RAMS-Europe 2025
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FAULT TREE SYNTHESIS FROM KNOWLEDGE GRAPHS

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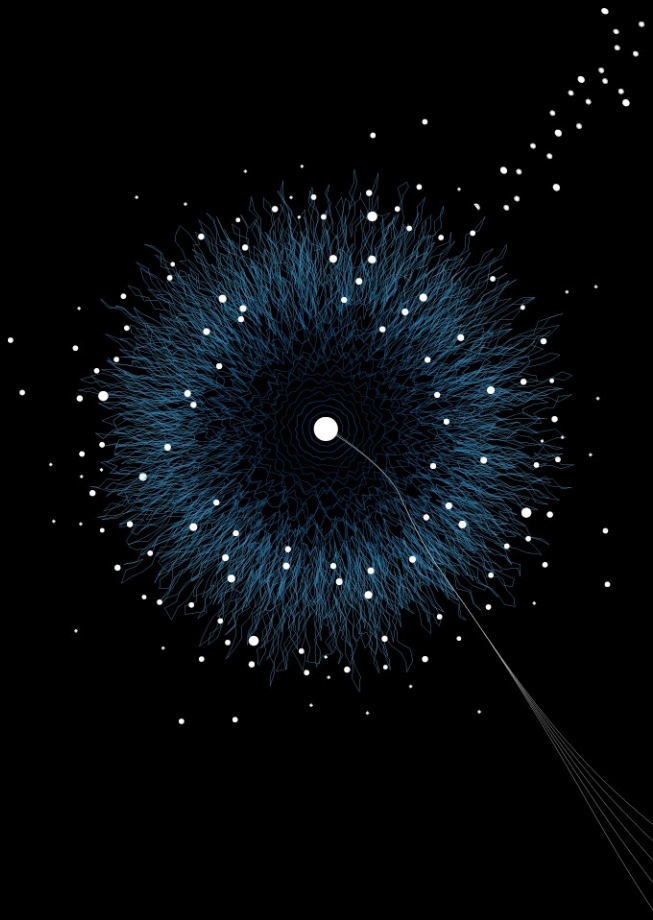
MARIËLLE STOELINGA



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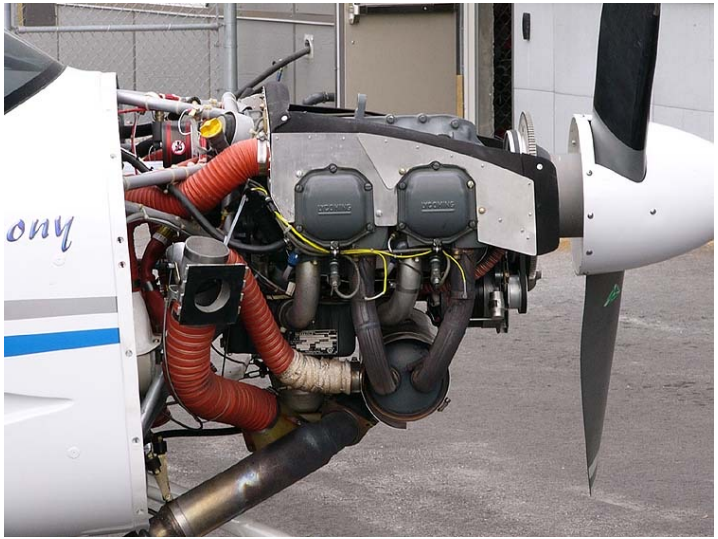
THE GOAL



