:58	001A5377163	Operator Update	TEAM0003	KM0000611	SD0000011
IM0000005	12-04-2013 11:03:27	001A4396943	Operator Update	TEAM0003	KM0000611	SD0000011
IM0000005	23-04-2013 08:22:09	001A4466088	Status Change	TEAM0003	KM0000611	SD0000011
IM0000005	02-12-2013 12:00:07	001A6068111	Update from customer	TEAM0002	KM0000611	SD0000011
IM0000005	02-12-2013 12:32:10	001A6068174	Reassignment	TEAM0002	KM0000611	SD0000011
IM0000005	02-12-2013 12:32:10	001A6068175	Assignment	TEAM0002	KM0000611	SD0000011
IM0000005	02-12-2013 12:36:26	001A6068564	Caused By CI	TEAM0003	KM0000611	SD0000011
IM0000005	02-12-2013 12:36:26	001A6068563	Closed	TEAM0003	KM0000611	SD0000011
IM0000005	02-12-2013 12:32:10	001A6068177	Update from customer	TEAM0002	KM0000611	SD0000011

Process Mining 1.0



Dumas et al. Fundamentals of Business Process Management, 2nd edition, Springer 2018

The Evolution of Process Mining

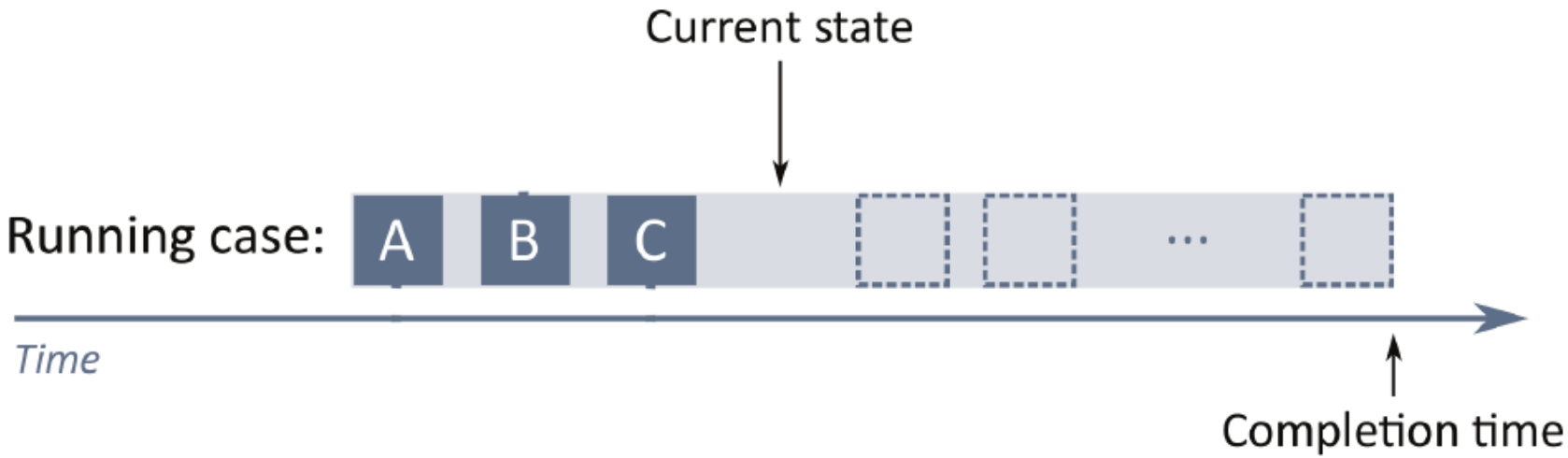
Process Mining 2.0
Predictive Process Monitoring
Automated Process Improvement

Process Mining 1.0
Automated Process Discovery & Analysis

Process Mining 2.0

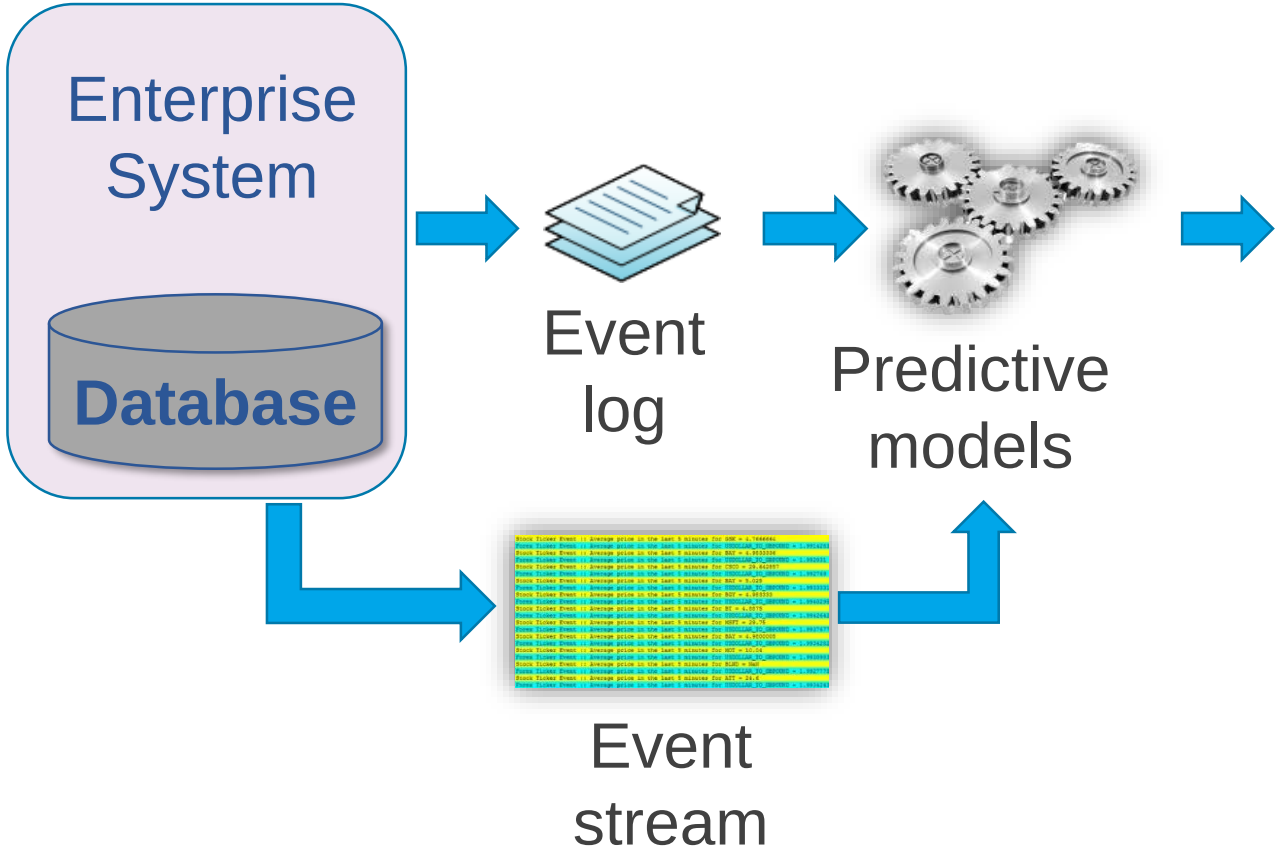
Operational Level	*Predictive Process Monitoring*	Predicting future states, outcomes, or properties of a process instance or group of process instances
	Prescriptive process monitoring	Recommending actions on the basis of predictions to maximize a performance indicator
Tactical Level	*Robotic process mining*	Discovering and automating routines from user interactions
	Search-Based Process Optimization	Assessing and discovering improvement opportunities from event logs

Predictive Process Monitoring

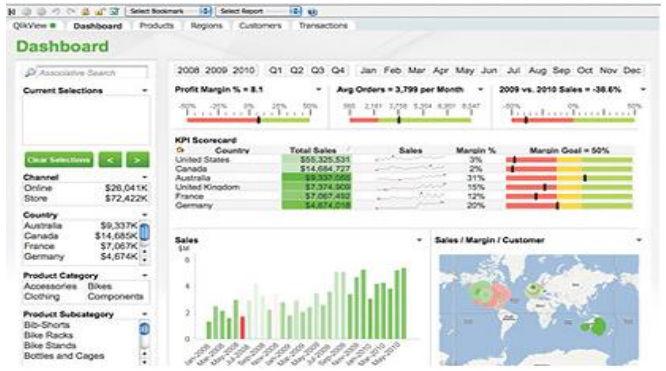


- What is the next activity for this case?
- When is this next activity going to take place?
- How long is this case still going to take until it is finished?
- What is the outcome of this case?
- Is the compensation going to be paid? Or rejected?

