Process Mining: Data Science in Action

Learning Causal Nets and Annotating Them

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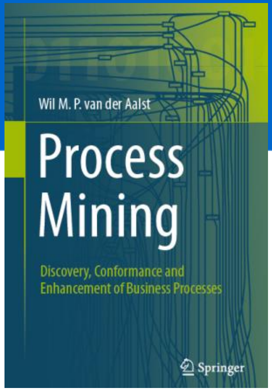
www.processmining.org



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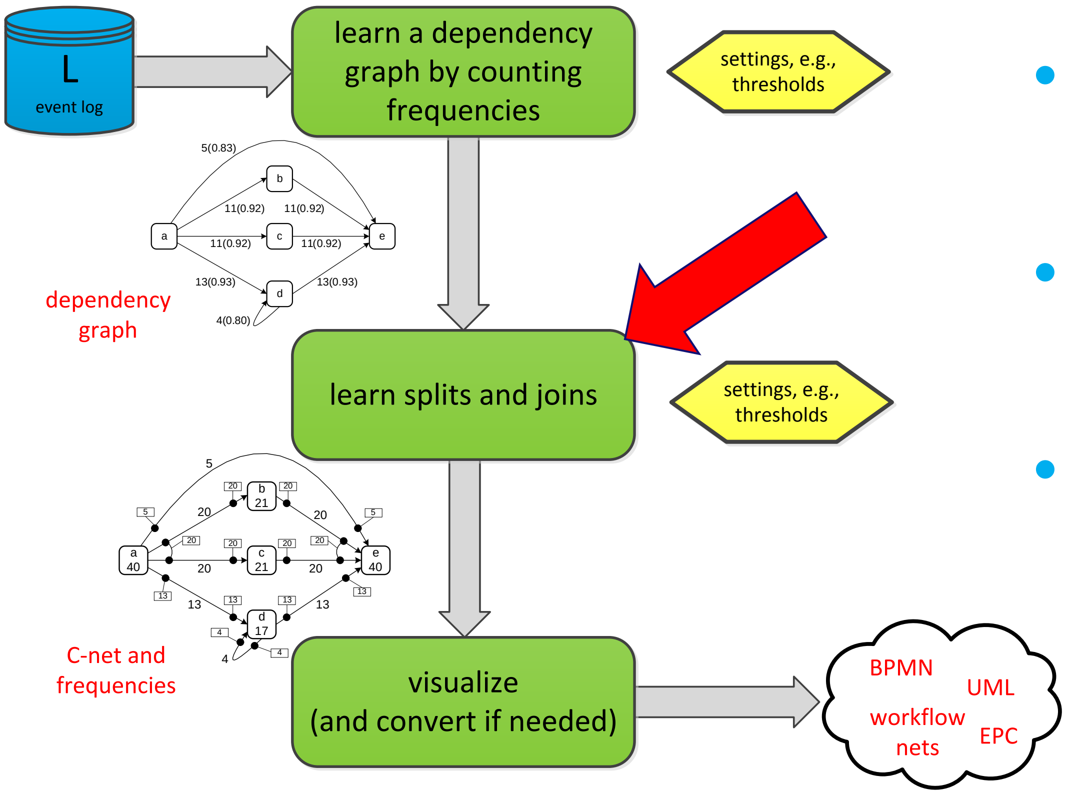
Where innovation starts

