Process Mining in Cybersecurity

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Outline

1. Introduction to process mining
2. Process mining in cybersecurity

Process mining

- Process-centric data analysis

- What really happened in the past?
- Why did it happen?
- What is likely to happen in the future?
- When and why do people deviate?
- How to redesign a process to improve it?
- ...

Process mining

- Typically working with event logs which represent processes
- These logs have to contain cases (sequences of events)

```
Martin;order_start
Martin;select_hamburger
Martin;choose_card_payment
Martin;confirm_order
Martin;order_end
```

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Process mining

- Each event has:
  - caseId
  - activity
  - timestamp (optional)
  - resource (optional)
  - other data (optional)

```
1;order_accept;Dec 2, 2017 10:30:58 AM;Peter;21
1;order_cooked;Dec 2, 2017 10:39:24 AM;Victor;24
1;order_delivered;Dec 2, 2017 11:12:37 AM;Emma;19
```

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Process mining

- Sometimes, the mapping is not clear

```
1;order_accept;Dec 2, 2017 10:30:58 AM;Peter;21
1;order_cooked;Dec 2, 2017 10:39:24 AM;Victor;24
2;order_accept;Dec 2, 2017 10:40:21 AM;Peter;21
3;order_accept;Dec 2, 2017 10:42:19 AM;Greg;34
1;order_delivered;Dec 2, 2017 11:12:37 AM;Emma;19
2;order_cooked;Dec 2, 2017 11:17:04 AM;Victor;24
2;order_delivered;Dec 2, 2017 11:24:00 AM;Peter;21
```

- For example, the name of the worker can be:
  - resource
  - activity
  - caseId

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Analysis of the past

- Process discovery techniques
- From the event log, we create a model that represents how the process was executed in reality
- Model can be represented as a petri net, activity diagram, BPMN diagram, …
- Conformance checking techniques

