A Model-Based Approach to Extract Health Information from Textual Data

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Equipment Reliability (ER) Data Analytics

- **Context:** ER data generated by nuclear power plants
  - Examples: monitoring data, condition report, corrective actions
  - Heterogenous formats
    - Textual (events, logs)
    - Numeric (e.g., pump oil temperature)
    - Other (e.g., images)
  - The integral analysis of all data elements provides an accurate representation of asset health and performance

Are both these elements adequately analyzed simultaneously?

- **Goal:** Assist system engineers to analyze ER data (numeric and textual)

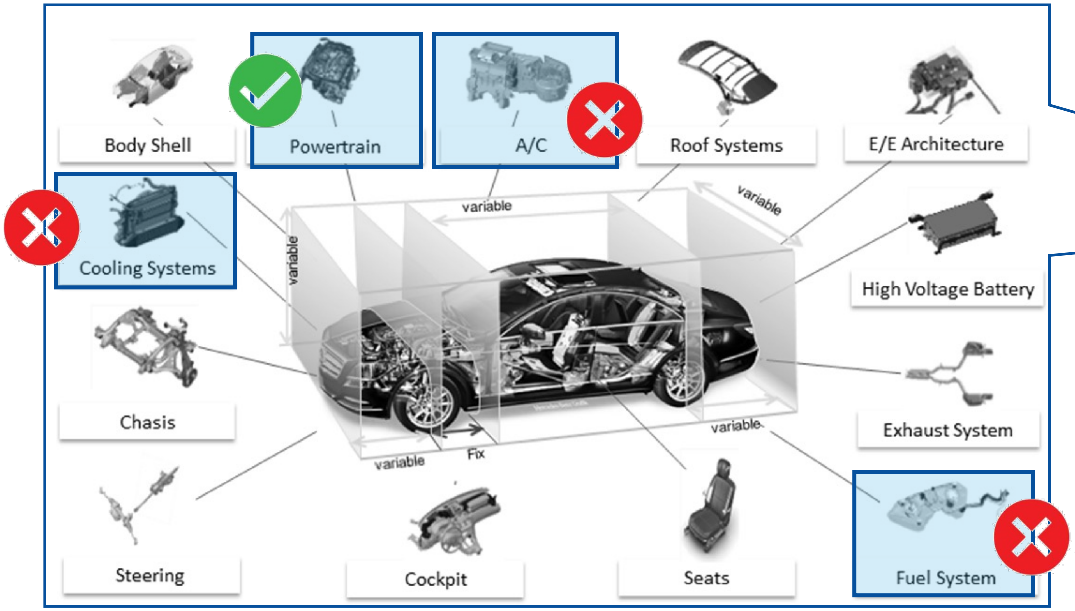
- **This paper:** Extract knowledge from textual data
  - Identify causal relations between events

- **Our work:** Causal reasoning applied to ER data
  - Data is not enough: models are needed
  - Merge two perspectives: System engineer and data scientist