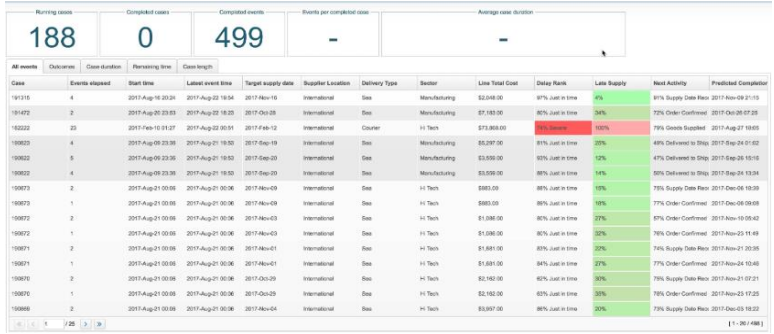
Predictive Process Monitoring



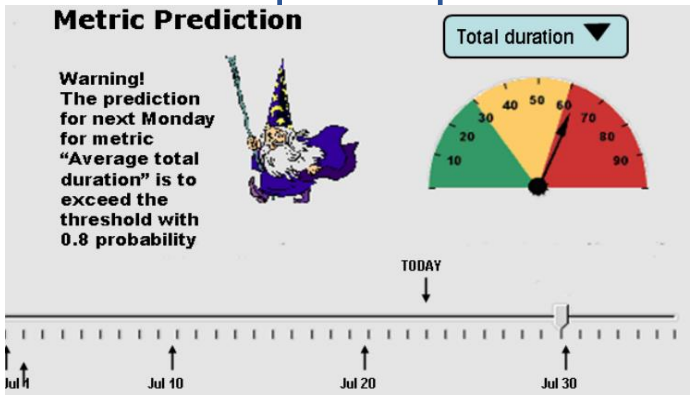
Aggregate predictive dashboards



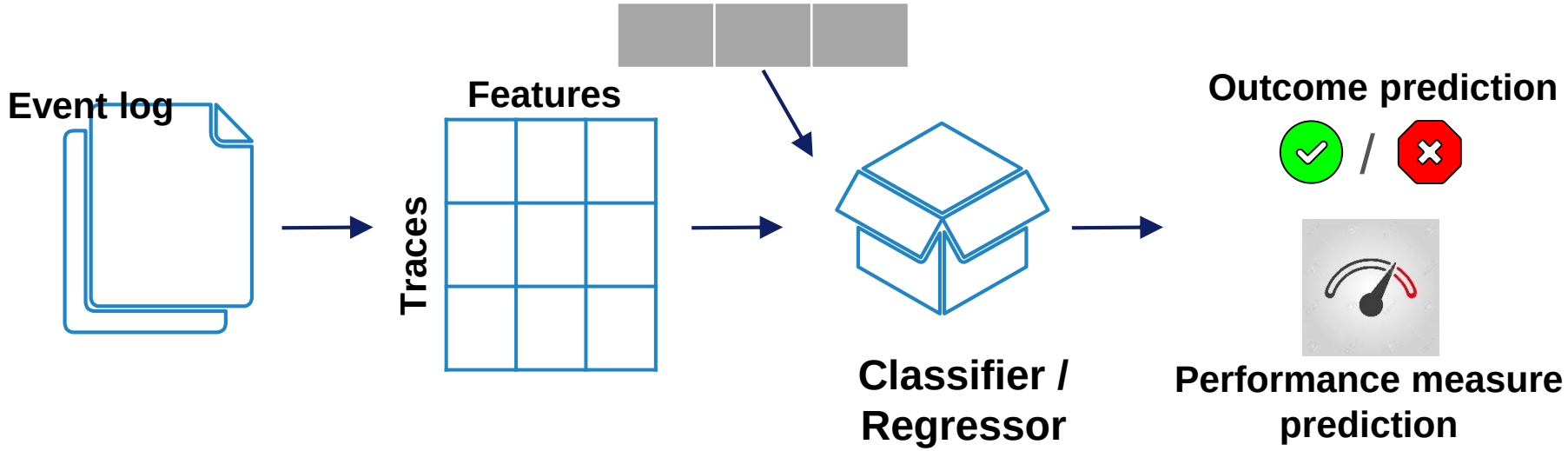
Detailed predictive dashboard

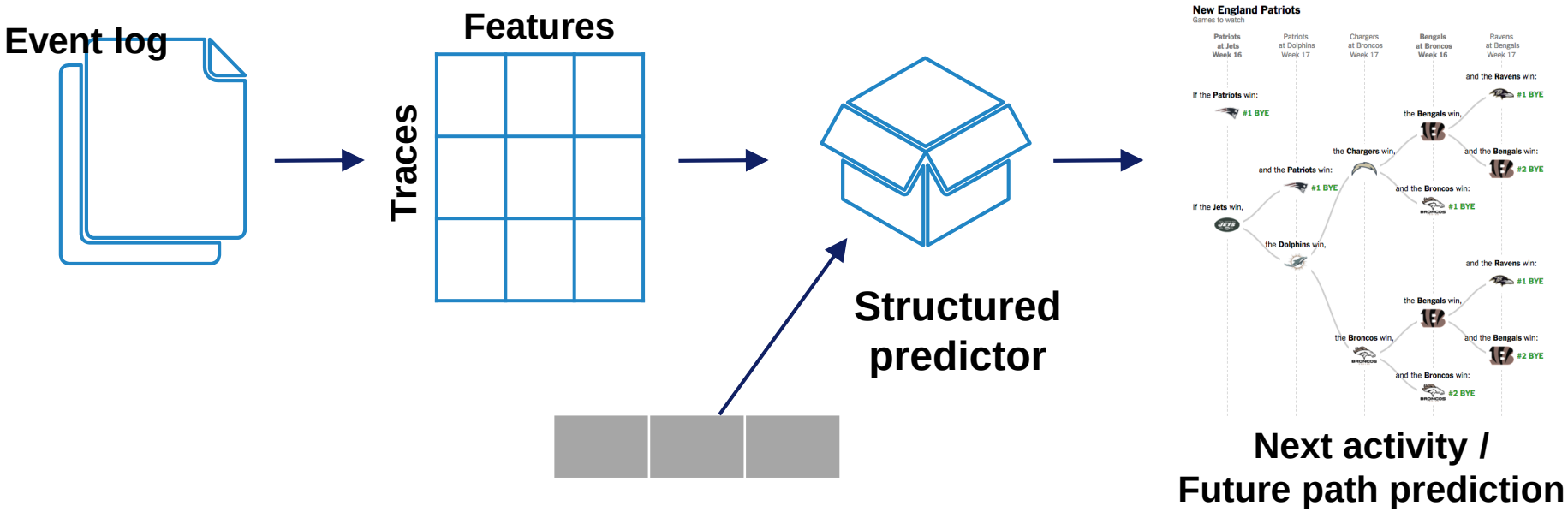


Alarm-based prescriptive dashboard

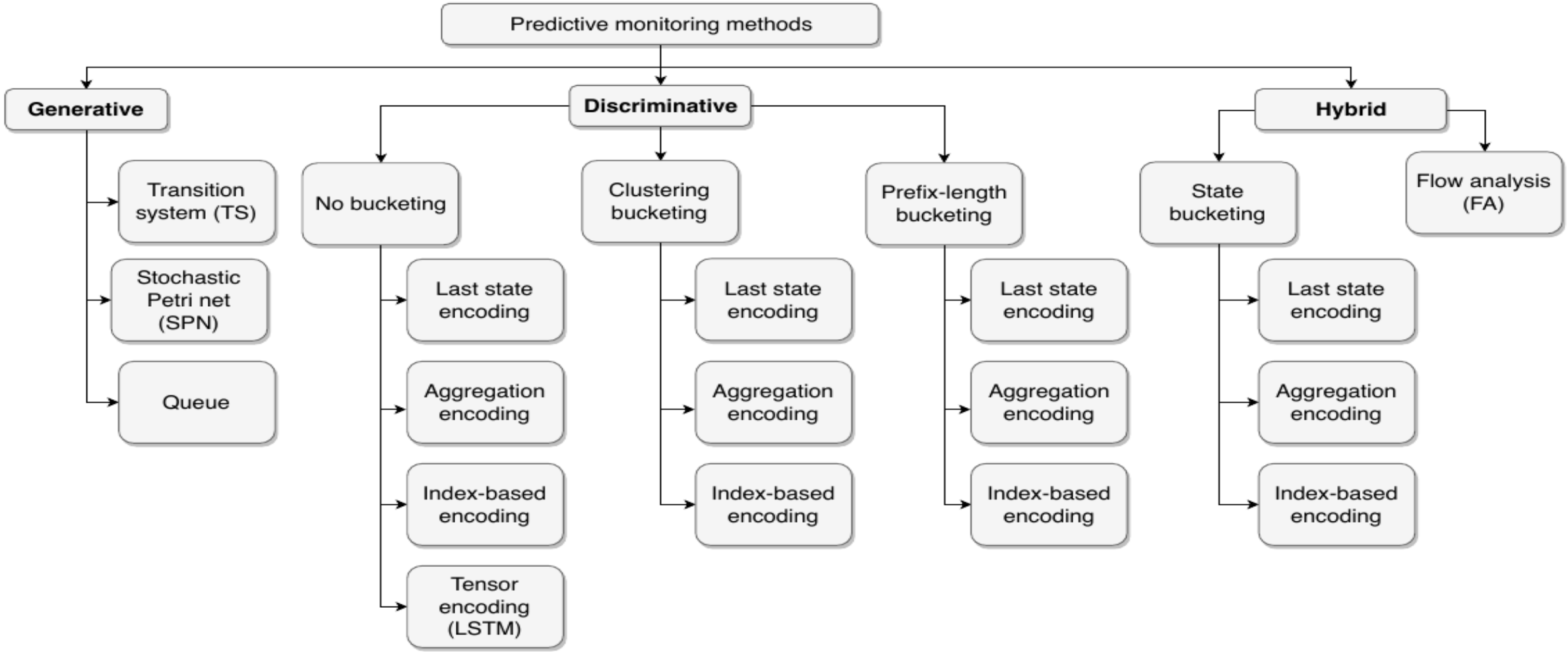


Predictive Process Monitoring: General Approach





Predictive Process Monitoring Approaches

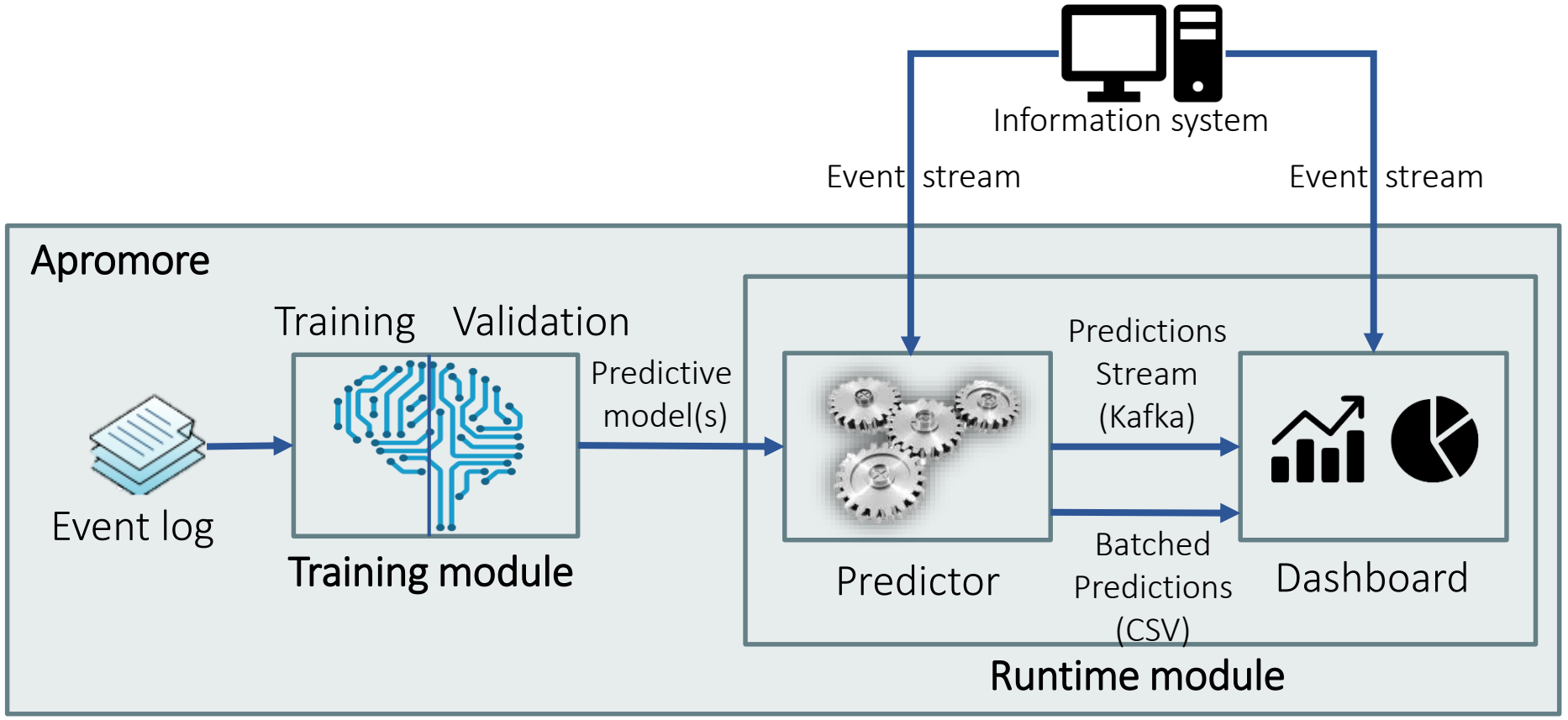


Teinemaa et al. Outcome-Oriented Predictive Process Monitoring: Review and Benchmark. TKDD 13(2):17:1-17:57, 2019.
Verenich et al. Survey and Cross-benchmark Comparison of Remaining Time Prediction Methods in Business Process Monitoring. TIST 10(4), 2019.