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Process discovery

```
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```

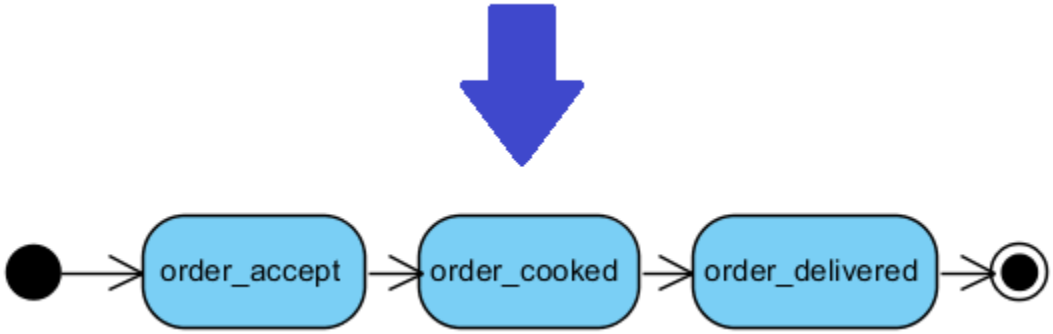

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Process discovery challenges

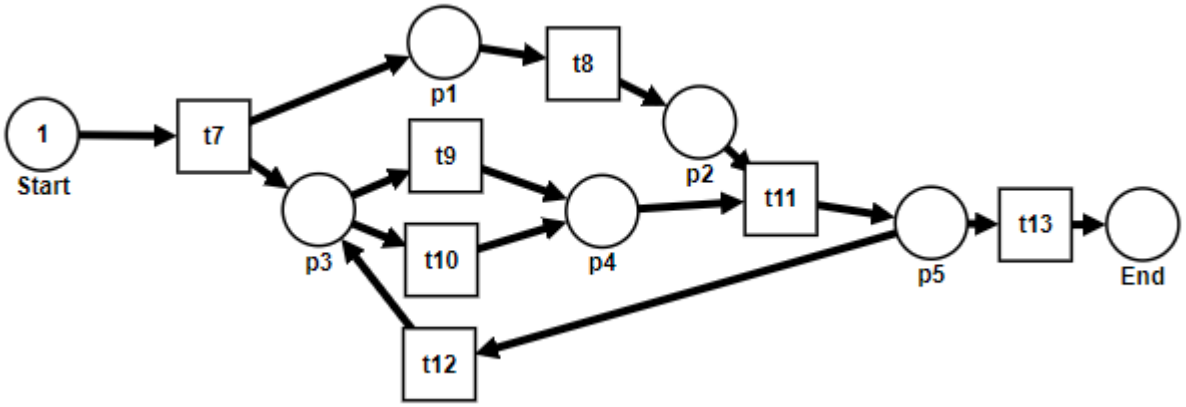
- Concurrency
- Loops
- Noisy behavior
- No negative examples in the log
- Too many allowed behaviors

Process discovery activities

- Explore processes at run-time
- Discover process models
- Compare the model of desired behavior with the model of reality
- Check the deviations in historic data
- Promote the model that shows the desired behavior