ER Data Analytics: Causal Reasoning

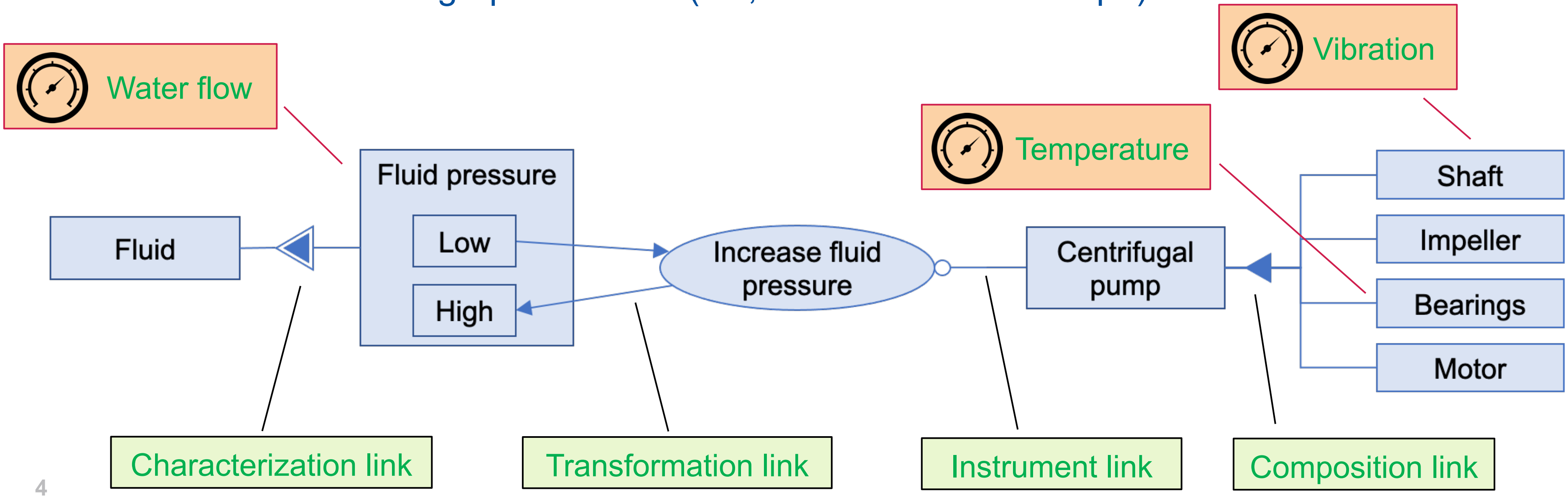
Asset

Available ER data



ER Data Analytics and MBSE

- Need to emulate system engineer knowledge about components and systems
- **Solution:** Model-Based System Engineering (MBSE) diagram-based representation
  - Identify causal dependencies (links) between “Form” and ”Function” elements
- Link to numeric and textual monitoring data can be easily established
- **MBSE language:** Object Process Methodology (OPM)
  - What about SysML?
- Workflow
  - OPM models are created for desired assets and systems
  - Translation into graph structure (i.e., networkX-multiDiGraph)