http://apromore.org

Predictive process monitoring (Apromore)

- Predict **process outcome** – *Is this loan offer going to be rejected?*
- Predict **process performance** – *Will this claim take more than 5 days to be handled?*
- Predict **future events** – *What activity is likely to be executed next? And after that?*



11

Challenges in Predictive Process Monitoring

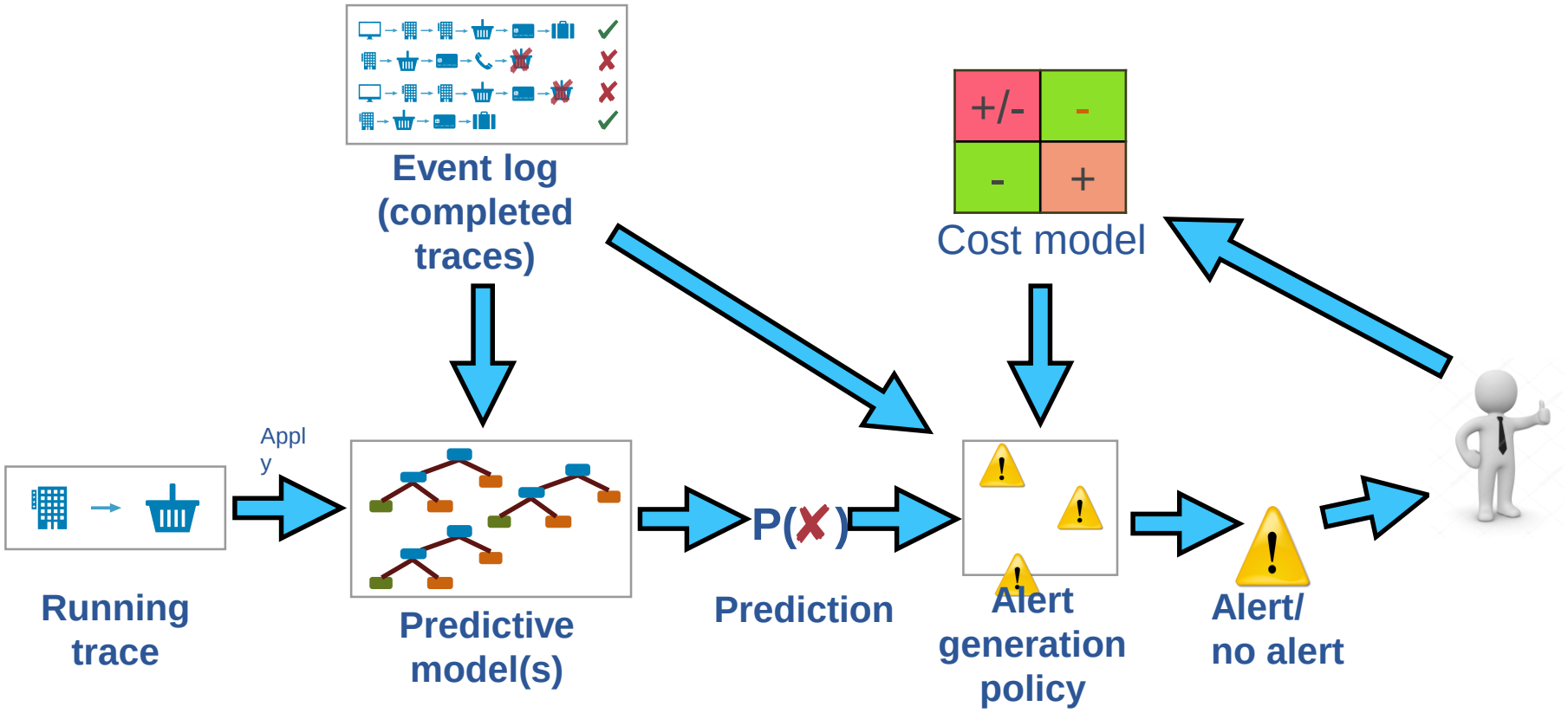
Explaining predictions

Helping users understand the causes of predicted outcomes

Turning predictions into actions

Prescriptive process monitoring

Prescriptive process monitoring

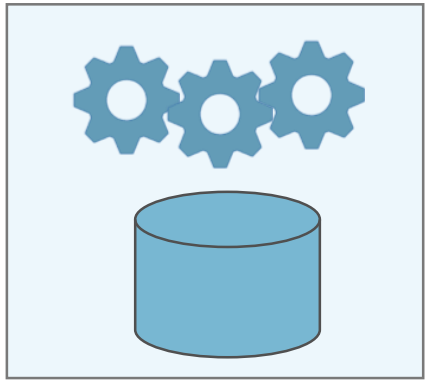


Teinemaa et al. “Alarm-Based Prescriptive Process Monitoring”. Proceedings of BPM Forum’2018