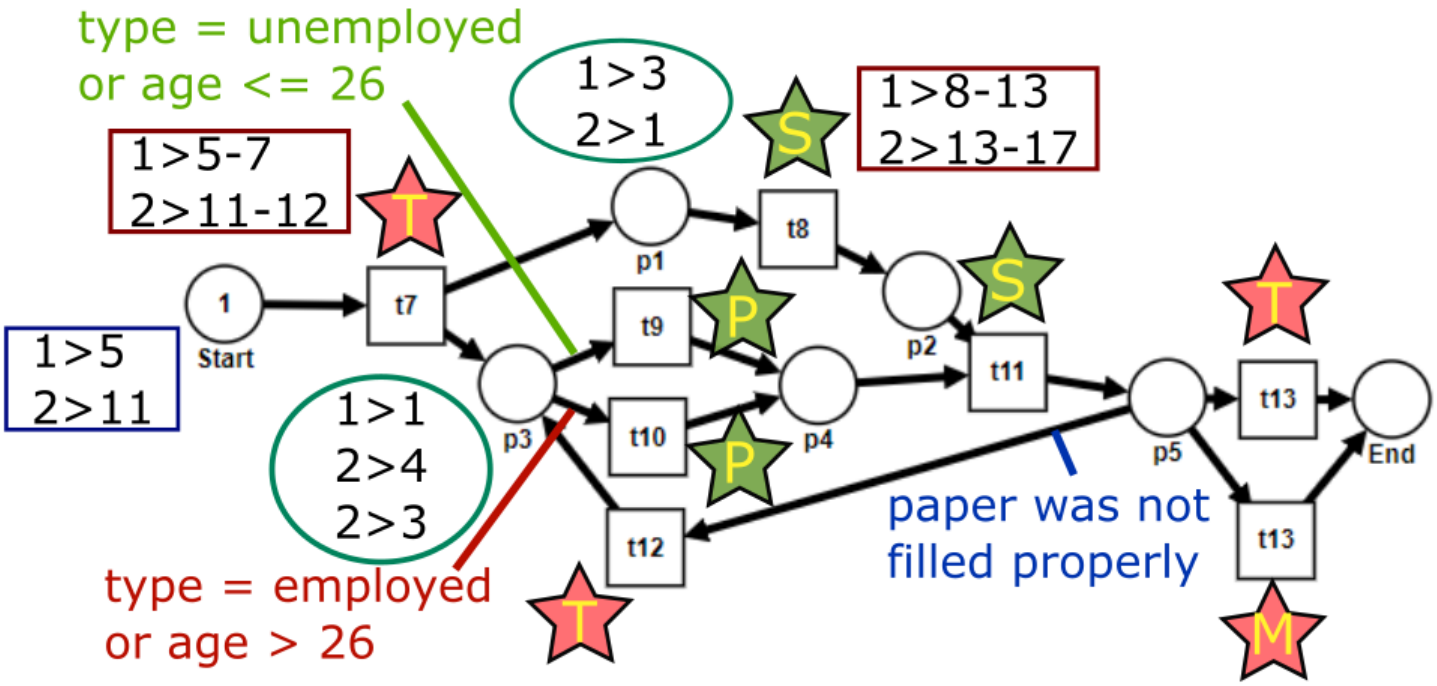
Adding additional perspectives

- Control flow is not the only perspective
- We can enhance the existing process models with:
  - Social network analysis
  - Organizational structures
  - Resource behavior analysis
  - Time perspective
  - Decision points mining
  - …



Additional perspectives

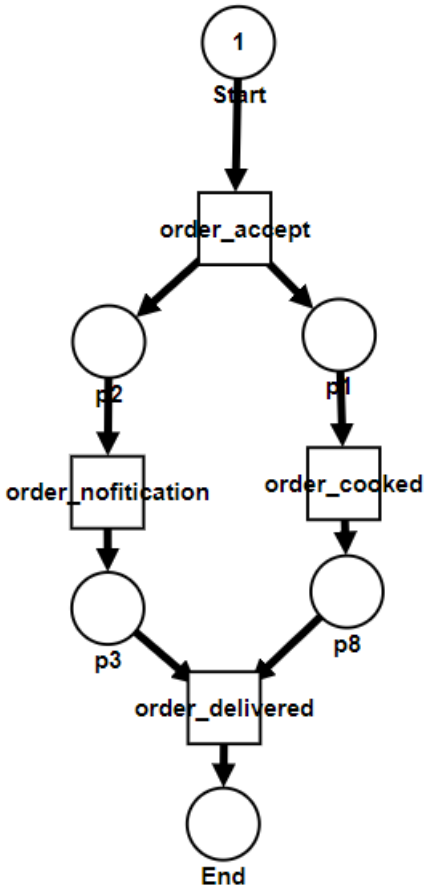
- We can add many others
- We can combine them to the integrated model
- Our model is enhanced, we might get better results



Conformance checking

- We can use the existing model to identify deviations in the behavior from logs