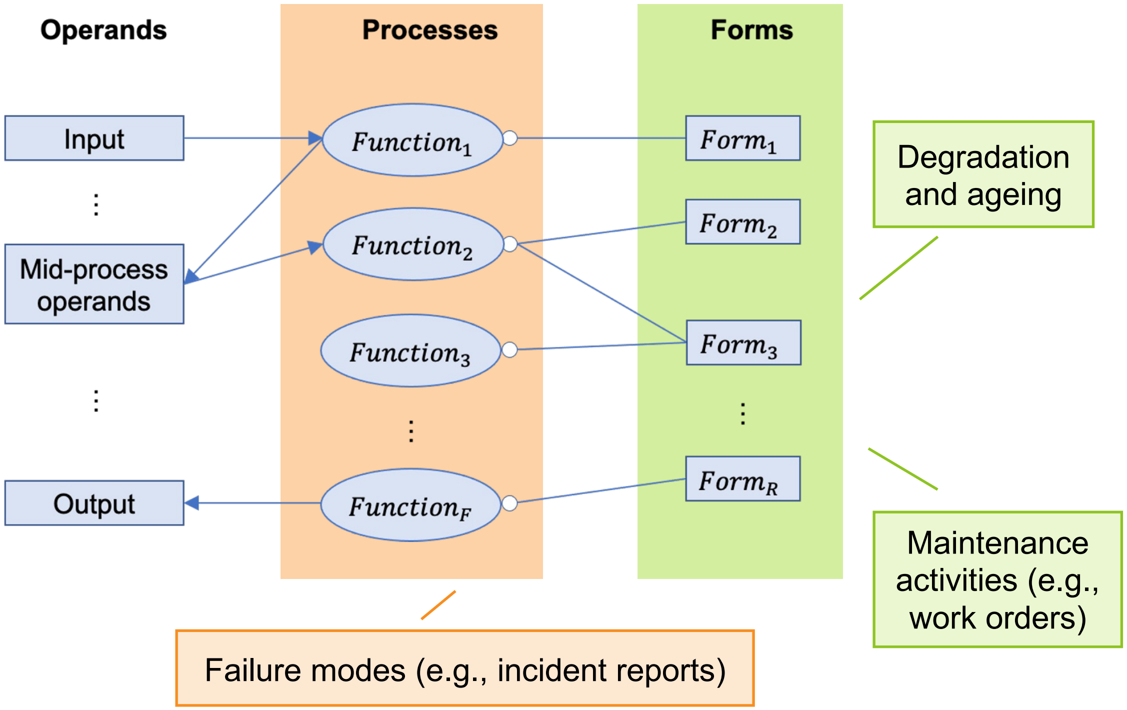


Linking ER Concepts to OPM Models

- OPM diagrams provide a clear link to typical ER concepts
  - Failure modes (function)
  - Ageing and maintenance activities (form)

- Are OPM diagrams sufficient?
  - No: quantification of OPM links is missing
  - Statistical analysis and machine learning are the key to quantify links