Heuristic mining: Two main phases



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

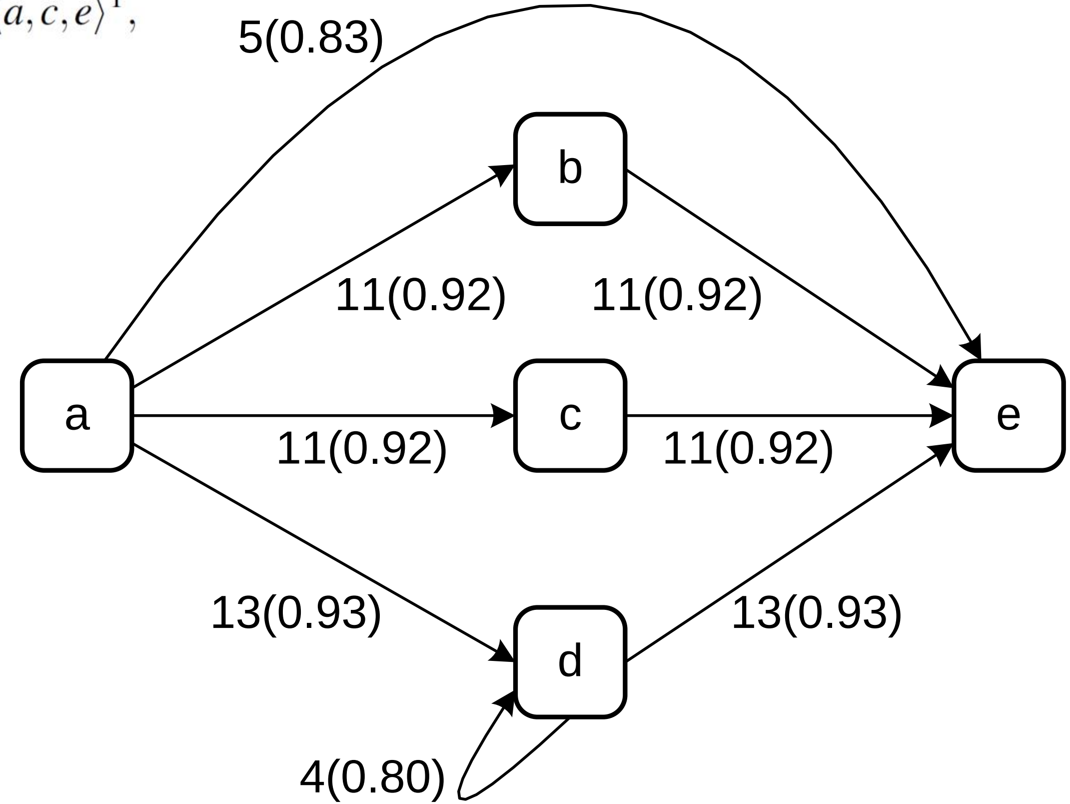
Reminder: First step

Create dependency graph

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

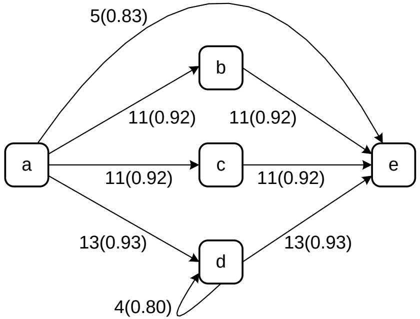
$\lvert >_L \rvert$	a	b	c	d	e
a	0	11	11	13	5
b	0	0	10	0	11
c	0	10	0	0	11
d	0	0	0	4	13
e	0	0	0	0	0

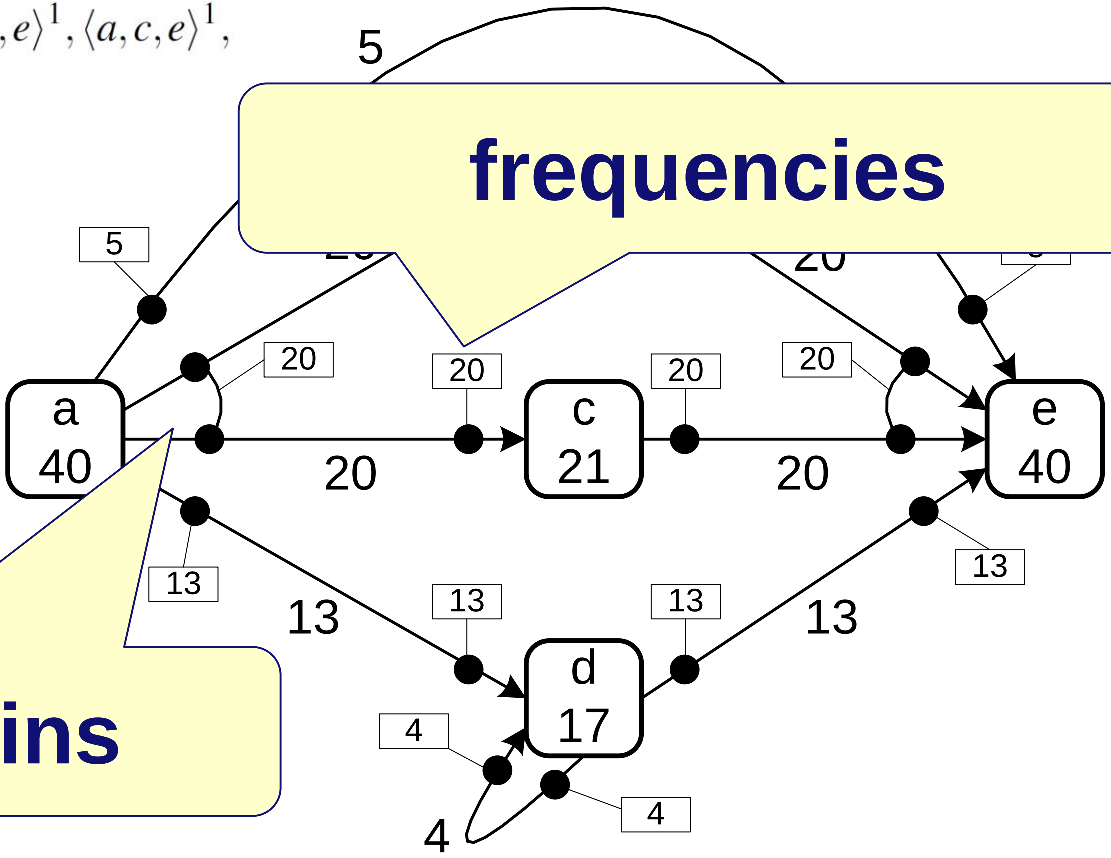
$\lvert \Rightarrow_L \rvert$	a	b	c	d	e
a	$\frac{0}{0+1}=0$	$\frac{11-0}{11+0+1}=0.92$	$\frac{11-0}{11+0+1}=0.92$	$\frac{13-0}{13+0+1}=0.93$	$\frac{5-0}{5+0+1}=0.83$
b	$\frac{0-11}{0+11+1}=-0.92$	$\frac{0}{0+1}=0$	$\frac{10-10}{10+10+1}=0$	$\frac{0-0}{0+0+1}=0$	$\frac{11-0}{11+0+1}=0.92$
c	$\frac{0-11}{0+11+1}=-0.92$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