Automated Process Improvement

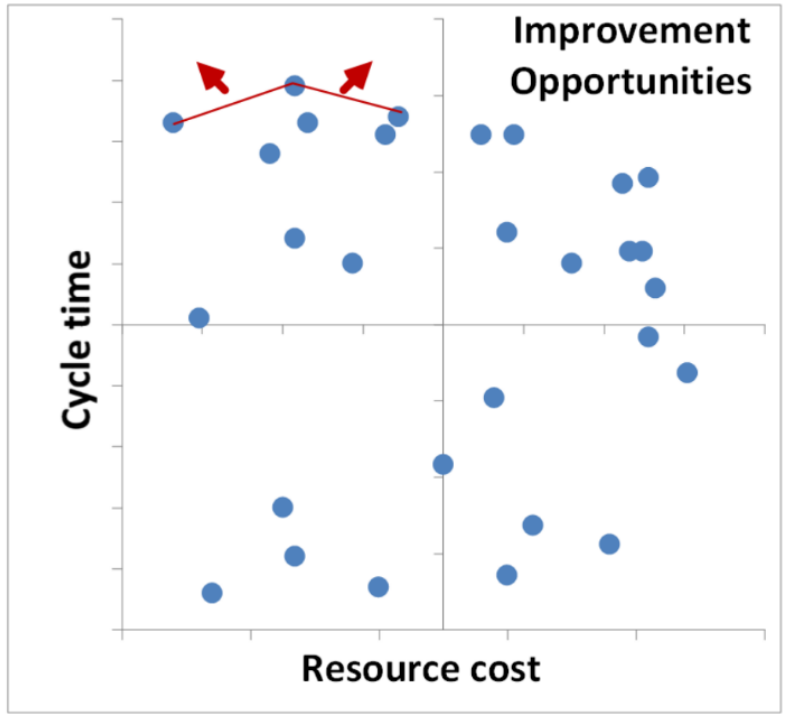
Domain Knowledge

Enterprise System

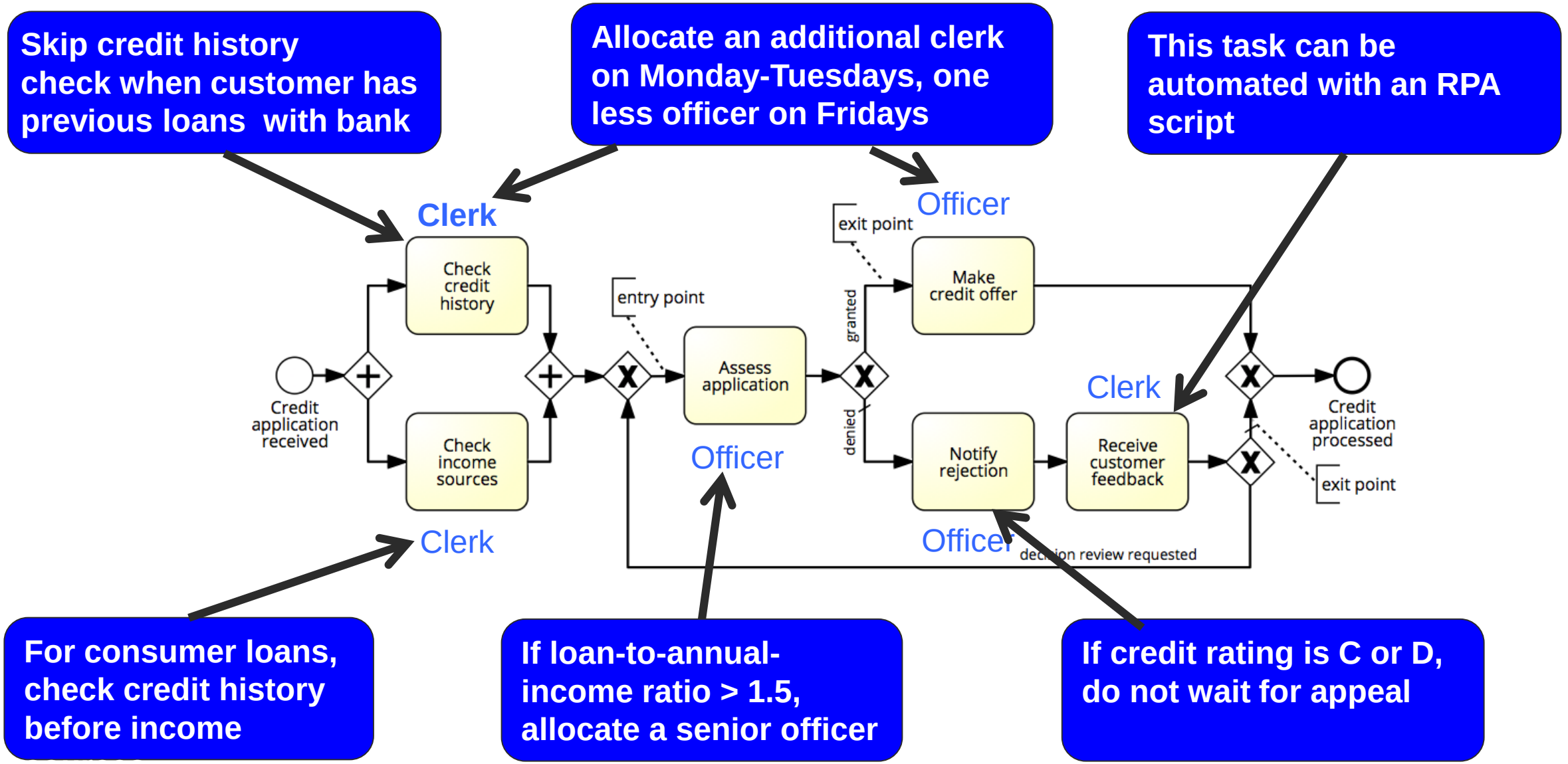


IoT, Web & social sensing streams

Search-Based Process Optimizer



Example: Improvement Opportunities



Automated Process Improvement

Given

- one or more event logs recording the execution of one or more processes
- one or more performance measures that we seek to maximize/minimize
- a process model, decision rules and resource allocation rules
- a set of allowed changes to the process model and associated rules

Find

- Possible sets of changes to the process to optimize the performance measures

Automated Process Improvement
Types of Changes

Task

- Automate individual tasks or groups of tasks
- Recommend best practices for task execution

Control-flow

- Task elimination/addition
- Task merging/splitting
- Task re-ordering, parallelization

Decision (data)

- Add / delete decision points
- Refine / enhance decision rules

Resource

- Re-allocate resources
- Refine / enhance resource allocation policies

Automated Process Improvement

Robotic Process Mining (Task Automation)

Executable routine specifications

Resource Optimization

Optimized resource allocation policies

Execution data

Flow Optimization

Optimized process model

Decision Rule Optimization

UC	Inputs		Outputs
	Annual Income	Loan Size	Grade
A	[0..1000]	[0..1000]	VG
B	[250..750]	[4000..5000]	G
C	[500..1500]	[500..3000]	F
D	[2000..2500]	[0..2000]	P

Decision rules

UC	Inputs		Outputs
	Annual Income	Loan Size	Grade
A	[0..1000]	[0..1000]	VG
B	[250..750]	[4000..5000]	G
C	[500..1500]	[500..3000]	F
D	[2000..2500]	[0..2000]	P

Optimized decision rules

Robotic Process Mining: Synthesis of RPA Scripts for Task Automation

	Timestamp	Action Type	Source	Content	Field name	Field value
…	…			…	…	…
17	2019-03-03T19:03:					“+ 61 043 512 4834”
18	2019-03-03T19:03:					
19	2019-03-03T19:03:					
20	2019-03-03T19:03:13	Edit field	Web			2-4834”
…	…	…	…	…	…	…

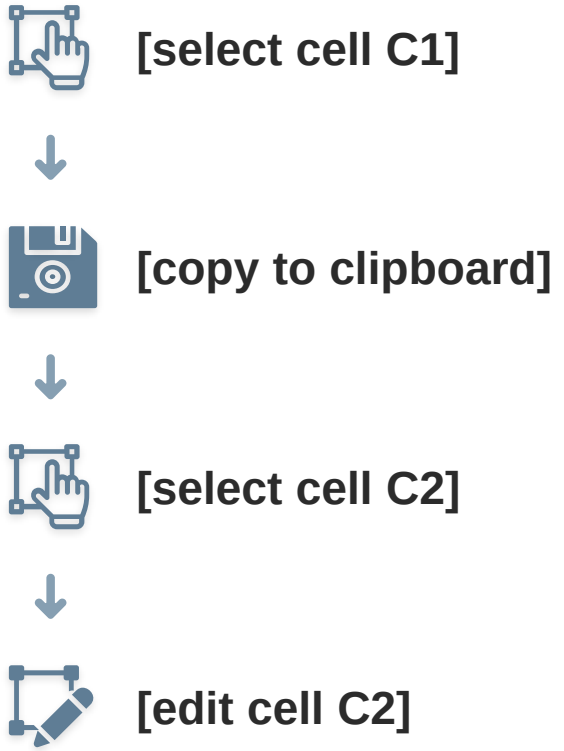
Can this task be automated and how?

```
1   Assign value of selected row to variable "$X$"
2   Excel: Get value of cell "A$X$" and assign to
        variable "$Clipboard$"
3   Assign value of Clipboard to variable "$FirstName.value$"
        in "http://www.unimelb.edu.au"
4   Excel: Get value of cell "B$X$" and assign to
        variable "$Clipboard$"
5   Assign value of Clipboard to variable "$LastName.value$"
        in "http://www.unimelb.edu.au"
6   Excel: Get value of cell "C$X$" and assign to
        variable "$Clipboard$"
7   Assign value of Clipboard to variable "$CountryOfResidence.value$"
        in "http://www.unimelb.edu.au"
8   If $CountryOfResidence.value$ Not Equal To (<>) "Australia" Then
9       Mouse Click: Left Button on "International Student"
            in "http://www.unimelb.edu.au"
10  End If
11  Mouse Click: Left Button on "Save"
        in "http://www.unimelb.edu.au"
```

