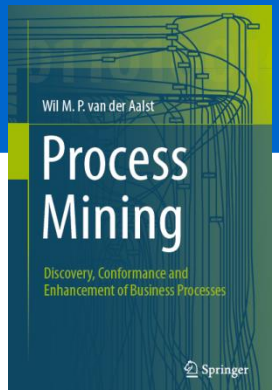
Process Mining: Data Science in Action

Learning Causal Nets and Annotating Them



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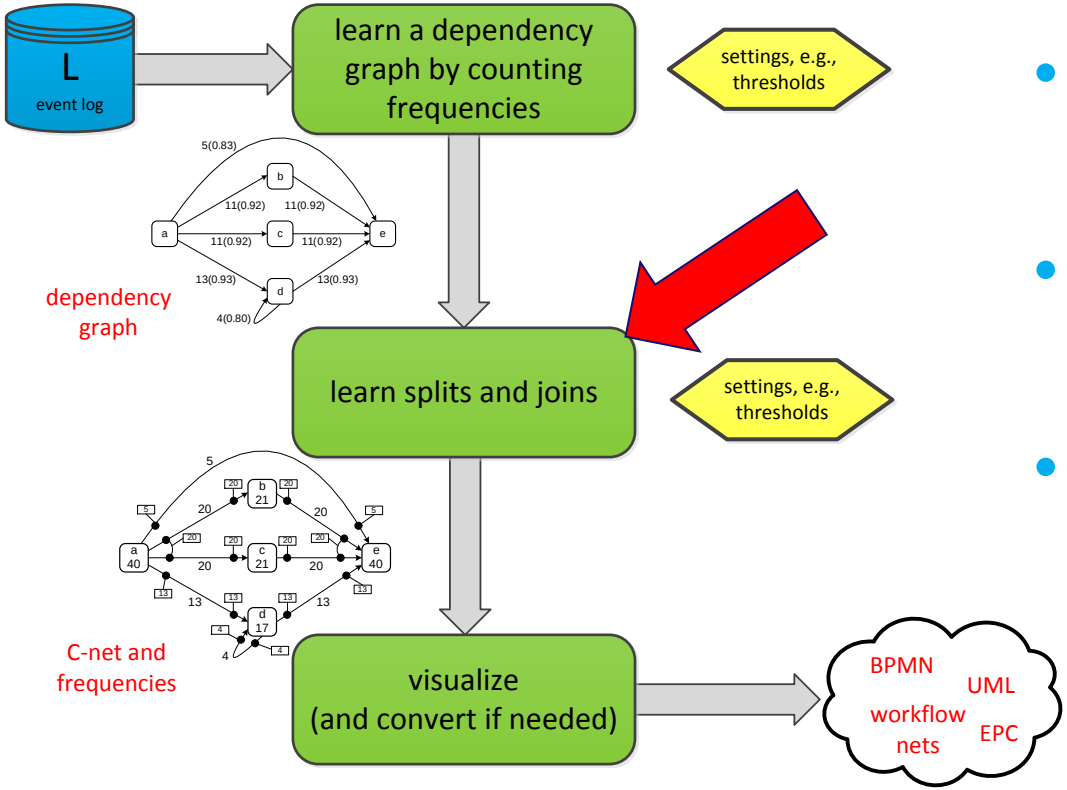
www.processmining.org

TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts

Heuristic mining: Two main phases



- **Here we focus on the second phase.**
- **Discovering splits and joins.**
- **Annotating C-nets with frequencies.**

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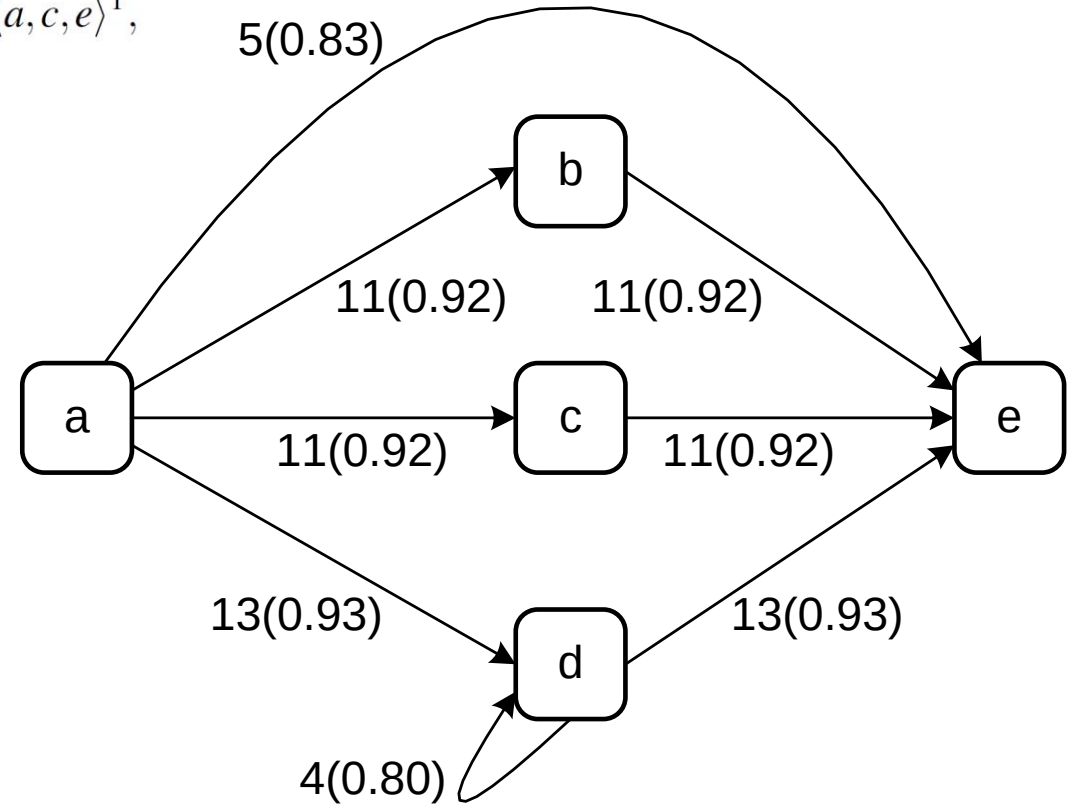
Reminder: First step

Create dependency graph

$$L = [\langle a,e\rangle^{5}, \langle a,b,c,e\rangle^{10}, \langle a,c,b,e\rangle^{10}, \langle a,b,e\rangle^{1}, \langle a,c,e\rangle^{1}, \langle a,d,e\rangle^{10}, \langle a,d,d,e\rangle^{2}, \langle a,d,d,d,e\rangle^{1}]$$