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



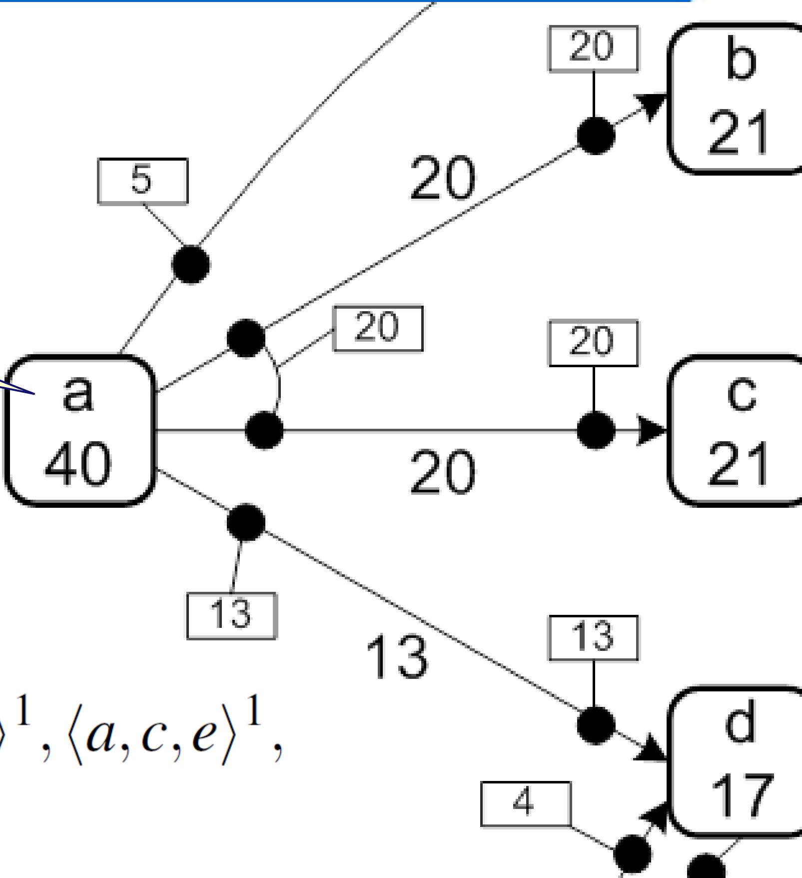


frequencies

splits and joins

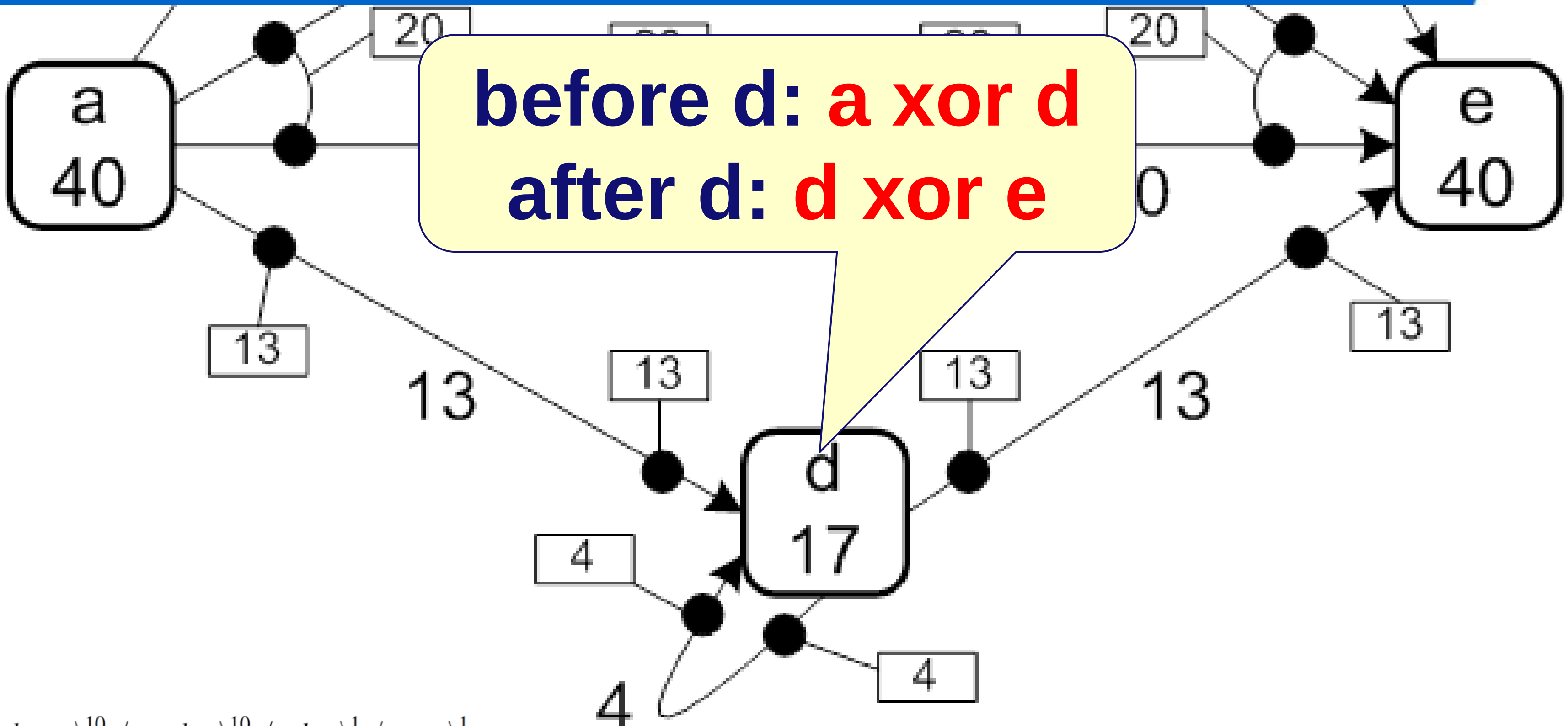
Output bindings of activity a

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



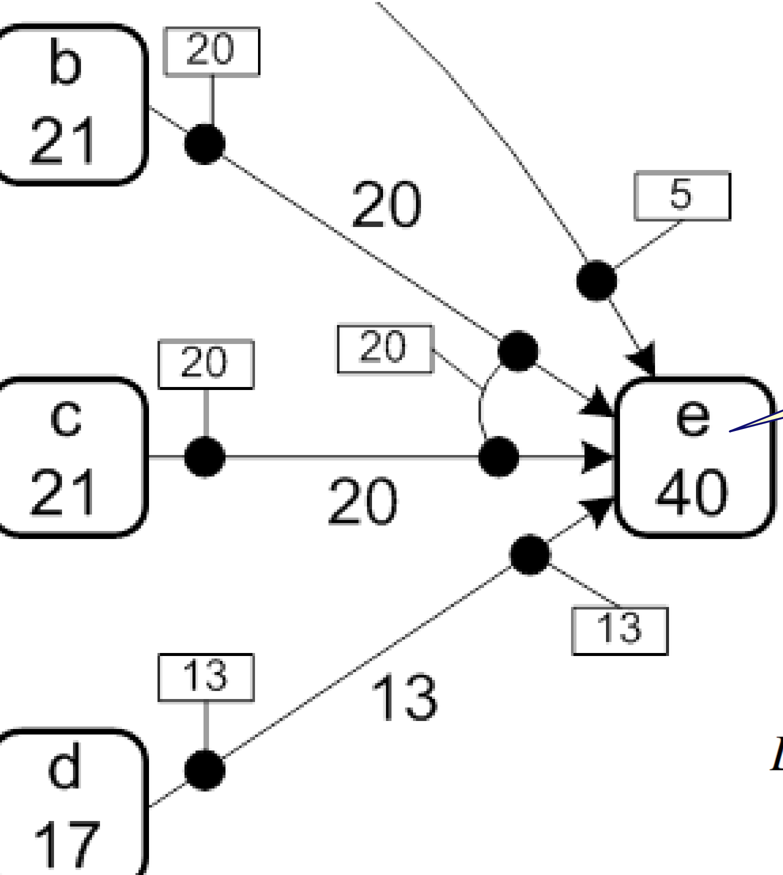
$$L = [\langle a,e\rangle^5, \langle a,b,c,e\rangle^{10}, \langle a,c,b,e\rangle^{10}, \langle a,b,e\rangle^1, \langle a,c,e\rangle^1, \langle a,d,e\rangle^{10}, \langle a,d,d,e\rangle^2, \langle a,d,d,d,e\rangle^1]$$