Automatable Task

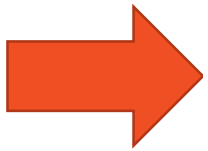
UNIVERSITY OF TARTU

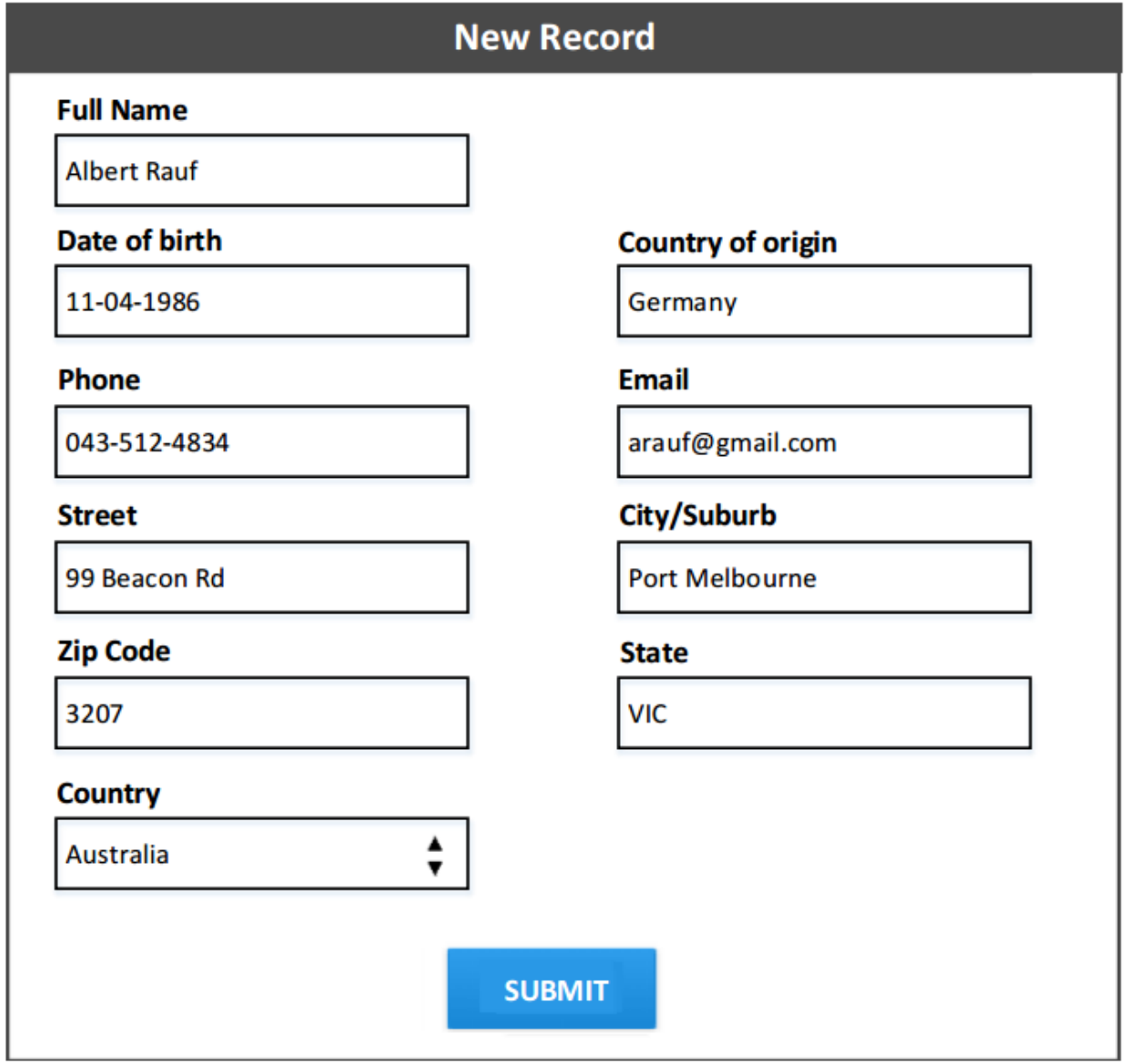
A task is **automatable** if every step in the task can be deterministically executed based on input data, or data produced by previous actions



Automatable Task Example

	A	B
1	First Name	Albert
2	Last Name	Rauf
3	Date of birth	11/04/1986
4	Phone number	+61 043 512 4834
5	Email	arauf@gmail.com
6	Country of Origin	Germany
7	Address	99 Beacon Rd, Port Melbourne, VIC 3207, Australia



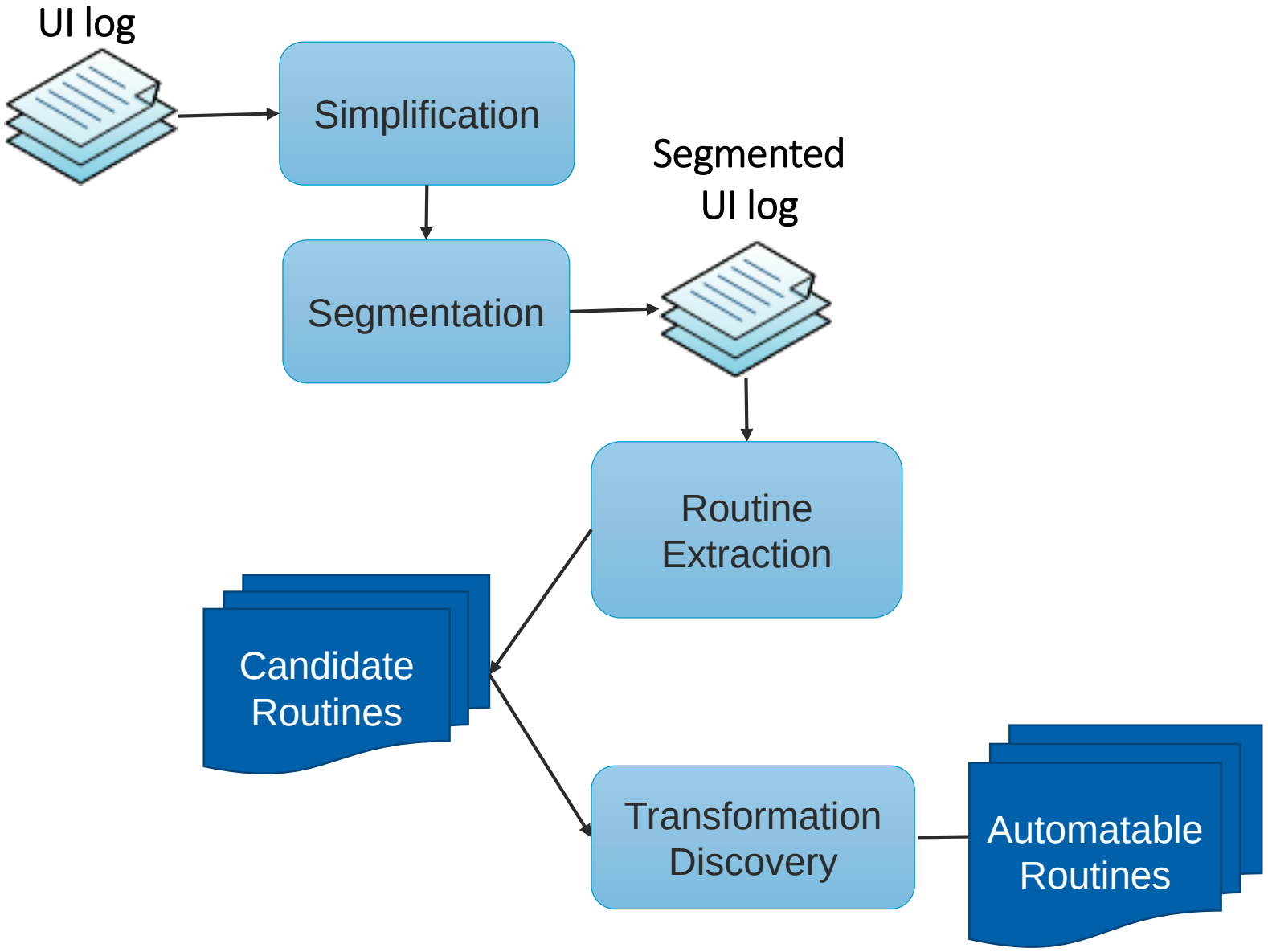


Starting Point: UI log

	Timestamp	Action Type	Source	Content	Field name	Field value
1	2019-03-03T19:02:18	Copy cell	Worksheet	“Albert”	A3	“Albert”
2	2019-03-03T19:02:23	Click field	Web		‘Full Name	“”
3	2019-03-03T19:02:26	Paste	Web	“Albert”	Full Name	“”
4	2019-03-03T19:02:27	Edit field	Web		Full Name	“Albert”
5	2019-03-03T19:02:32	Copy cell	Worksheet	“Rauf”	B3	“Rauf”
6	2019-03-03T19:02:35	Click field	Web		Full Name	“Albert”
7	2019-03-03T19:02:37	Paste	Web	“Rauf”	Full Name	“Albert”
8	2019-03-03T19:02:39	Edit field	Web		Full Name	“Albert Rauf”
9	2019-03-03T19:02:43	Copy cell	Worksheet	“Germany”	F3	“Germany”
10	2019-03-03T19:02:45	Click field	Web		Country	“”
11	2019-03-03T19:02:46	Paste	Web	“Germany”	Country	“”
12	2019-03-03T19:02:47	Edit field	Web		Country	“Germany”
13	2019-03-03T19:02:50	Copy cell	Worksheet	“11/04/1986”	C3	“11/04/1986”
14	2019-03-03T19:02:52	Click field	Web		Date	“”
15	2019-03-03T19:02:53	Paste	Web	“11/04/1986”	Date	“”
16	2019-03-03T19:02:58	Edit field	Web		Date	“11-04-1986”
17	2019-03-03T19:03:01	Copy cell	Worksheet	“+ 61 043 512 4834”	D3	“+ 61 043 512 4834”
18	2019-03-03T19:03:05	Click field	Web		Phone	“”
19	2019-03-03T19:03:07	Paste	Web	“+ 61 043 512 4834”	Phone	“”
20	2019-03-03T19:03:13	Edit field	Web		Phone	“043-512-4834”