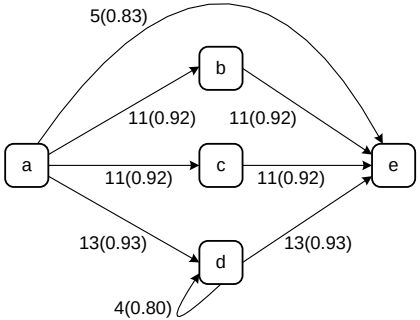
$\lvert >_L \rvert$	a	b	c	d	e
a	0	11	11	13	5
b	0	0	10	0	11
c	0	10	0	0	11
d	0	0	0	4	13
e	0	0	0	0	0

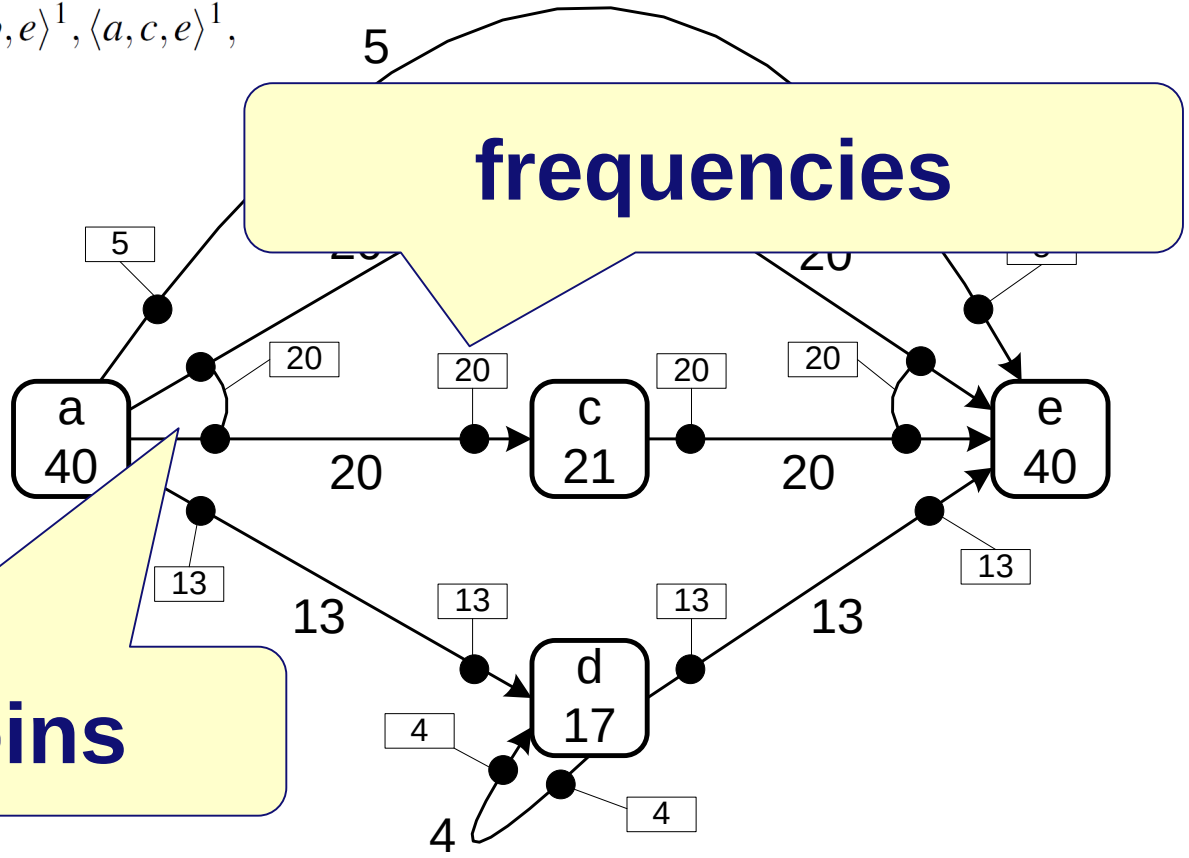
$\lvert \Rightarrow_L \rvert$	a	b	c	d	e
a	$\frac{0}{0+1}=0$	$\frac{11-0}{11+0+1}=0.92$	$\frac{11-0}{11+0+1}=0.92$	$\frac{13-0}{13+0+1}=0.93$	$\frac{5-0}{5+0+1}=0.83$
b	$\frac{0-11}{0+11+1}=-0.92$	$\frac{0}{0+1}=0$	$\frac{10-10}{10+10+1}=0$	$\frac{0-0}{0+0+1}=0$	$\frac{11-0}{11+0+1}=0.92$
c	$\frac{0-11}{0+11+1}=-0.92$	$\frac{10-10}{10+10+1}=0$	$\frac{0}{0+1}=0$	$\frac{0-0}{0+0+1}=0$	$\frac{11-0}{11+0+1}=0.92$
d	$\frac{0-13}{0+13+1}=-0.93$	$\frac{0-0}{0+0+1}=0$	$\frac{0-0}{0+0+1}=0$	$\frac{4}{4+1}=0.80$	$\frac{13-0}{13+0+1}=0.93$
e	$\frac{0-5}{0+5+1}=-0.83$	$\frac{0-11}{0+11+1}=-0.92$	$\frac{0-11}{0+11+1}=-0.92$	$\frac{0-13}{0+13+1}=-0.93$	$\frac{0}{0+1}=0$



Desired output: splits/joins & frequencies

$$L = [\langle a,e\rangle^{5}, \langle a,b,c,e\rangle^{10}, \langle a,c,b,e\rangle^{10}, \langle a,b,e\rangle^{1}, \langle a,c,e\rangle^{1},$$
$$\langle a,d,e\rangle^{10}, \langle a,d,d,e\rangle^{2}, \langle a,d,d,d,e\rangle^{1}]$$