Input and output bindings of activity d



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

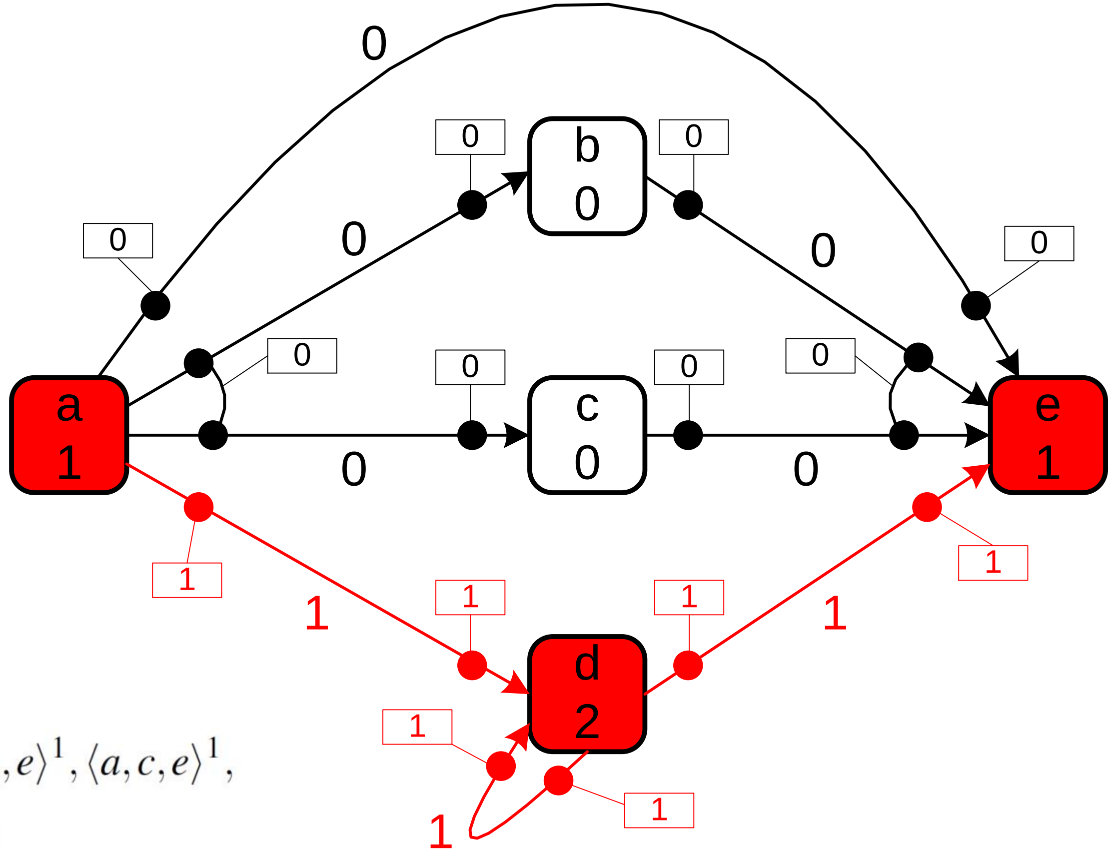
Input bindings of e



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

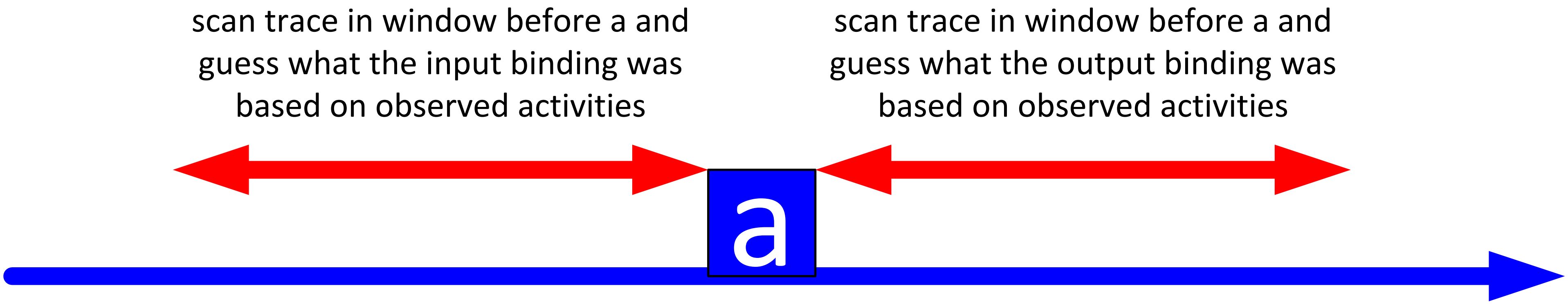


$$L = [\langle a,e\rangle^5, \langle a,b,c,e\rangle^{10}, \langle a,c,b,e\rangle^{10}, \langle a,b,e\rangle^1, \langle a,c,e\rangle^1,$$