```
1;order_accept;
1;order_nofitication;
1;order_delivered;
1;order_cooked;
//NOK
```



Analysis of the present

- Also called operational support
- We use our model to analyze running cases
- We can:
  - Detect deviations in real-time data using the model of the desired behavior
  - Do real-time predictions (prob. of success, remaining time,…)
  - Make recommendations

Operational support: Detect deviations

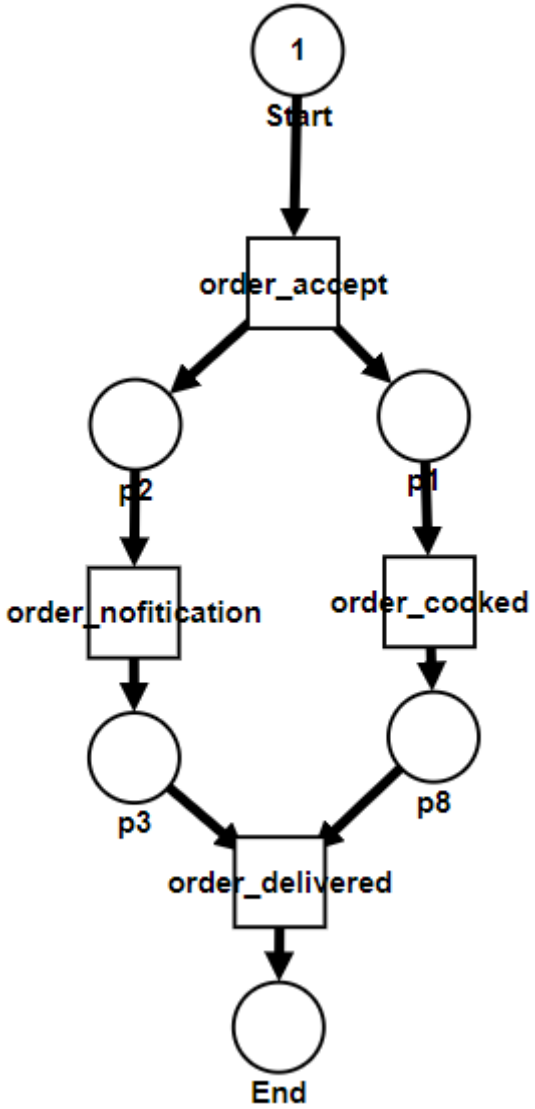
- We consider only the partial trace of a particular case
- We want immediate response when the deviation occurs

    a) Token-based replay
    b) Business rules

Detect deviations: Token-based replay

- Check the conformance with the model

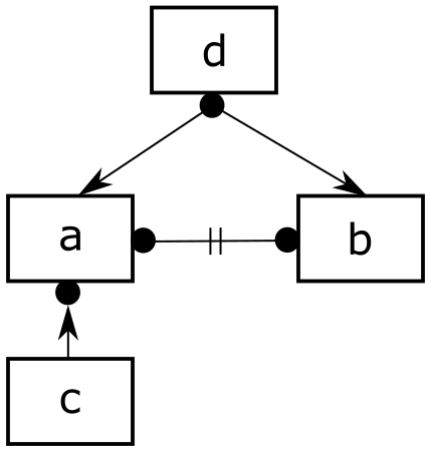
```
1;order_accept;          //OK
1;order_nofitication;    //OK
1;order_cooked;          //OK
1;order_delivered;       //OK