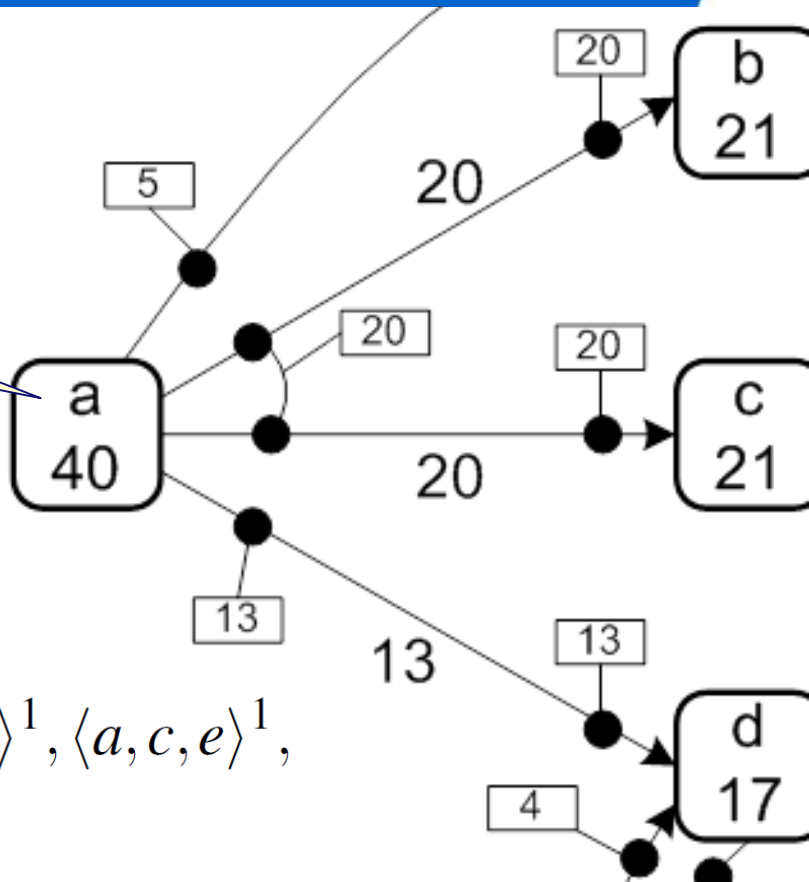


frequencies

splits and joins

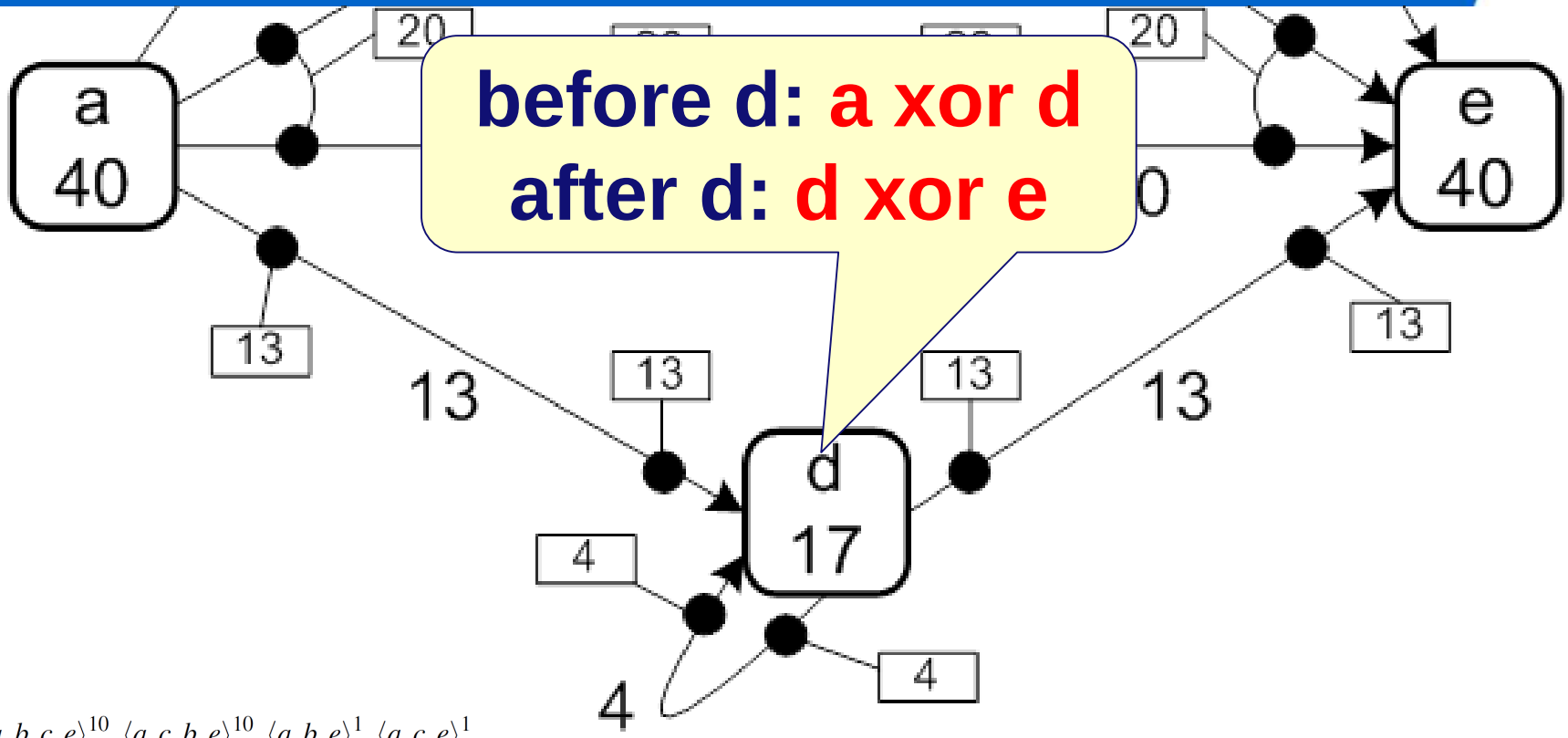
Output bindings of activity a

after a:
e xor (b and c) xor d



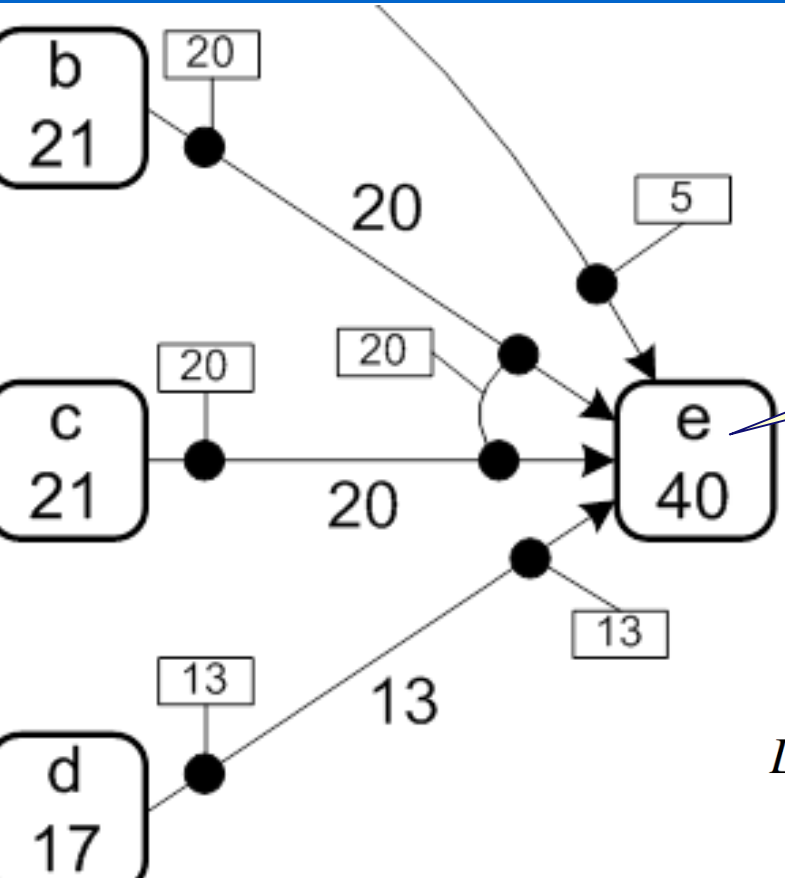
$$L = [\langle a,e\rangle^{5}, \langle a,b,c,e\rangle^{10}, \langle a,c,b,e\rangle^{10}, \langle a,b,e\rangle^{1}, \langle a,c,e\rangle^{1},$$
$$\langle a,d,e\rangle^{10}, \langle a,d,d,e\rangle^{2}, \langle a,d,d,d,e\rangle^{1}]$$

Input and output bindings of activity d