A Lycoming O-320-D2A installed in a Symphony SA-160
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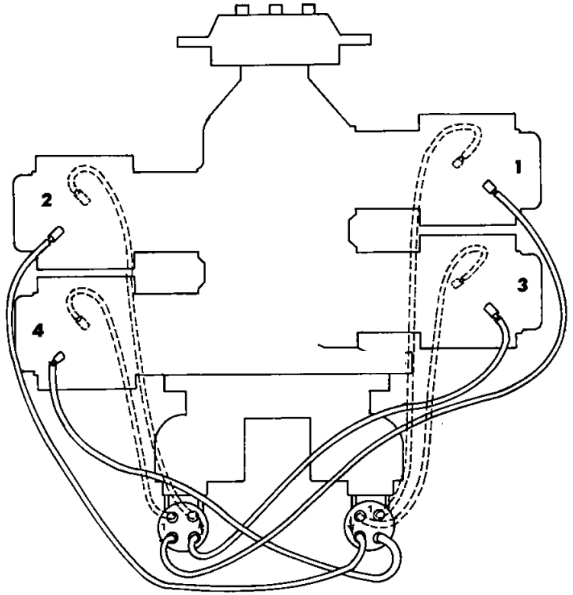

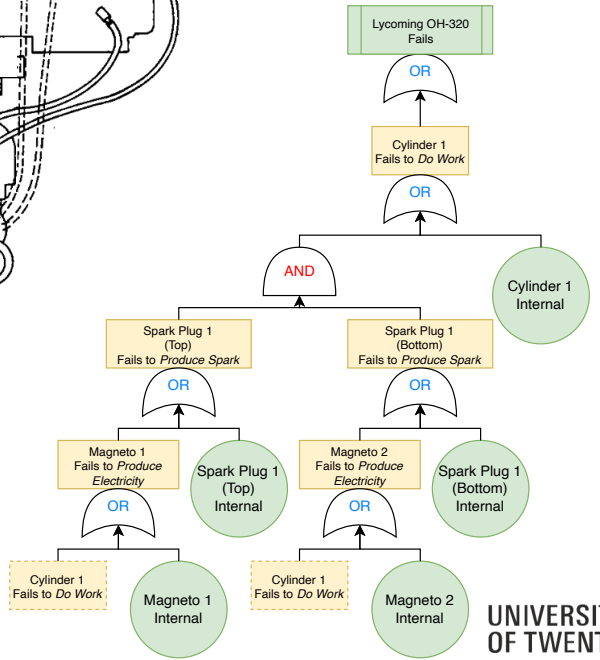

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MOTIVATION

- Incompatible modeling languages across engineering teams
- Limited system knowledge is early design stages
- Risk analysis is costly

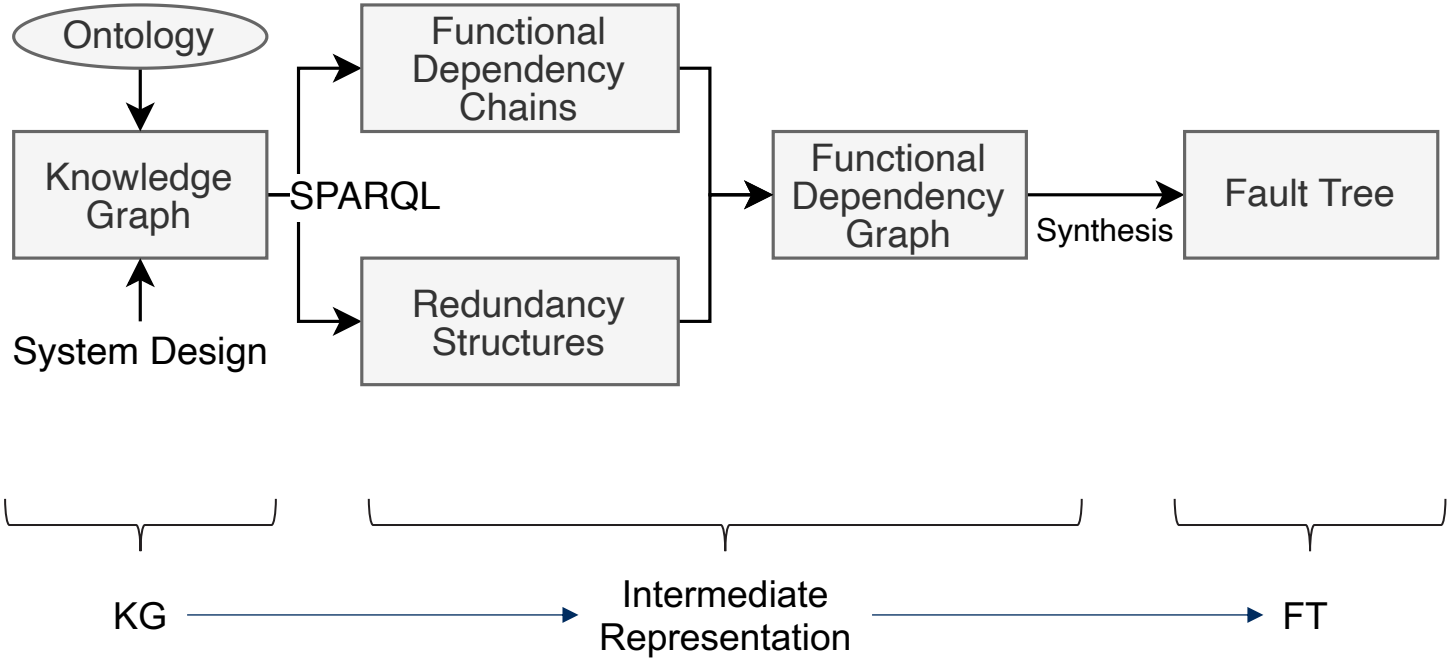
Hence...