V. Leno, A. Polyvyanyy, M. La Rosa, M. Dumas and F. Maria Maggi. Action logger: Enabling process mining for robotic process automation. In Proceedings of Demonstration Track at BPM 2019, 124–128, 2019

Robidium: Synthesizing RPA Scripts From UI Logs



Transformation discovery

For each edit action:

- Collect the target element and its value
- Collect corresponding source elements and their values
- Create input-output transformation examples (Input, Output, Source, Target)

	Timestamp	Action Type	Source	Content	Field name	Field value
...	...	...	...	...	...	...
17	2019-03-03T19:03:01	Copy cell	Worksheet	"+ 61 043 512 4834"	D3	"+ 61 043 512 4834"
18	2019-03-03T19:03:05	Click field	Web		Phone	""
19	2019-03-03T19:03:07	Paste	Web	"+ 61 043 512 4834"	Phone	""
20	2019-03-03T19:03:13	Edit field	Web		Phone	"043-512-4834"
21	2019-03-03T19:03:18	Copy cell	Worksheet	"arauf@gmail.com"	E3	"arauf@gmail.com"
22	2019-03-03T19:03:21	Click field	Web		Email	""
23	2019-03-03T19:03:23	Paste	Web	"arauf@gmail.com"	Email	""
24	2019-03-03T19:03:24	Edit field	Web		Email	"arauf@gmail.com"

Edit action *Target* *Output*

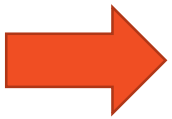
Read action *Source* *Input*

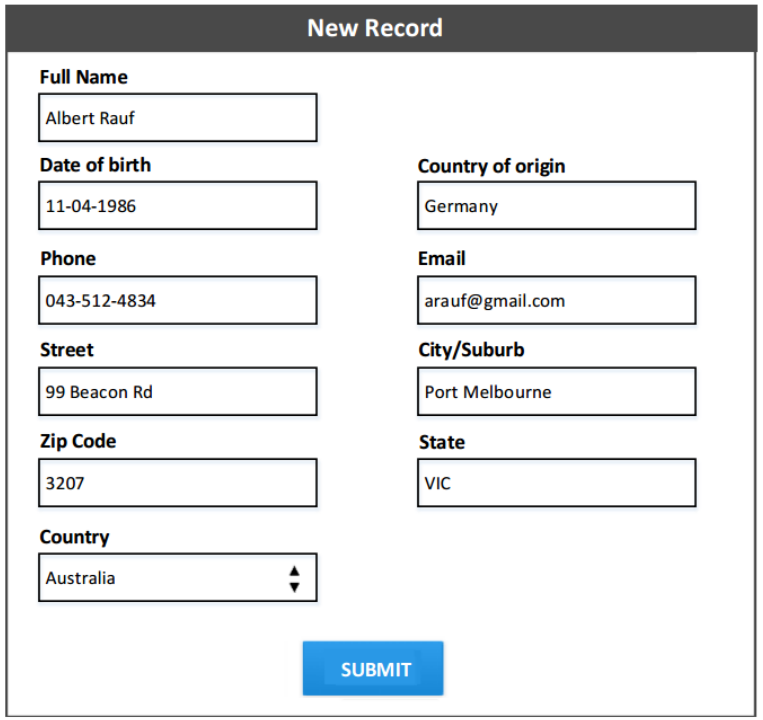
Extracting examples from candidate routines

For each candidate routine trace:

- Collect the values of all read cells/fields (Inputs)
- Collect the latest values of all modified cells/fields (Outputs)
- Create input-output transformation example (Inputs, Outputs)

	A	B
1	First Name	Albert
2	Last Name	Rauf
3	Date of birth	11/04/1986
4	Phone number	+61 043 512 4834
5	Email	arauf@gmail.com
6	Country of Origin	Germany
7	Address	99 Beacon Rd, Port Melbourne, VIC 3207, Australia





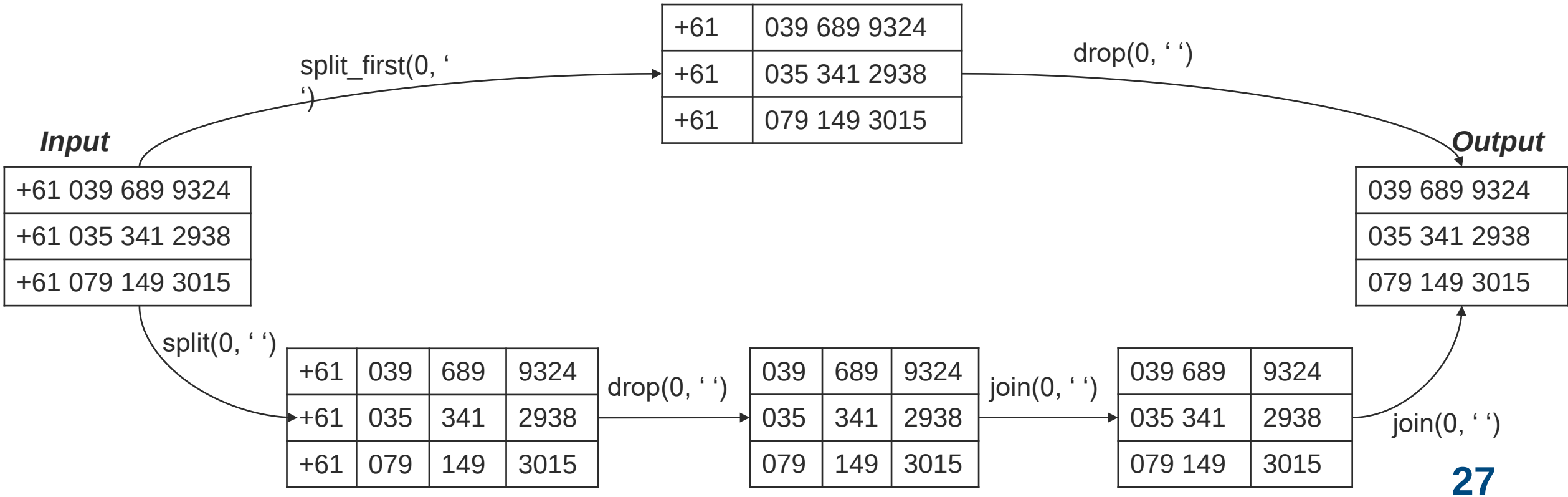
Inputs = [“Albert”, “Rauf”, “11/04/1986”, “+61 043 512 4834”, “arauf@gmail.com”, “Germany”, “99 Beacon Rd, Port Melbourne, VIC 3207, Australia”]

Outputs = [“Albert Rauf”, “11-04-1986”, “Germany”, “043-512-4834”, “arauf@gmail.com”, “99 Beacon Rd”, “Port Melbourne”, “VIC”, “3207”, “Australia”]

Transformation discovery

FOOFAH – transformation discovery by example

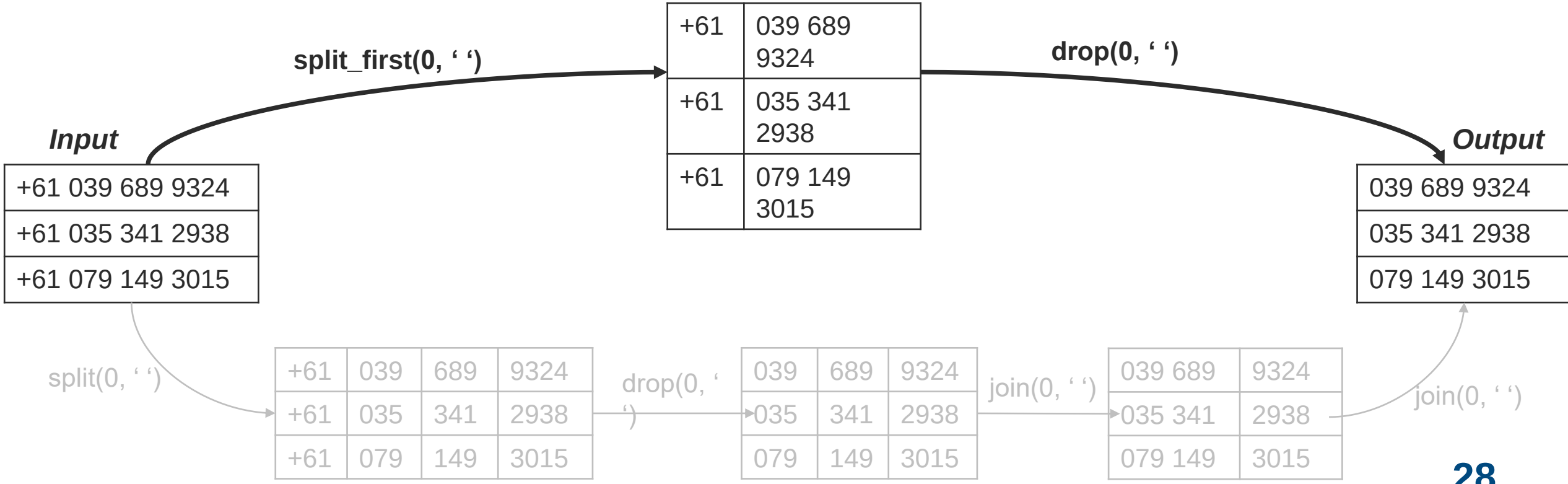
- Program synthesis as a search problem in a state space graph
- Heuristic search approach based on A* algorithm
- Cost function is the amount of manipulations
- Deals with string and table manipulations