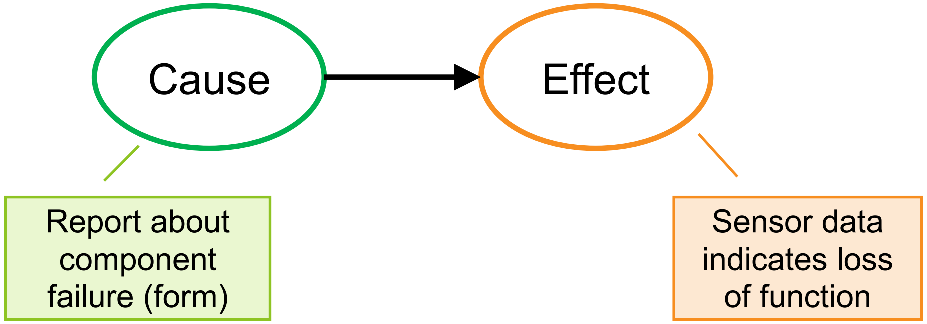
- Is modeling & simulation needed?
  - First principle laws (conservation, equations of state)
- Causal reasoning directions
  - Precursor analysis
  - Cause-effect analysis



Degradation and ageing

Maintenance activities (e.g., work orders)

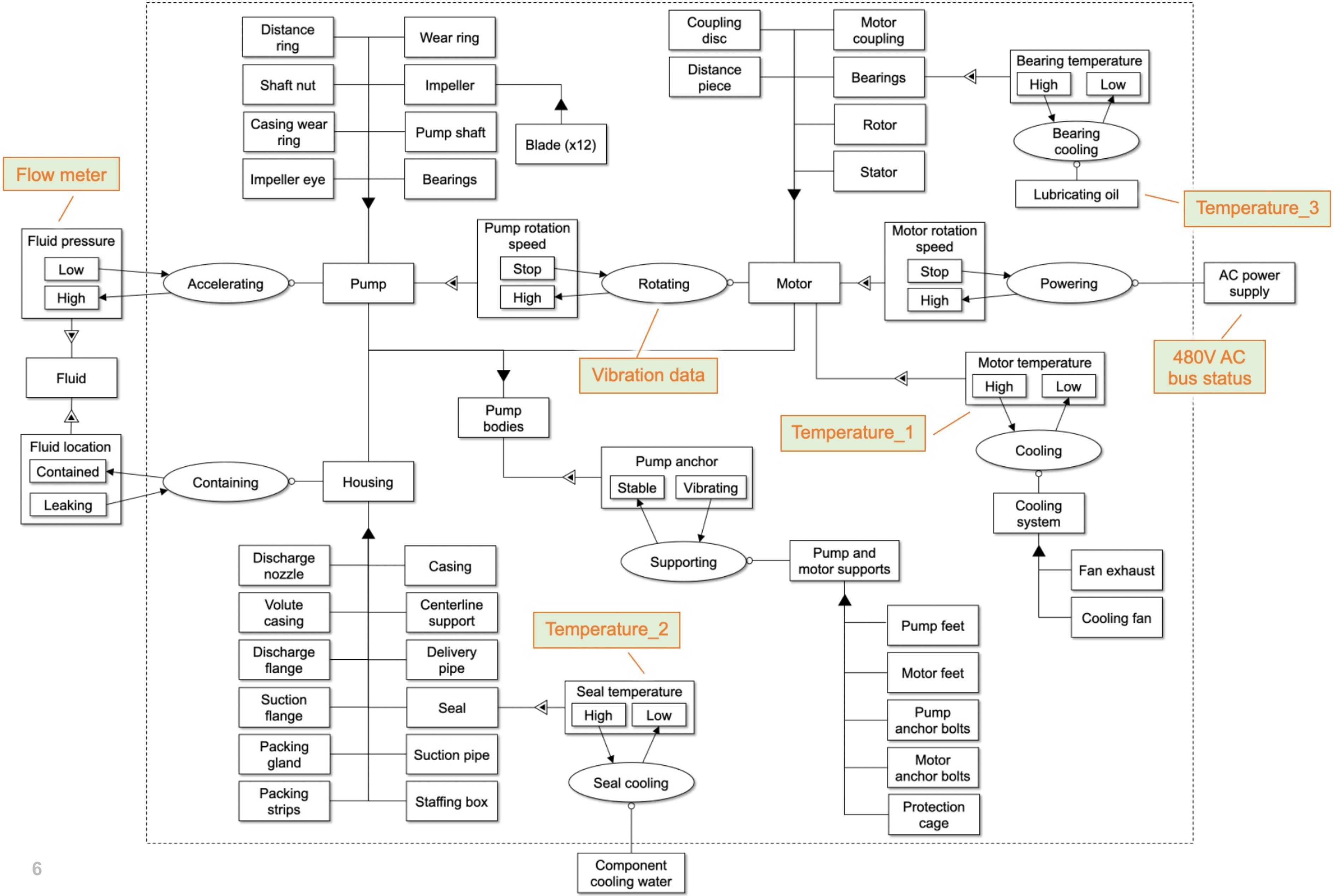
Failure modes (e.g., incident reports)