$$\langle a,d,e\rangle^{10}, \langle a,d,d,e\rangle^2, \langle a,d,d,d,e\rangle^1]$$

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!

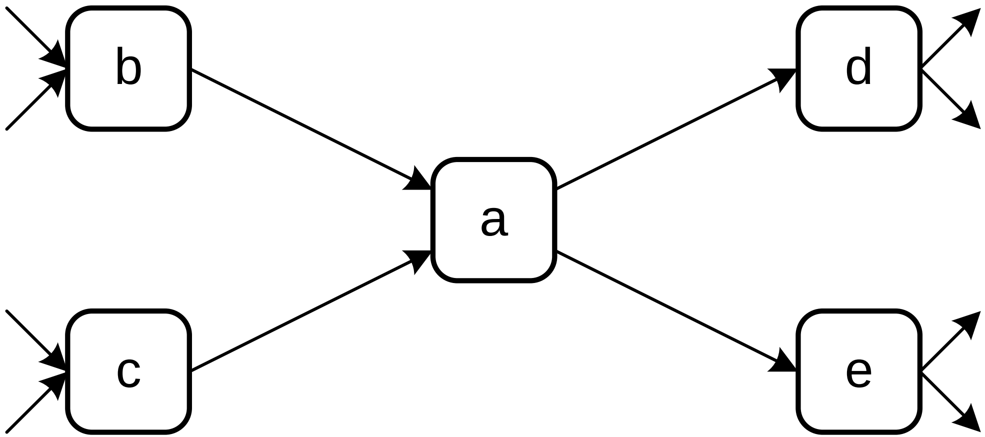
Approach 1: Based on heuristics



- **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

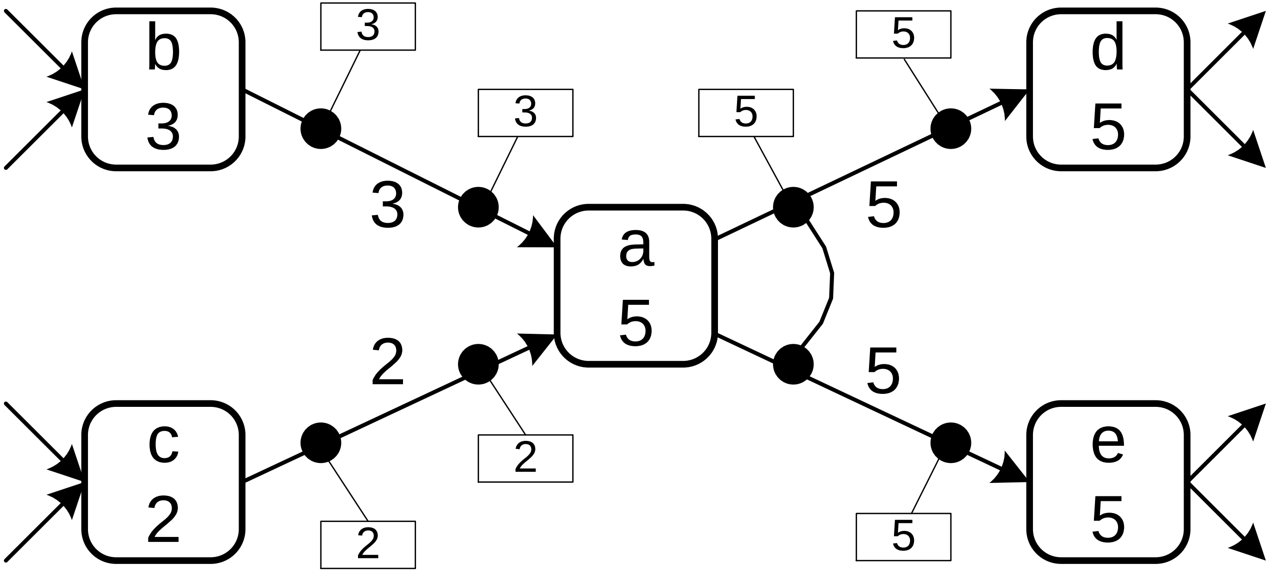
1....klbgadhek...
2....lkgcahedl...
3....kblgaehdk...
4....klgbadehk...
5....klkcadkeh...