$$L = [\langle a,e\rangle^{5}, \langle a,b,c,e\rangle^{10}, \langle a,c,b,e\rangle^{10}, \langle a,b,e\rangle^{1}, \langle a,c,e\rangle^{1}, \langle a,d,e\rangle^{10}, \langle a,d,d,e\rangle^{2}, \langle a,d,d,d,e\rangle^{1}]$$

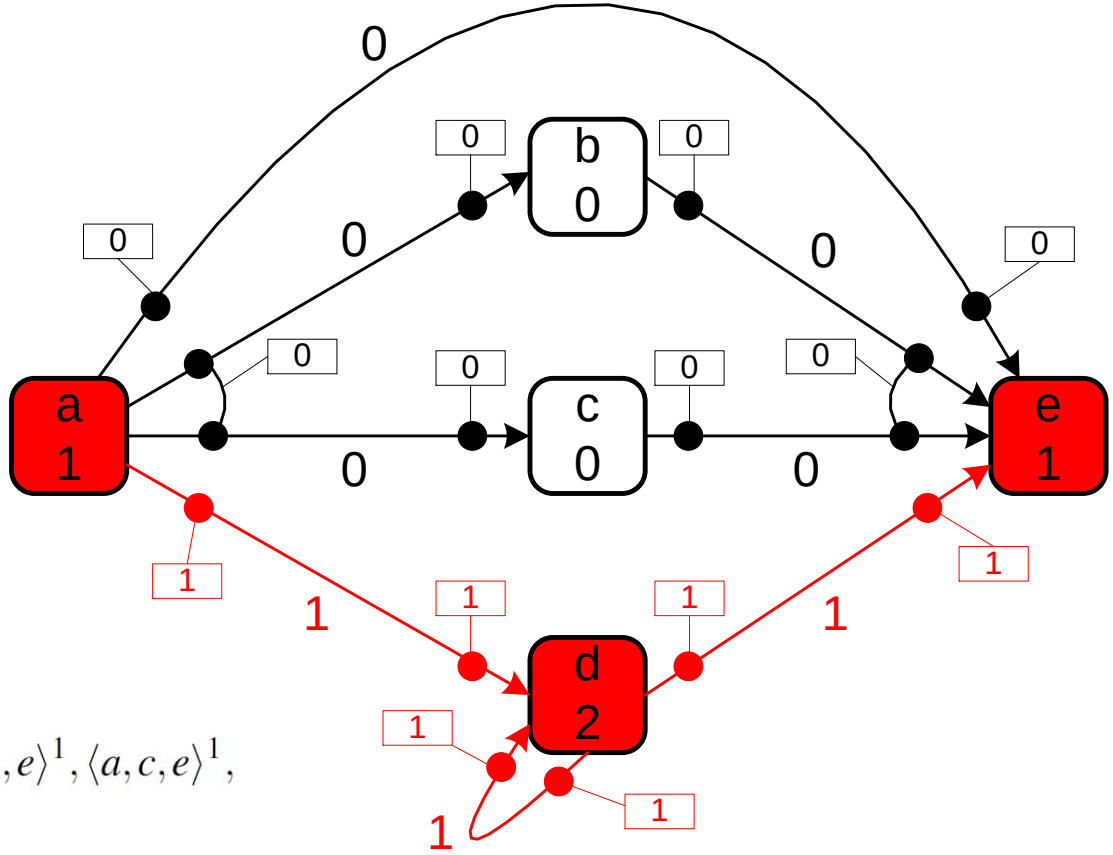
Input bindings of e



before e:
a xor (b and c) xor d

$$L = [\langle a,e\rangle^{5}, \langle a,b,c,e\rangle^{10}, \langle a,c,b,e\rangle^{10}, \langle a,b,e\rangle^{1}, \langle a,c,e\rangle^{1},$$
$$\langle a,d,e\rangle^{10}, \langle a,d,d,e\rangle^{2}, \langle a,d,d,d,e\rangle^{1}]$$