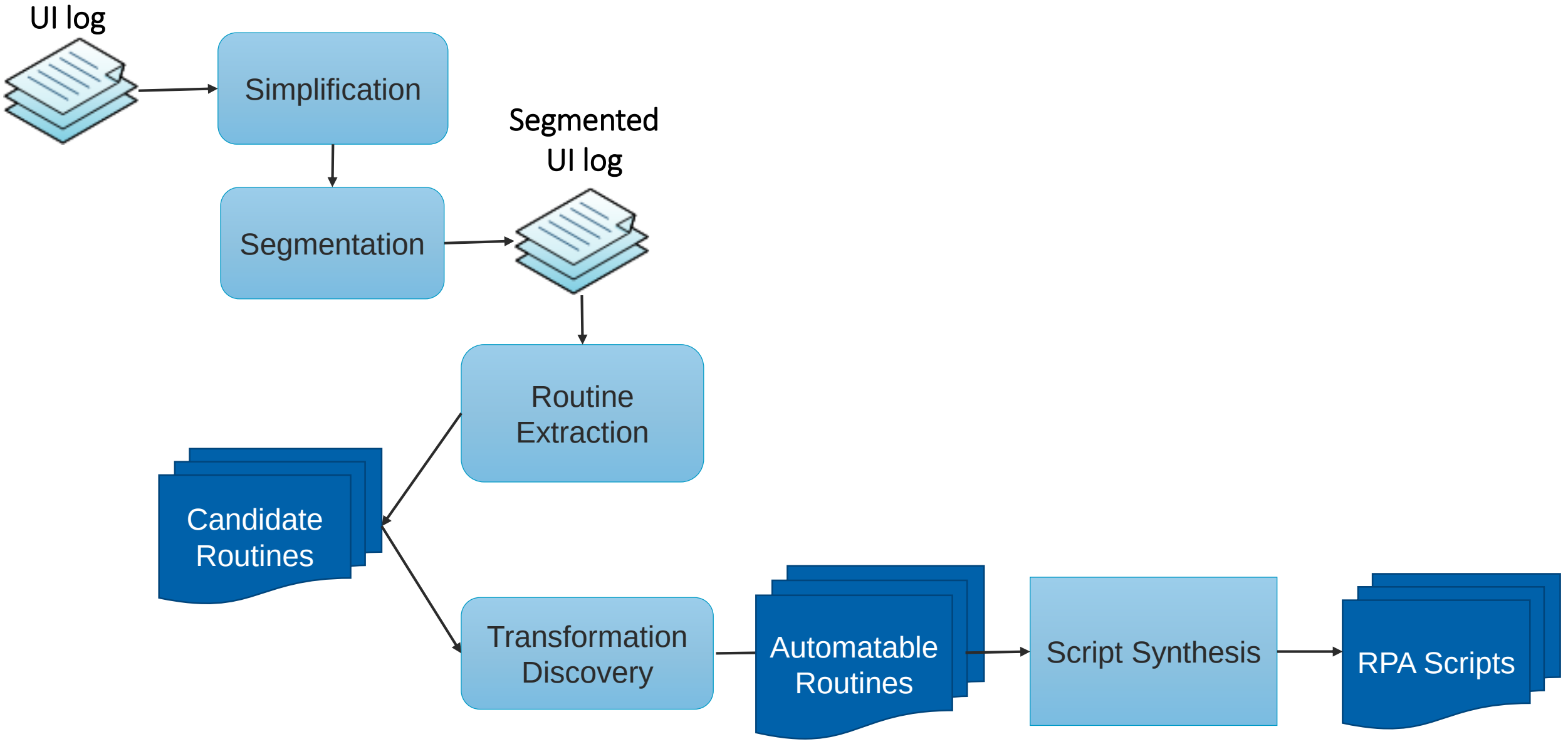
Transformation discovery

FOOFAH – transformation discovery by example

- Program synthesis as a search problem in state space graph
- Heuristic search approach based on A* algorithm
- Cost function is an amount of manipulations
- Deals with string and table manipulations



Robidium: Synthesizing RPA Scripts From UI Logs



Robidium:
Robotic Process Mining

Tool (hosted version)

- http://robidium.cloud.ut.ee

Video demo

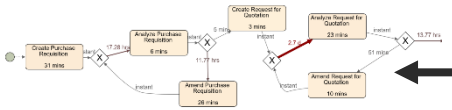
- https://youtu.be/24-pjFshquk

Automated Process Improvement

Robotic Process Mining (Task Automation)

Executable routine specifications

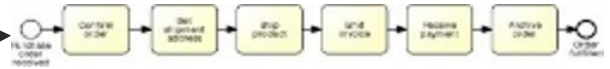
Resource Optimization



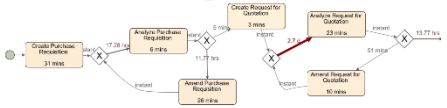
Optimized resource allocation policies

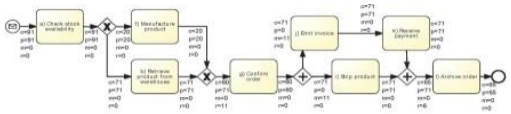
Execution data

Flow Optimization



Optimized process model





Decision Rule Optimization

UC	Inputs		Outputs
	Annual Income	Loan Size	Grade
A	[0..1000]	[0..1000]	VG
B	[250..750]	[4000..5000]	G
C	[500..1500]	[500..3000]	F
D	[2000..2500]	[0..2000]	P

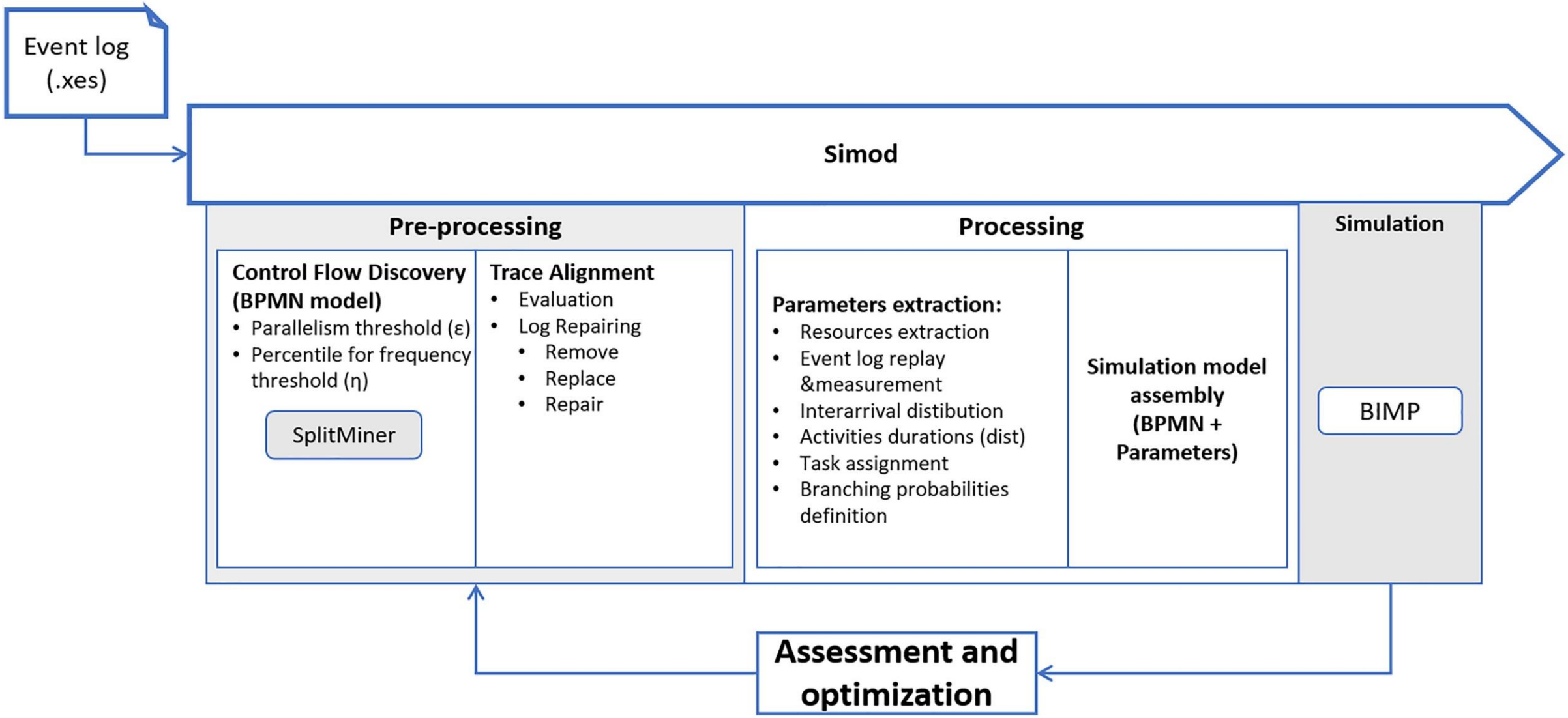
Decision rules

UC	Inputs		Outputs
	Annual Income	Loan Size	Grade
A	[0..1000]	[0..1000]	VG
B	[250..750]	[4000..5000]	G
C	[500..1500]	[500..3000]	F
D	[2000..2500]	[0..2000]	P

Optimized decision rules

How to determine if a given process change would improve a business process and by how much?