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…

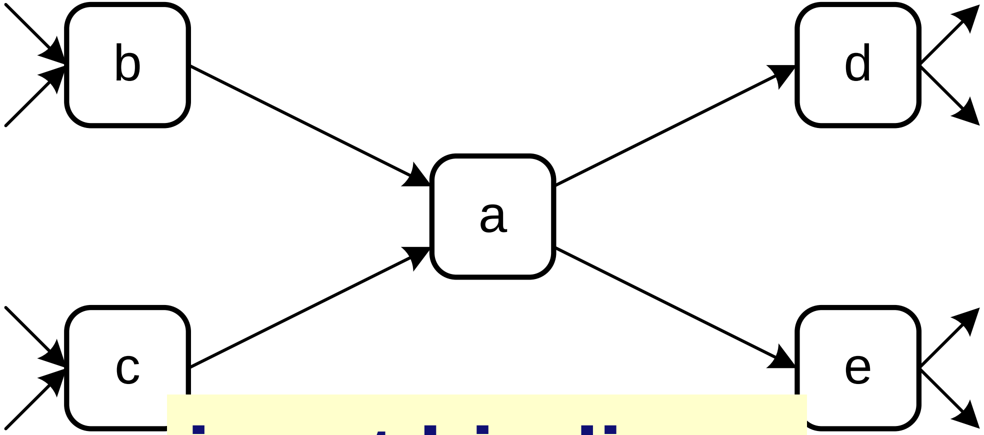


input bindings
- {b}: 3 times
- {c}: 2 times

output bindings
- {d,e}: 5 times

Another example: Window size 4

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



input bindings

output bindings

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

Adding bindings and frequencies

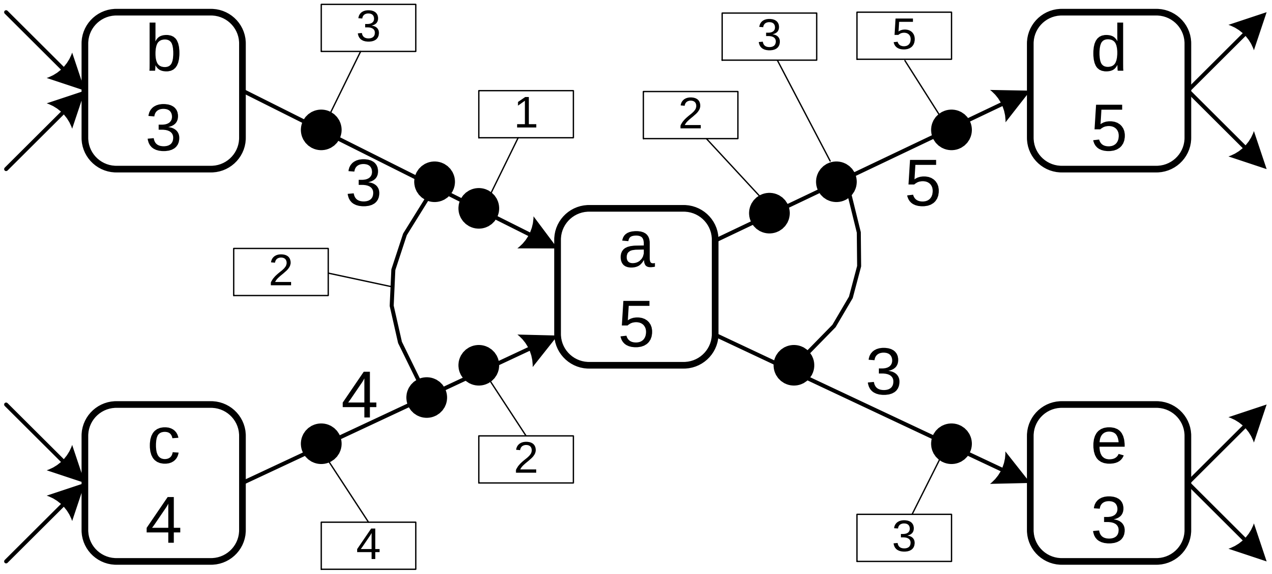
1. …klbgadhek…
2. …lkgcahhdl…
3. …kbcgaehdk…
4. …klcbadkhk…
5. …klkcadkeh…

input bindings

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

output bindings

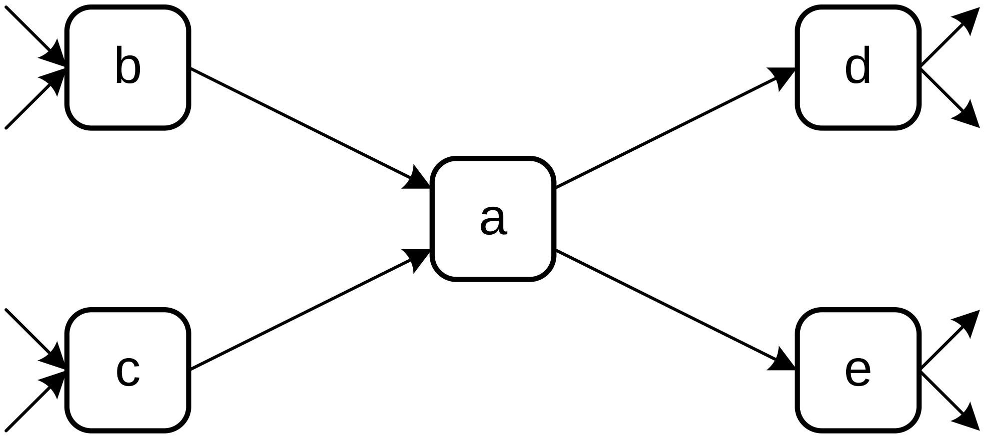
- {d}: 2 times
- {d,e}: 3 times



Question

Determine input and output bindings (window size 4)