Example path: adde

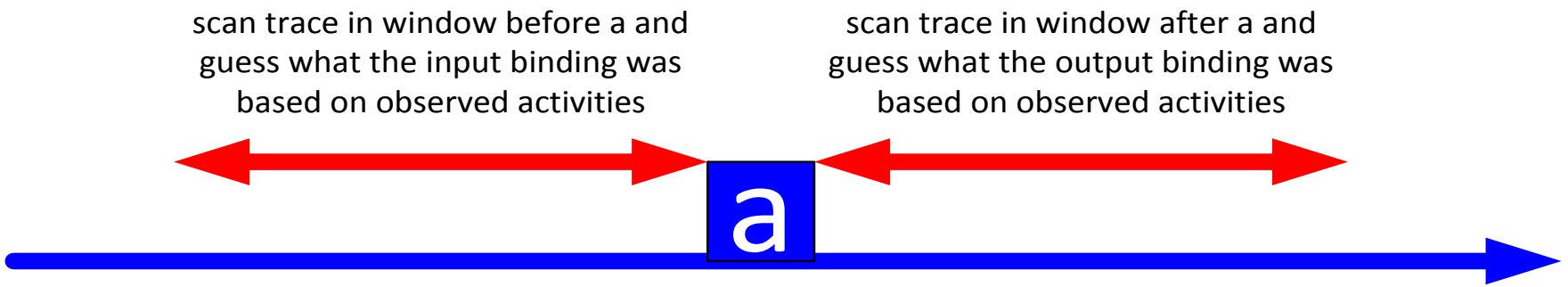


$$L = [\langle a,e\rangle^{5}, \langle a,b,c,e\rangle^{10}, \langle a,c,b,e\rangle^{10}, \langle a,b,e\rangle^{1}, \langle a,c,e\rangle^{1},$$
$$\langle a,d,e\rangle^{10}, \langle a,d,d,e\rangle^{2}, \langle a,d,d,d,e\rangle^{1}]$$

How to discover splits and joins?

- **Two classes of approaches:**
  1. **Heuristics using a time window before and after each activity. By counting sets of input and output activities the bindings can be determined (local decision).**
  2. **Optimization approaches based on replay. Given a set of possible input and output bindings one can see whether reality can be replayed properly. The set of possible input and output bindings is finite, so a "best set of bindings" can be determined using some goal function.**
- **Many variations are possible!**

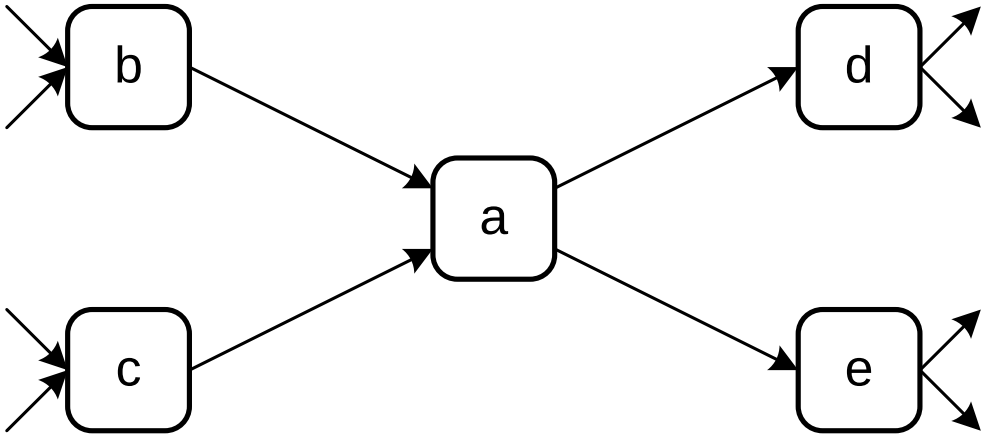
Approach 1: Based on heuristics



- **Activities have possible inputs and outputs (based on dependency graph).**
- **Count how often they appear in a window before (for input bindings) and a window after (for output bindings)**

Example: Window size 4

1….klbgadhek…
2….lkgcahedl…
3….kblgaehdk…
4….klgbadehk…
5….klkcadkeh…



input output bindings
- {b}: • {d,e}: 5 times
- {c}: 2 times

Adding bindings and frequencies

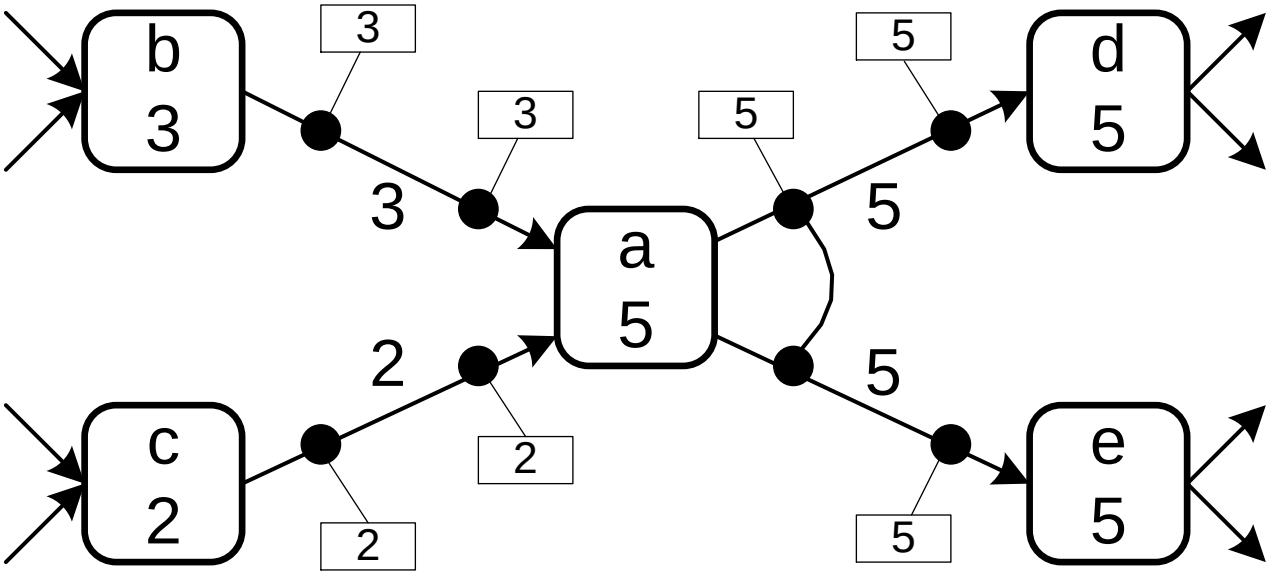
1. …klbgadhek…
2. …lkgcahedl…
3. …kblgaehdk…
4. …klgbadehk…
5. …klkcadkeh…