Report about component failure (form)

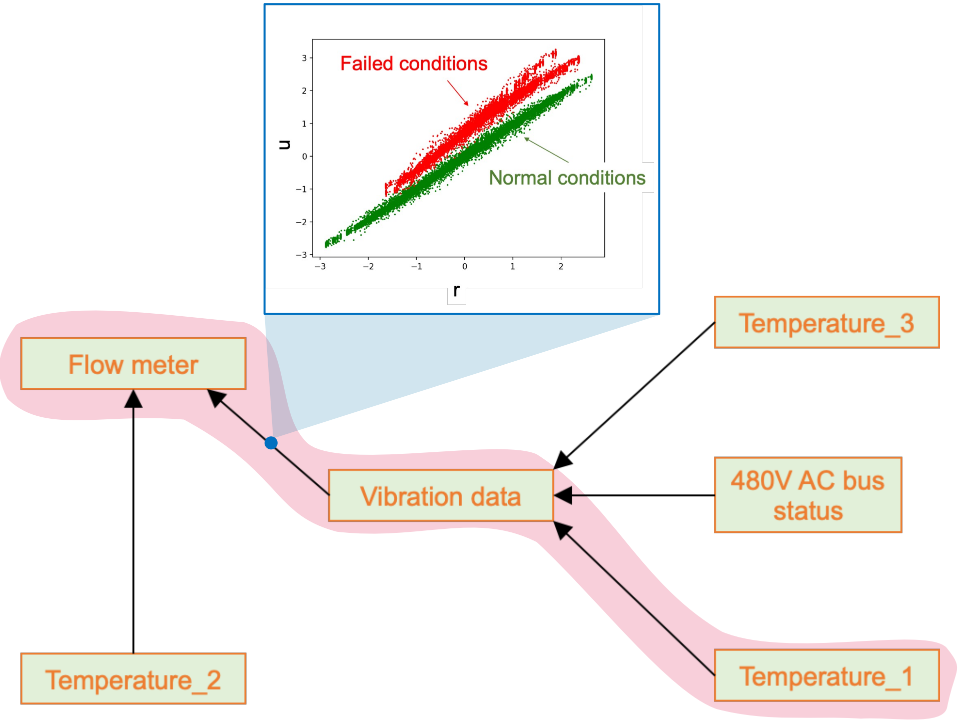
Sensor data indicates loss of function

Causal Reasoning

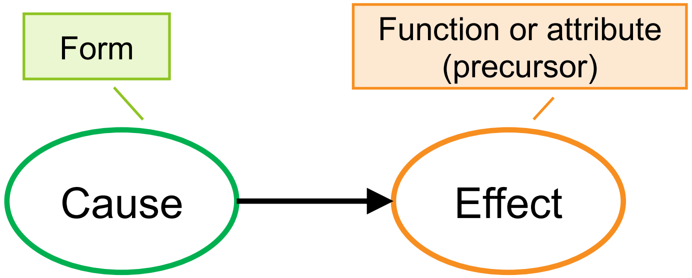


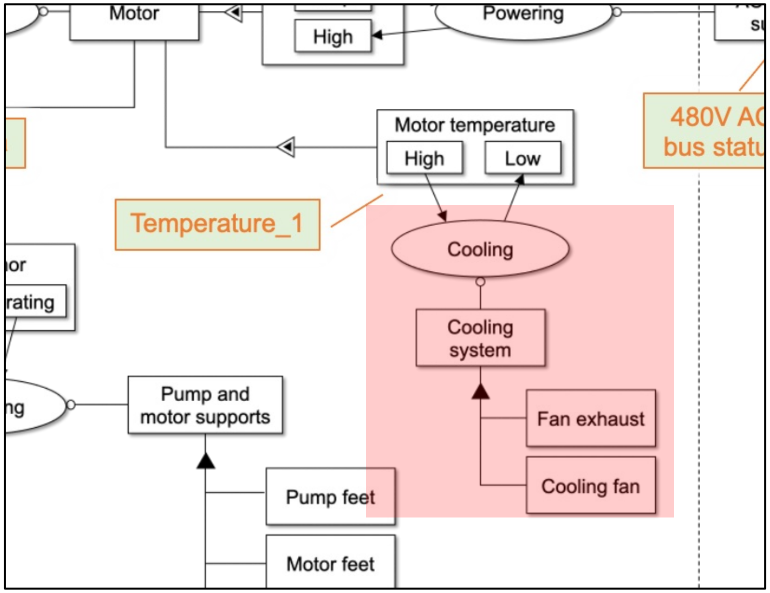
Causal Reasoning

- **Precursor analysis: Identify the event that triggers following events**
  - OPM models are used to create a graph among ER data elements
  - Available anomaly detection and diagnostic methods can be employed to quantify graph edges



- **Cause-effect analysis: Identify form element(s) that have caused the precursor**
  - OPM models provide information on the form elements that support the precursor (function or attribute)





Analysis of Textual Data

- Information extraction from textual data using Natural Language Processing (NLP) methods
  - Rule based text processing
  - Machine learning for relation identification

- **Bounding the analysis**
  1. Event report (e.g., anomalous behavior or a corrective action)
  2. Cause-effect relation between events
  3. Temporal relations between events

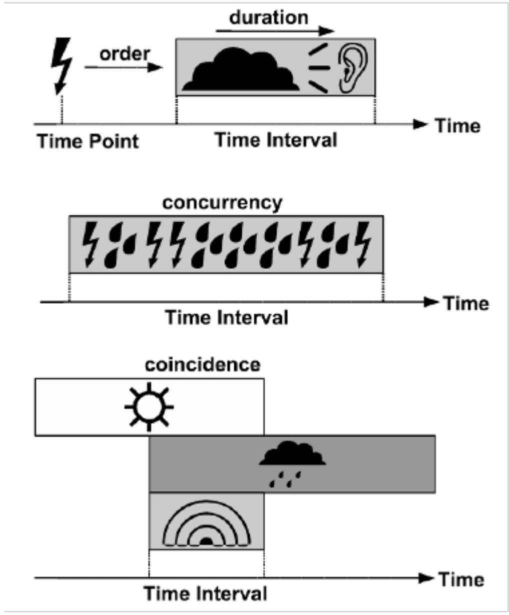
- **Under the hood**
  - Open-source NLP libraries (Spacy, NLTK)
  - BERT: transformer-based NLP model (ongoing)