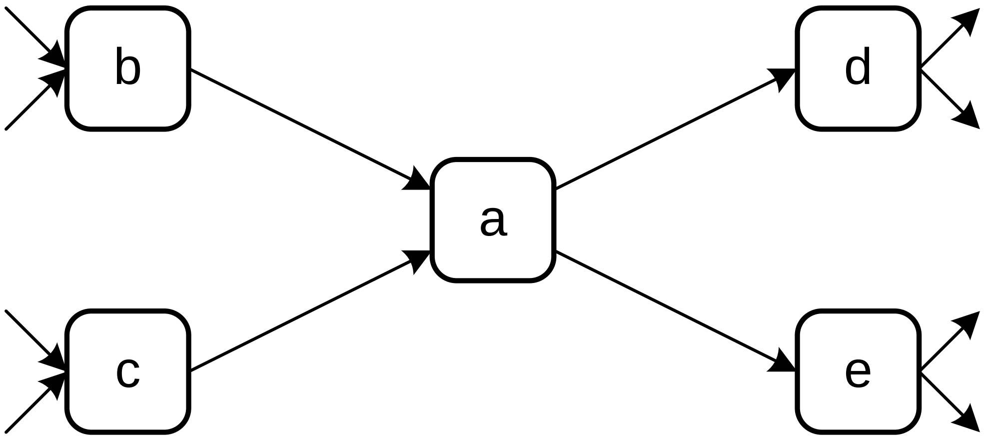
1. ....kcbgadhek....
2. ....lbgcaehdl....
3. ....bkcgaehhk....
4. ....cklbakkhe....
5. ....kbkcadkeh....



Answer

Input and output bindings (window size 4)

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

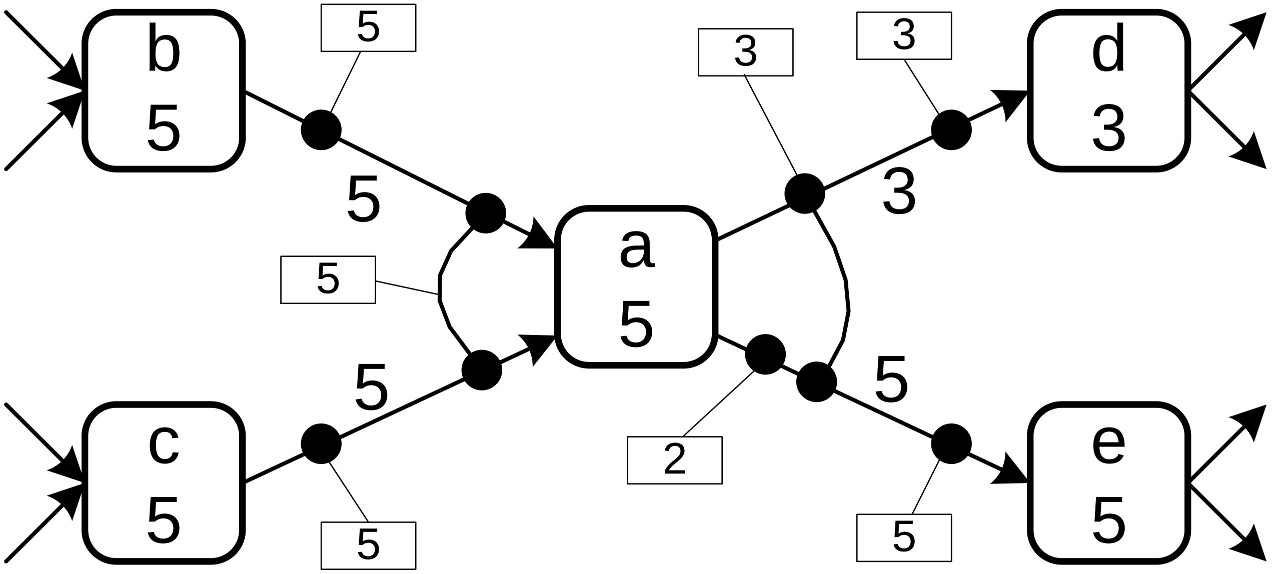


input | output bindings

- {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!

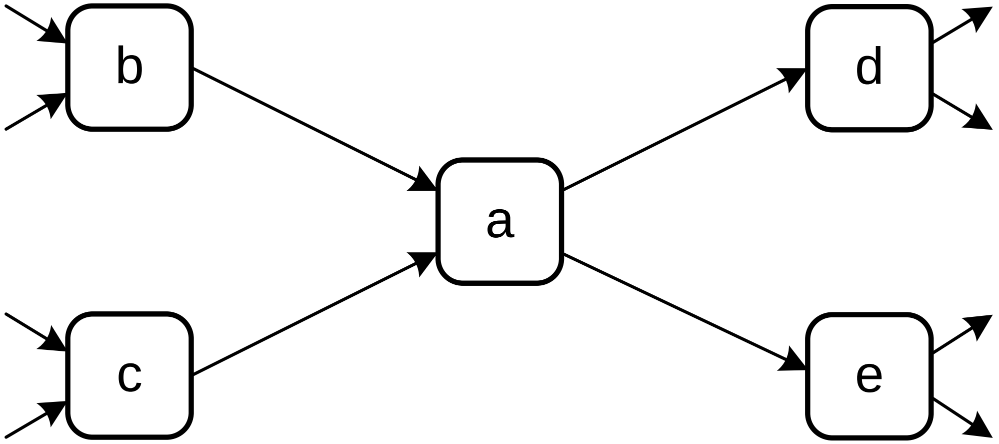
- What if there are no corresponding activities in the input or output window?
- Noise filtering (remove infrequent bindings).
- Handling repeating activities (e.g., cut off window size).
- Details are out of scope, but be aware of such complications when interpreting results!

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**.

Example: Sets of input and output bindings

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

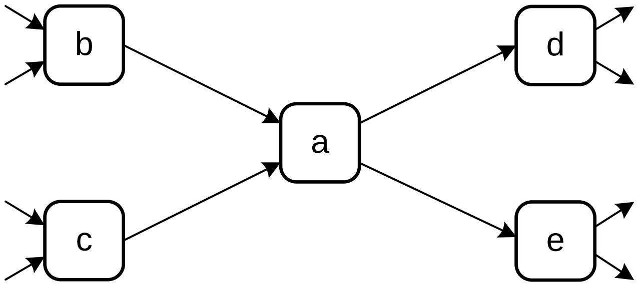


There are

|{ {{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.