input bindings

- {b}: 3 times
- {c}: 2 times

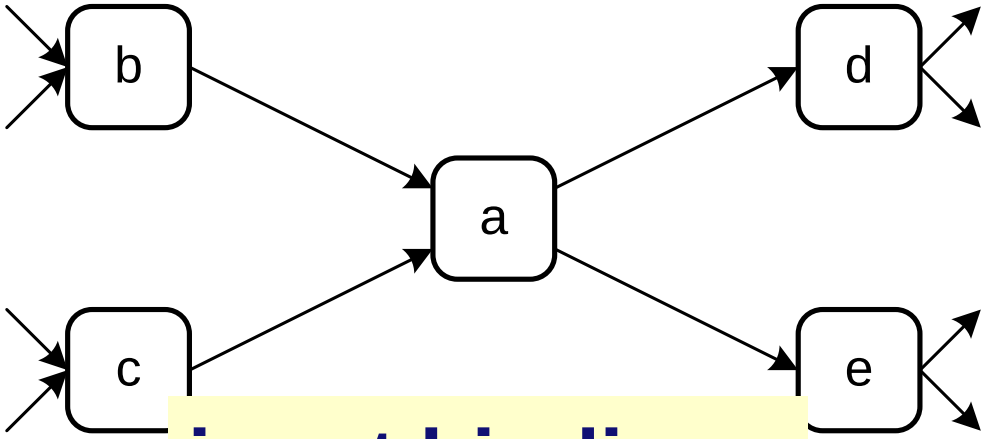
output bindings

- {d,e}: 5 times



Another example: Window size 4

1….klbgadhek…
2….lkgcahhdl…
3….kbcgaehdk…
4….klcbadkhk…
5….klkcadkeh…



input bindings
- {l
- {(

output bindings
- {d}: 2 times
- {d,e}: 3 times

Adding bindings and frequencies

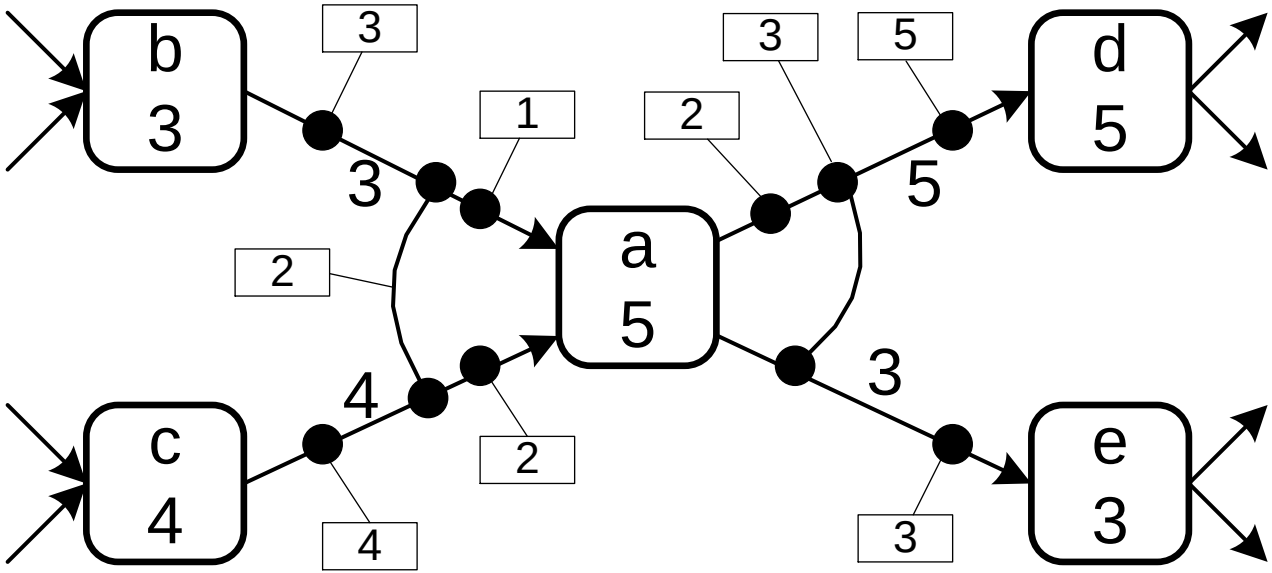
1. …klbgadhek…
2. …lkgcahhdl…
3. …kbcgaehdk…
4. …klcbadkhk…
5. …klkcadkeh…

input bindings

- {b}: 1 time
- {c}: 2 times
- {b,c}: 2 times

output bindings

- {d}: 2 times
- {d,e}: 3 times



Question

Determine input and output bindings (window size 4)

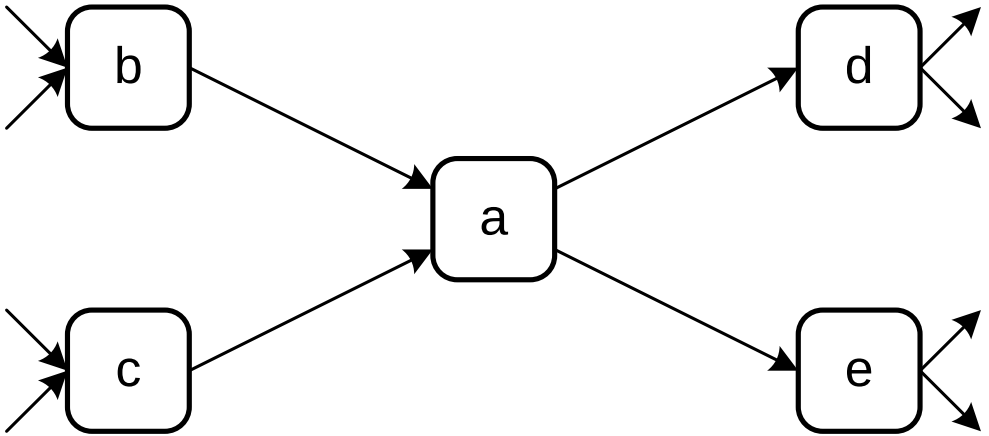
1….kcbgadhek…

2….lbgcaehdl…

3….bkcgaehhk…

4….cklbakkhe…

5….kbkcadkeh…



Answer

Input and output bindings (window size 4)