Analysis of Textual Data: NLP Workflow (1/3)

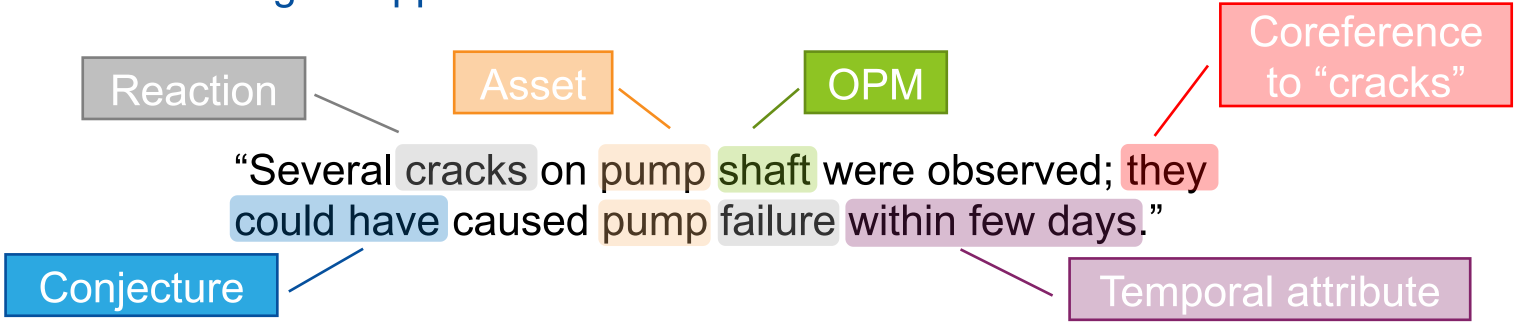
- **Step 1: Sentence segmentation and tokenization**
- **Step 2: Grammar check**
  - Identify typos
  - Identify component/asset IDs (list of allowed IDs might not be available)
  - Identify acronyms and abbreviations: this is the most critical point (40-55% accuracy)
- **Step 3: Part of speech (POS) tagging and lemmatization**
- **Step 4: Named entity recognition (NER):** Database of entities has been created
  - Focus on nuclear power plants
    - Entity types: components, assets, systems, materials, chemical, reactions, …
    - Entity nature: electric/electronic, hydraulic/pneumatic, mechanical, structural, architectural, I&C, …
    - Entity property: measured/observed quantities (with associated unit of measure)
    - Link to OPM entities
  - Sources: Available online databases, domain experts
  - NER testing with actual plant text and NRC reports (>94% accuracy)

Analysis of Textual Data: NLP Workflow (2/3)

- **Step 5: Identification of text attributes** (rule-based NLP pipeline)
  - Location and temporal
    - Time of occurrence, duration
    - Concurrence of events
    - Sequence/order of events
  - Measured quantities
    - Numeric value identification (text, number)
    - Unit identification
  - Testing with actual plant text and NRC reports: 97% accuracy
- **Step 6: Coreference resolution** (Spacy-coreferee)
  - Testing with actual plant text and NRC reports: 77% accuracy
- **Step 7: Conjecture identification (rule-based NLP pipeline)**
  - Events that could have happened in the past
  - Events that might happen in the future



Moerchen, F. 2007. "Unsupervised Pattern Mining from Symbolic Temporal Data." ACM SIGKDD Explorations Newsletter 9: 41–55.



"Several cracks on pump shaft were observed; they could have caused pump failure within few days."