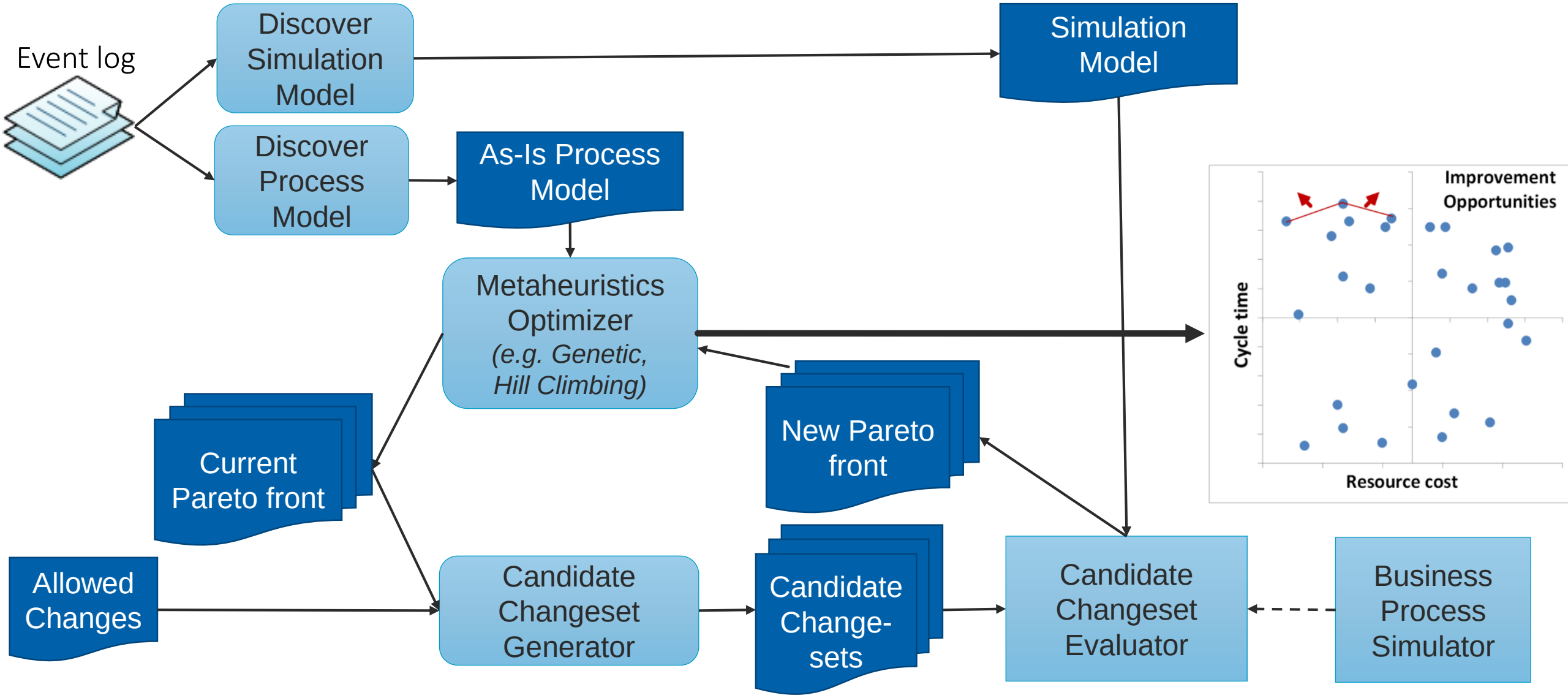
Data-Driven Process Simulation



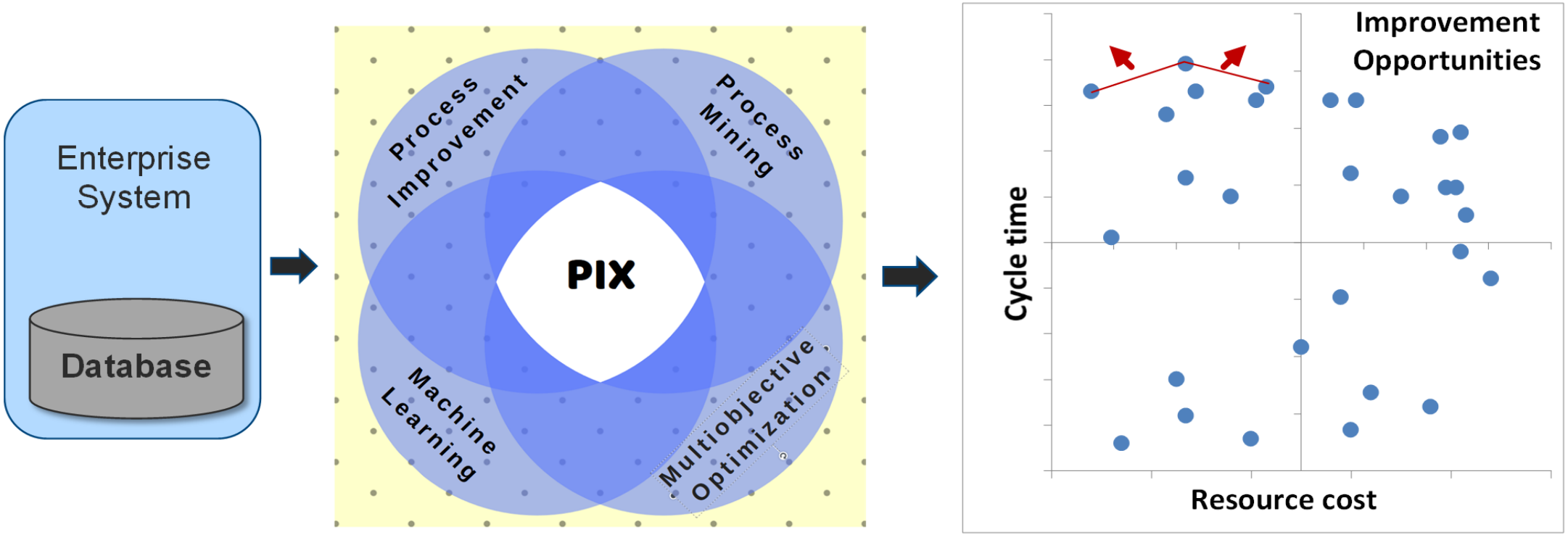
https://github.com/AdaptiveBProcess/Simod

Camargo et al. Automated Discovery of Simulation Models for Event Logs, Decision Support Systems, to appear, 2020

The Next Frontier: Search-Based Process Optimization



The Process Improvement Explorer (PIX)



https://sep.cs.ut.ee/Main/PIX

erc

There’s much more AI can do for BPM

- Natural Language Processing (NLP) for BPM
  - Natural Language in Business Process Models - Theoretical Foundations, Techniques, and Applications. Lecture Notes in Business Information Processing 168, Springer 2013
- Rule mining from event logs
  - RuM: https://rulemining.org/
- Causal process mining
  - https://www.linkedin.com/pulse/causal-process-mining-marlon-dumas/
- Automated reasoning and planning for goal-based synthesis of processes
- …

References

Predictive Process Monitoring

- Teinemaa et al. *Outcome-Oriented Predictive Process Monitoring: Review and Benchmark, 2019* https://arxiv.org/abs/1707.06766
- Verenich et al. *Survey and Cross-benchmark Comparison of Remaining Time Prediction Methods in Business Process Monitoring, 2019* https://arxiv.org/abs/1805.02896
- Rama-Maneiro et al. *Deep Learning for Predictive Business Process Monitoring: Review and Benchmark. 2020* https://arxiv.org/abs/2009.13251

Prescriptive Process Monitoring

- Fahrenkrog-Petersen et al. *Fire Now, Fire Later: Alarm-Based Systems for Prescriptive Process Monitoring*, 2019 https://arxiv.org/abs/1905.09568
- Metzger et al. *Triggering Proactive Business Process Adaptations via Online Reinforcement Learning.* http://shorturl.at/bgtKO

Robotic Process Mining

- Leno *et al. Robotic Process Mining: Vision and Challenges*. Bus Inf Syst Eng (2020). https://doi.org/10.1007/s12599-020-00641-4
- Leno et al. *Automated Discovery of Data Transformations for Robotic Process Automation*, 2020 https://arxiv.org/abs/2001.01007
- Agostinelli et al. *Automated Generation of Executable RPA Scripts from User Interface Logs*. Blockchain and RPA Forum 2020

Data-Driven Simulation

- Camargo et al. *Automated discovery of business process simulation models from event logs*. Decis. Support Syst. 134:113284, 2020 https://arxiv.org/abs/2009.03567
- Camargo et al. *Discovering Generative Models from Event Logs: Data-driven Simulation vs Deep Learning*, 2020 https://arxiv.org/abs/2009.03567