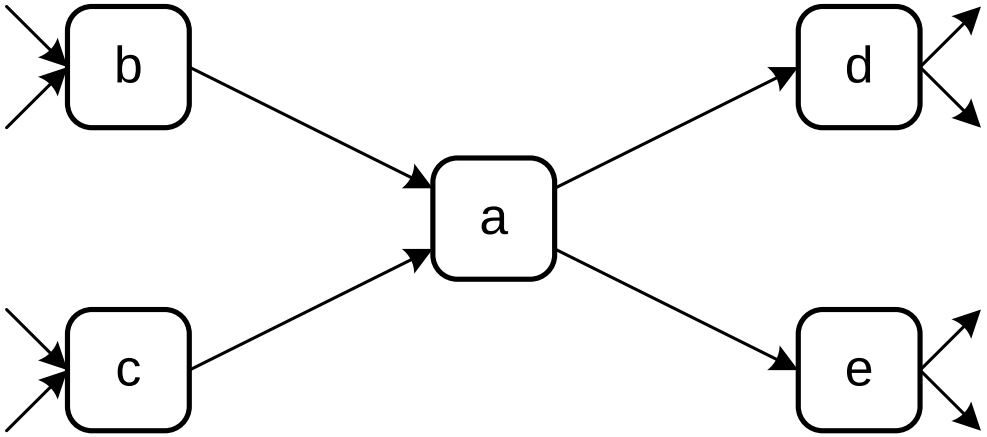
1….kcbgadhek…

2….lbgcaehdl…

3….bkcgaehhk…

4….cklbakkhe…

5….kbkcadkeh…

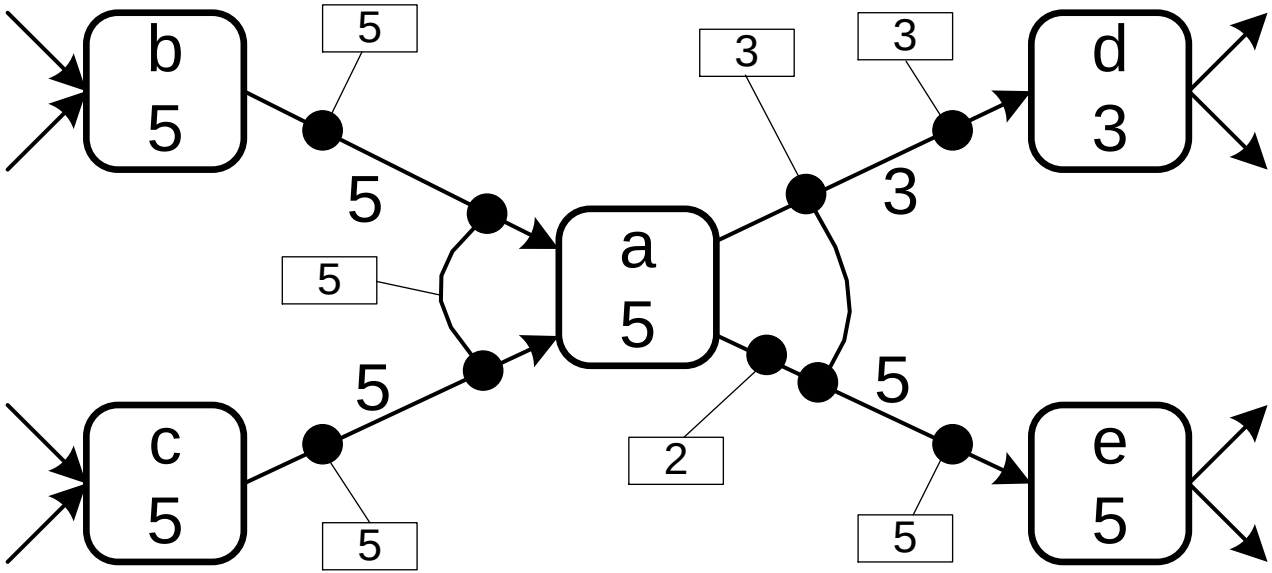


input | output bindings

- {b,c} • {e}: 2 times
- {d,e}: 3 times

Adding bindings and frequencies

1. …kcbgadhek…
2. …lbgcaehdl…
3. …bkcgaehhk…
4. …cklbakkhe…
5. …kbkcadkeh…



input bindings

- {b,c}: 5 times

output bindings

- {e}: 2 times
- {d,e}: 3 times

Refinements needed!

- What if there are no corresponding activities in the input or output window?
- Noise filtering (remove infrequent bindings).
- Handling repeating activities (e.g., cut off window size).
- Details are out of scope, but be aware of such complications when interpreting results!

Approach 2: Optimization problem

- **Evaluate all possible activity bindings and take best one.**
- **Based on the idea that ideally a trace can be replayed from the initial state to the final state.**
- **This can be checked precisely using various replay approaches (will be discussed later).**
- **Hence, one can use approaches that simply "try bindings" exhaustively.**

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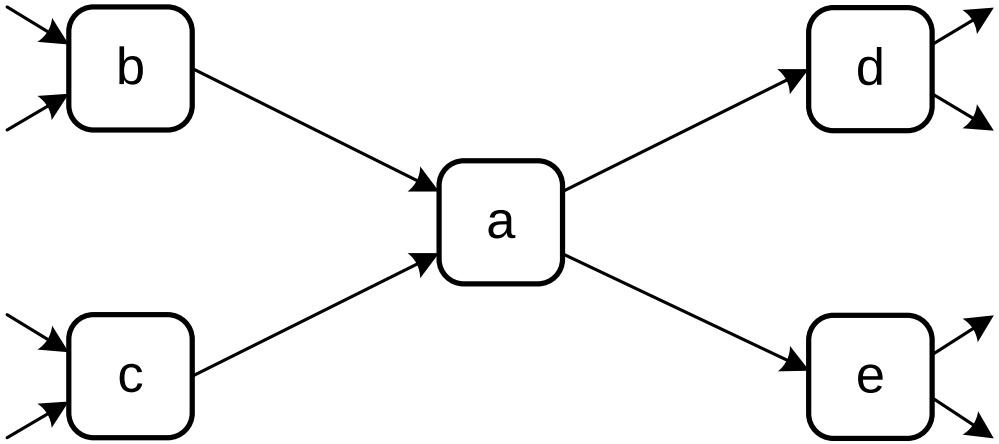
Example: Sets of input and output bindings

- **Each input/output arc needs to be involved in at least one binding.**



There are

|{ {{b,c}}, {{b},{c}} , {{b},{b,c}} , {{c},{b,c}} , {{b},{c},{b,c}} }| x
|{ {{d,e}}, {{d},{e}} , {{d},{d,e}} , {{e},{d,e}} , {{d},{e},{d,e}} }|
= 5 x 5 = 25 possible a activities.