Analysis of Textual Data: NLP Workflow (3/3)

- **Step 8: Identification of nature of paragraph** (rule-based NLP pipeline)
  - Starting point: set of nouns, verbs, adverbs, adjectives, relations, transition words
  - Identification of negations, passive forms
  - Health status

Relation	Example
Subj + “status verb”	Pump was not functioning
Subj + “status verb” + “status adjective”	Pump performances were acceptable

  - Causal relation

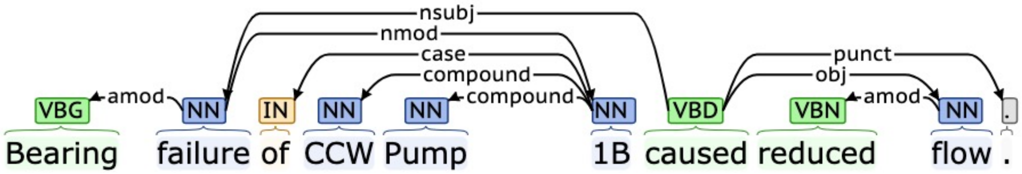
Relation	Causal relation
Event_A + “causal verb” (active) + Event_B	Event_A → Event_B
Event_A + “causal verb” (passive) + Event_B	Event_B → Event_A

  - Testing with NRC documents, available plant data, and medical available datasets
    - Health status: 89% accuracy
    - Causal relation: 95% accuracy
- **Step 9: Identification of relations using Bert** (ongoing)
  - Graph structure between entities
  - Search for synonyms/antonyms (Spacy-wordnet)

Analysis of Textual Data

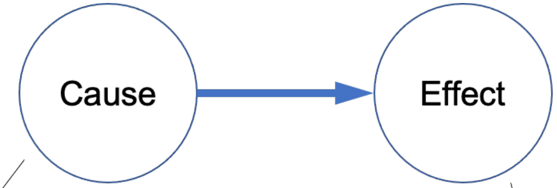
- Example
  - “Bearing failure of CCW Pump 1B caused reduced flow.”
- **NLP syntactic analysis**

- Sentence segmentation and word tokenization
- Part of speech tagging
- Named entity recognition



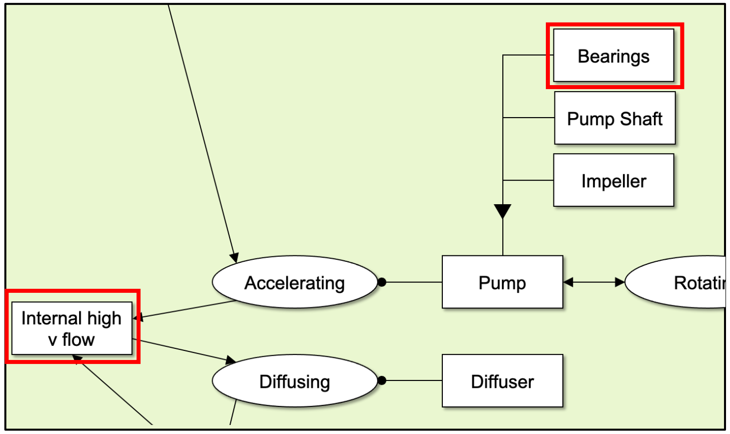
- **NLP semantic analysis**
  - Rely on component and system OPM models
  - Generated causal graph

- Identification of specific nouns, verbs and adjectives
- Identify OPM elements (form or function)
- Identify the sentence logic structure



(CCW Pump 1B, bearing, failed)

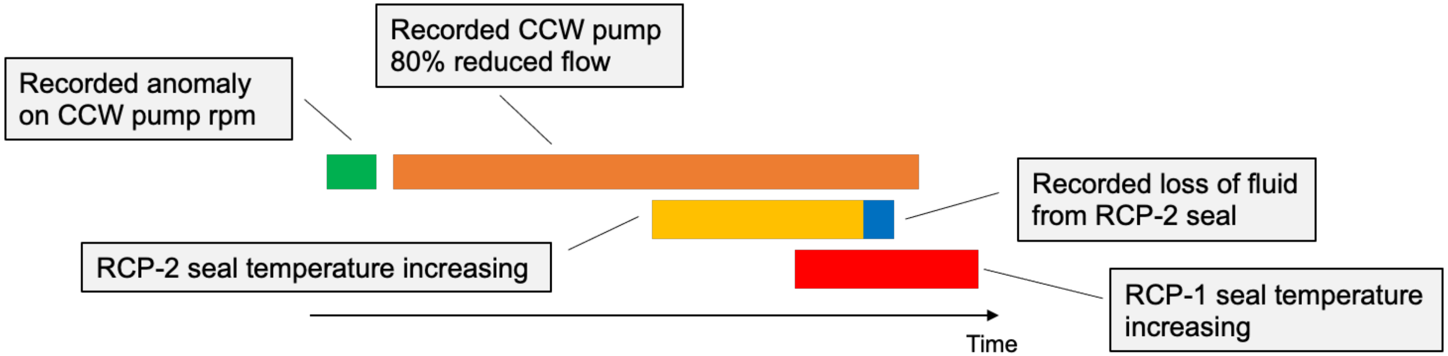
(CCW Pump 1B, internal high v flow, degraded)