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).

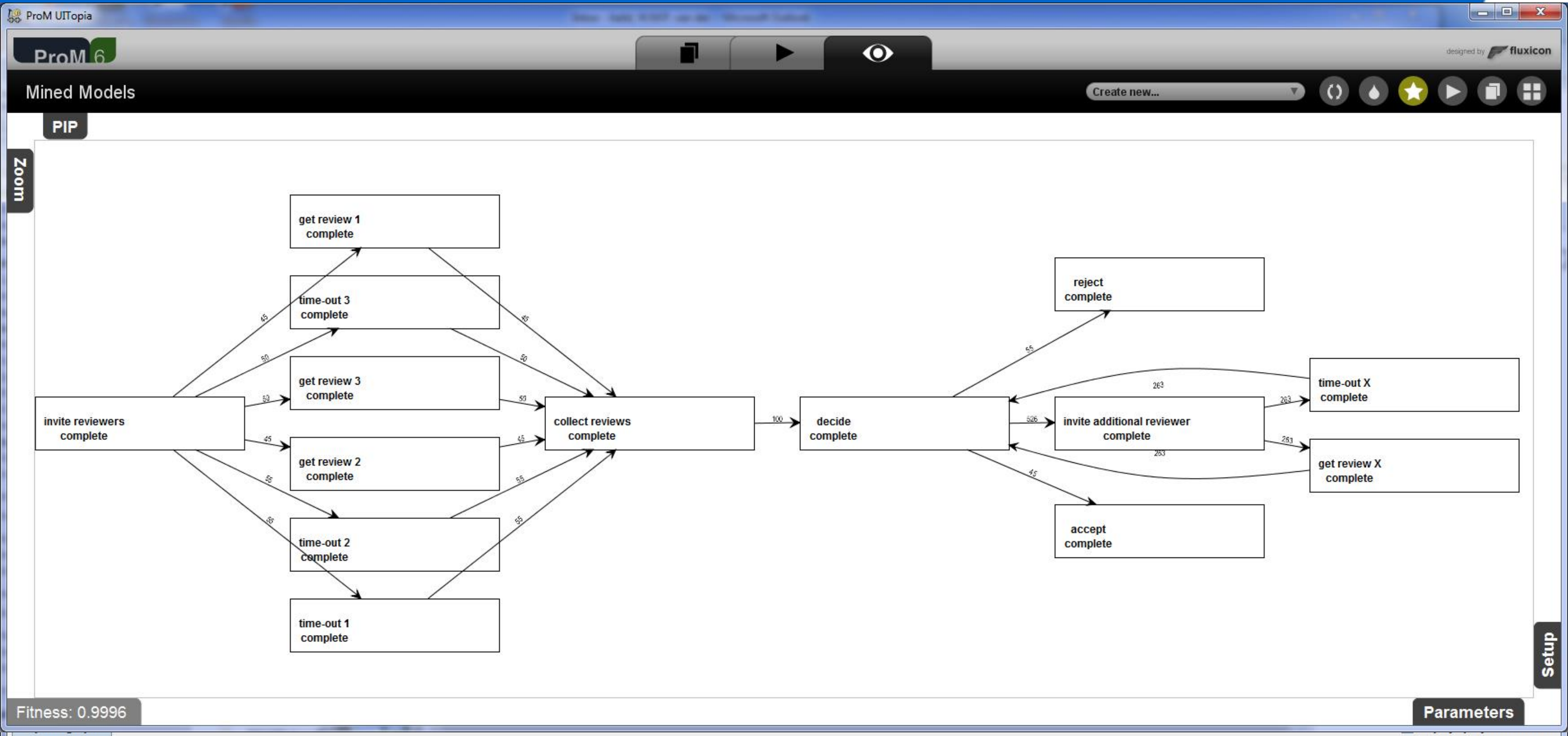


|{ {{b,c}}, {{b},{c}} , {{b},{b,c}} , {{c},{b,c}} , {{b},{c},{b,c}} }| x
|{ {{d,e}}, {{d},{e}} , {{d},{d,e}} , {{e},{d,e}} , {{d},{e},{d,e}} }|
= 5 x 5 = 25 possible a activities

If too time consuming, …

- Randomize
- Use a genetic algorithm

Example: Heuristic miner



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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 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

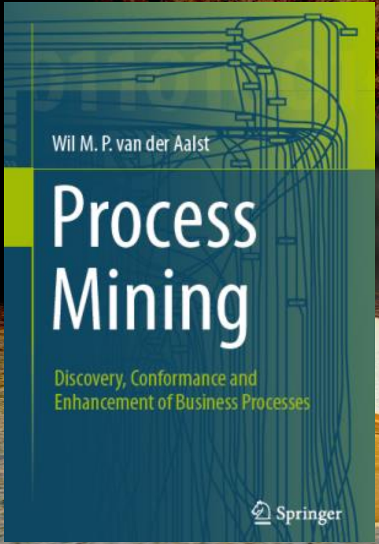
Chapter 11
Analyzing “Lasagna Processes”

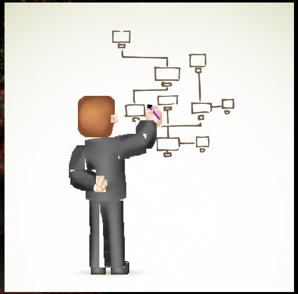
Chapter 12
Analyzing “Spaghetti Processes”

Part V: Reflection

Chapter 13
Cartography and Navigation

Chapter 14
Epilogue





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