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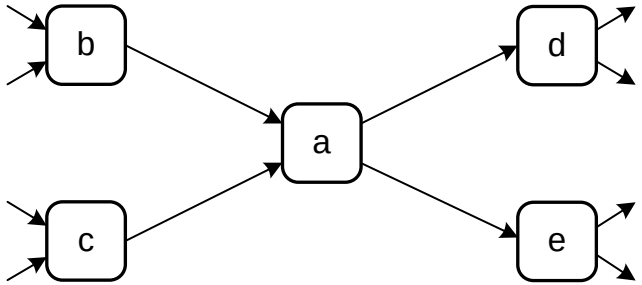
Optimization approach

- For each activity select one of the input-output binding combinations.
- One can do this exhaustively and try all combinations.
- Evaluation can be done using replay.
- Take best one (taking into account fitness, precision, generalization, and simplicity).



|{ {{b,c}}, {{b},{c}} , {{b},{b,c}} , {{c},{b,c}} , {{b},{c},{b,c}} }| x
|{ {{d,e}}, {{d},{e}} , {{d},{d,e}} , {{e},{d,e}} , {{d},{e},{d,e}} }|
= 5 x 5 = 25 possible a activities

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If too time consuming, …

- **Randomize**
- **Use a genetic algorithm**

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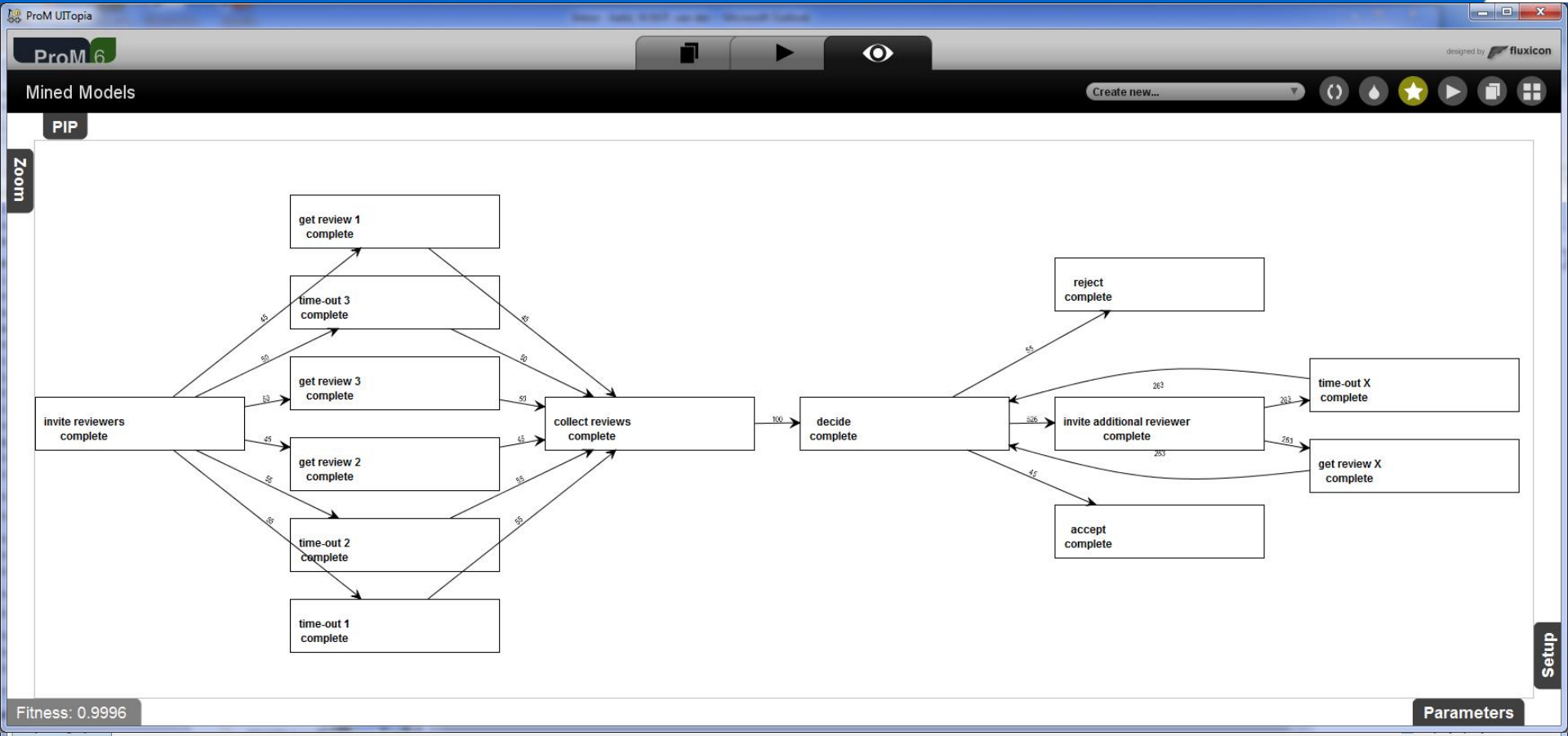
Example: Heuristic miner



Part I: Preliminaries

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Introduction

Chapter 2
Process Modeling and Analysis

Chapter 3
Data Mining

Part II: From Event Logs to Process Models

Chapter 4
Getting the Data

Chapter 5
Process Discovery: An Introduction

Chapter 6
Advanced Process Discovery [illegible]iques

Part III: Beyond Process Discovery

Chapter 7
Conformance Checking

Chapter 8
Mining Additional Perspectives

Chapter 9
Operational Support

Part IV: Putting Process Mining to Work

Chapter 10
Tool Support

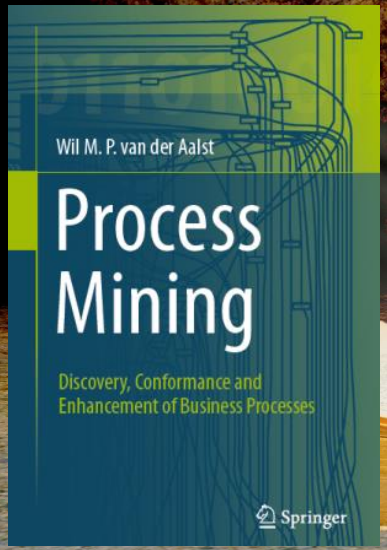
Chapter 11
Analyzing "Lasagna Processes"

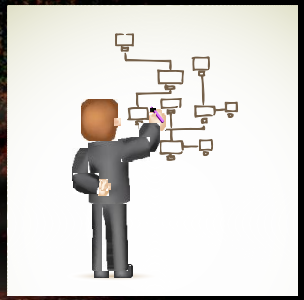
Chapter 12
Analyzing "Spaghetti Processes"

Part V: Reflection

Chapter 13
Cartography and Navigation

Chapter 14
Epilogue





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