5;order_accept;          //OK
5;order_nofitication;    //OK
5;order_delivered;       //NOK
```



Detect deviations: Business rules

- Specific rules we want to follow
- To define them, we can use *Declare*
  - Constraint-based workflow language that uses graphical notations and semantics based on Linear Temporal Logic
- Example:
  - **a** and **b** cannot happen in the same case
  - **a** cannot happen before **c** has happened
  - every **d** have to be eventually followed by **a** or **b**

$$!((\blacklozenge a) \wedge (\blacklozenge b))$$
$$(!a)\ W\ c$$
$$\square(d \Rightarrow (\blacklozenge(a \vee b)))$$



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Operational support: Predict & Recommend

- We can apply data mining techniques (supervised learning, …)
- Examples of predictions:
  - Total cost of the current case
  - Total service time for the current case
  - Probability of meeting the deadline
  - Remaining flow time
- Examples of recommendations:
  - Minimize the total costs
  - Maximize the number of accepted cases
  - Minimize resource usage
  - Minimize the remaining flow time

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Process Mining in Cybersecurity

- Visual analysis of model
- Model comparison
- Conformance checking

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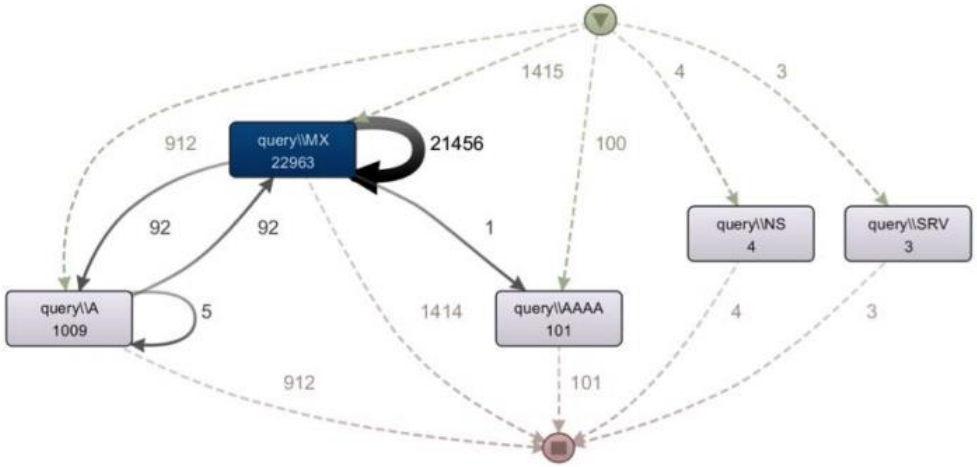
Visual analysis of model: DNS traces

- Event log built from DNS traces (caseID, activity, timestamp)
- caseID = {client, DNS Server}
- activity = {query/response, type}
- Detection of spambots

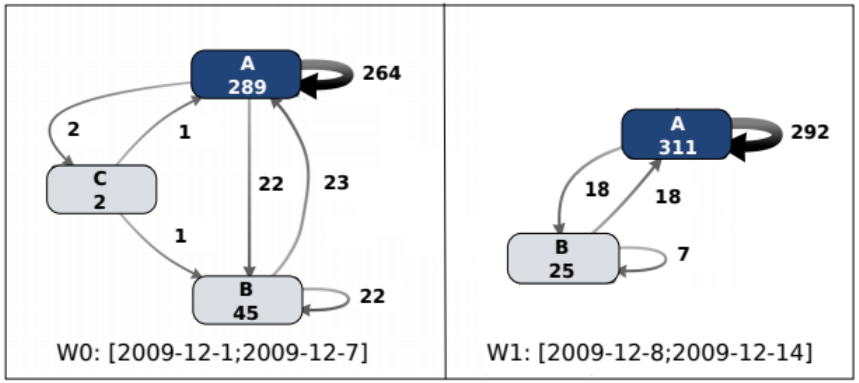


[1]

Fig. 6. Simplified graph of the attack shown in Figure 5. We show the model after filtering the 10% of most active IPs.

Model comparison : Smart Grids

- Anomaly detection of power consumption
- Classification of consumption to levels
- Then they discover graphs of consumption per short period
- Time-evolving graph approach: comparing consecutive graphs using a distance or similarity function
- They chose Hamming distance and cosine similarity measure

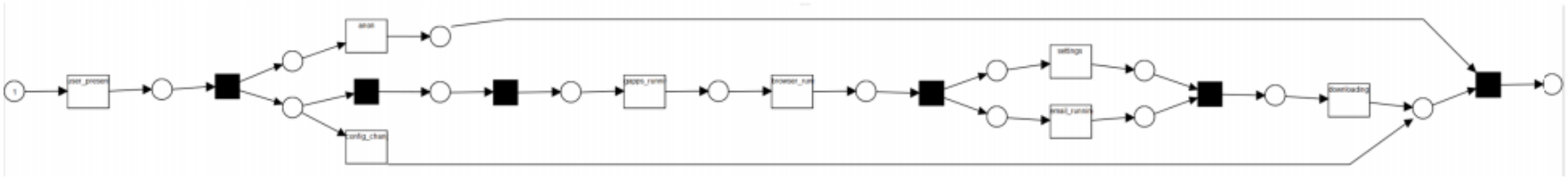


[2]

Figure 3. Consumption graphs of customer #1565 of two consecutive weeks.

Conformance checking: Smartphones

- Attack: user activated a malicious URL, which resulted in downloading personal user data via known vulnerability
- They designed a model of this attack from OS-generated information about performed actions, browser history, and network connection log
- Token-based replay with this model



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Process mining cybersecurity domains (fields)

- Network (IS, DNS, IDS, websites)
- Smart grids (anomalous behaviour of energy usage)
- Smartphones (social engineering attacks, malwares)
- Banking (frauds, security deviations)
- Industrial Control Systems (cyberattacks)
- Business processes (anomalies, deviations in the event data)

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Conclusion

Process mining: discover, enhance, operational support

Usage of process mining in cybersecurity:

- Visual analysis of model
- Model comparison
- Conformance checking

Current domains:

- Smart grids, Banking, Smartphones, Business processes, Network, Industrial Control Systems

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Questions & comments?

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Sources

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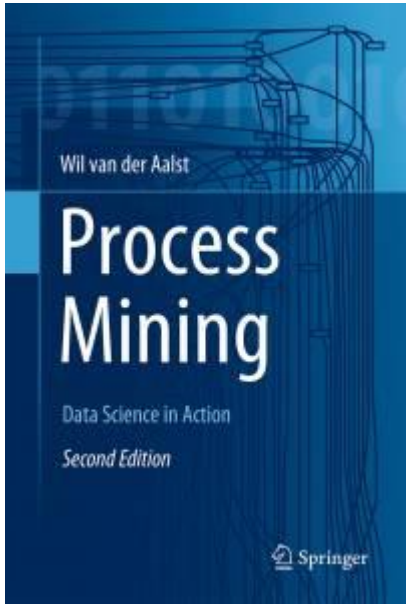
- [2] S. Bernardi, R. Trillo-Lado, and J. Merseguer, “Detection of integrity attacks to smart grids using process mining and time-evolving graphs,” in 2018 14th European Dependable Computing Conference (EDCC), Sep. 2018. doi: 10.1109/EDCC.2018.00032 pp. 136–139.
- [3] L. Hluchý and O. Habala, “Enhancing mobile device security with process mining,” in 2016 IEEE 14th International Symposium on Intelligent Systems and Informatics (SISY) , Aug 2016. doi: 10.1109/SISY.2016.7601493. ISSN 1949-0488 pp. 181–184.

Sources

- Presentation based on the book **Process Mining: Data Science in Action**
- https://www.springer.com/gp/book/9783662498507



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