Centrifugal pump OPM model

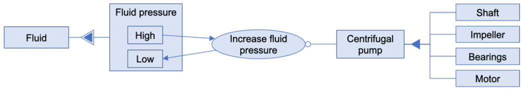
Final Remarks

Data space

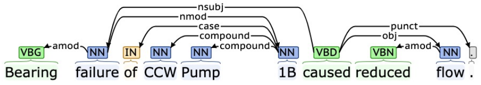


Recorded anomaly on CCW pump rpm
Recorded CCW pump 80% reduced flow
Recorded loss of fluid from RCP-2 seal
RCP-2 seal temperature increasing
RCP-1 seal temperature increasing
Time

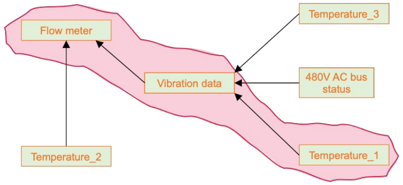
OPM models



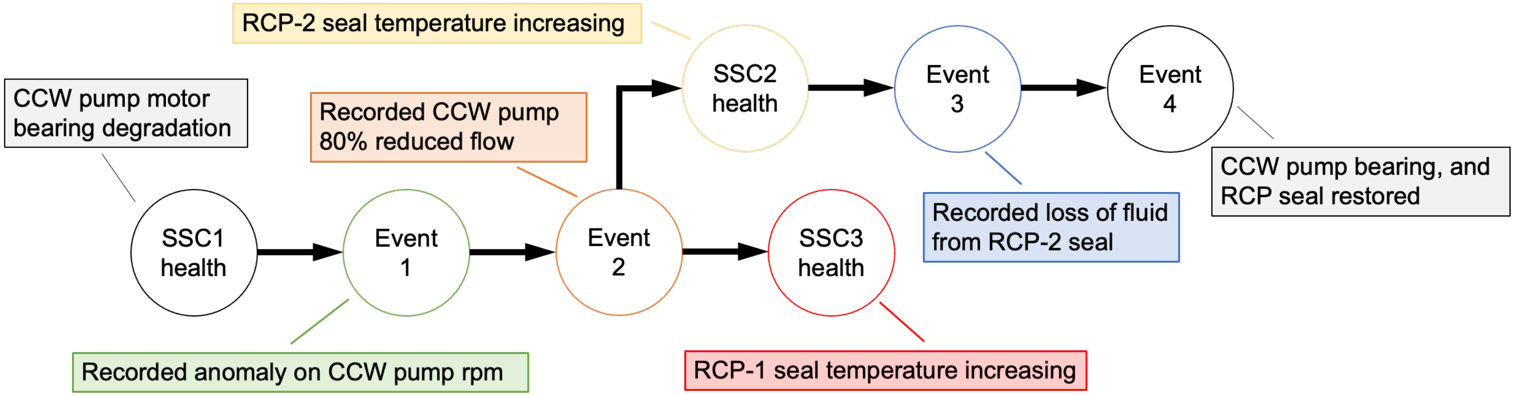
NLP Methods



Precursor & cause-effect analysis



Knowledge space



RCP-2 seal temperature increasing
CCW pump motor bearing degradation
Recorded CCW pump 80% reduced flow
SSC2 health
Event 3
Event 4
CCW pump bearing, and RCP seal restored
SSC1 health
Event 1
Event 2
SSC3 health
Recorded loss of fluid from RCP-2 seal
Recorded anomaly on CCW pump rpm
RCP-1 seal temperature increasing