- Central conceptual model of CPS design (ontology)
- Minimal knowledge assumptions
- Automatic synthesis of risk models (Fault Trees)

OVERVIEW

- **Methodology Overview**
- Background
- From Knowledge Graphs to Fault Trees
  - Running Example
- Limitations and Future Work

METHODOLOGY



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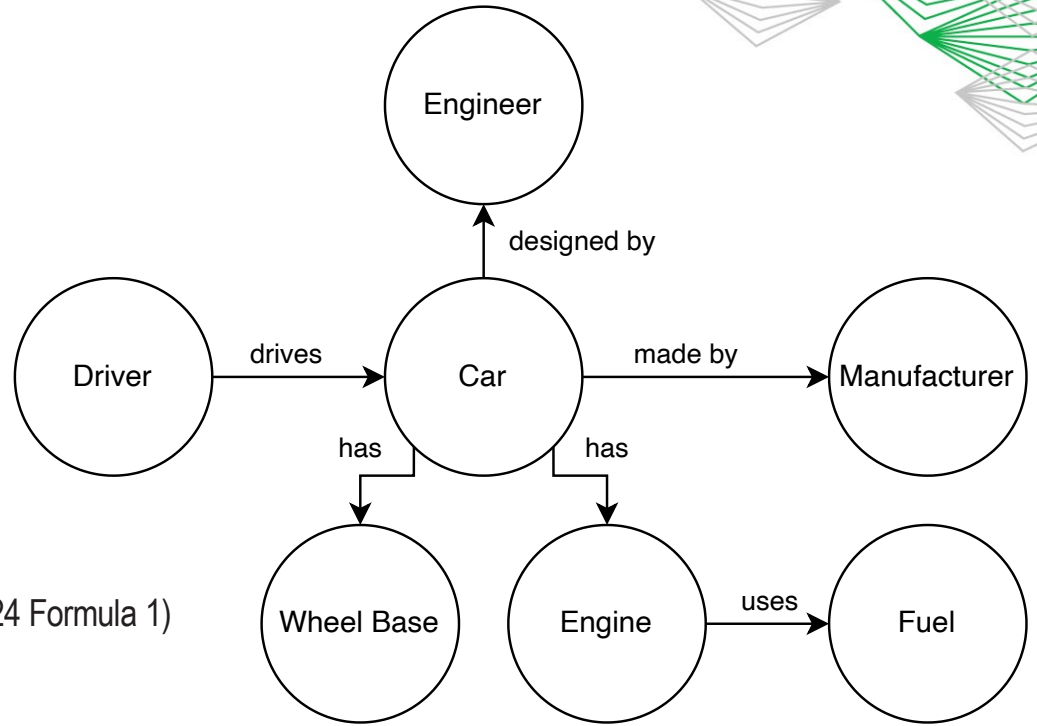
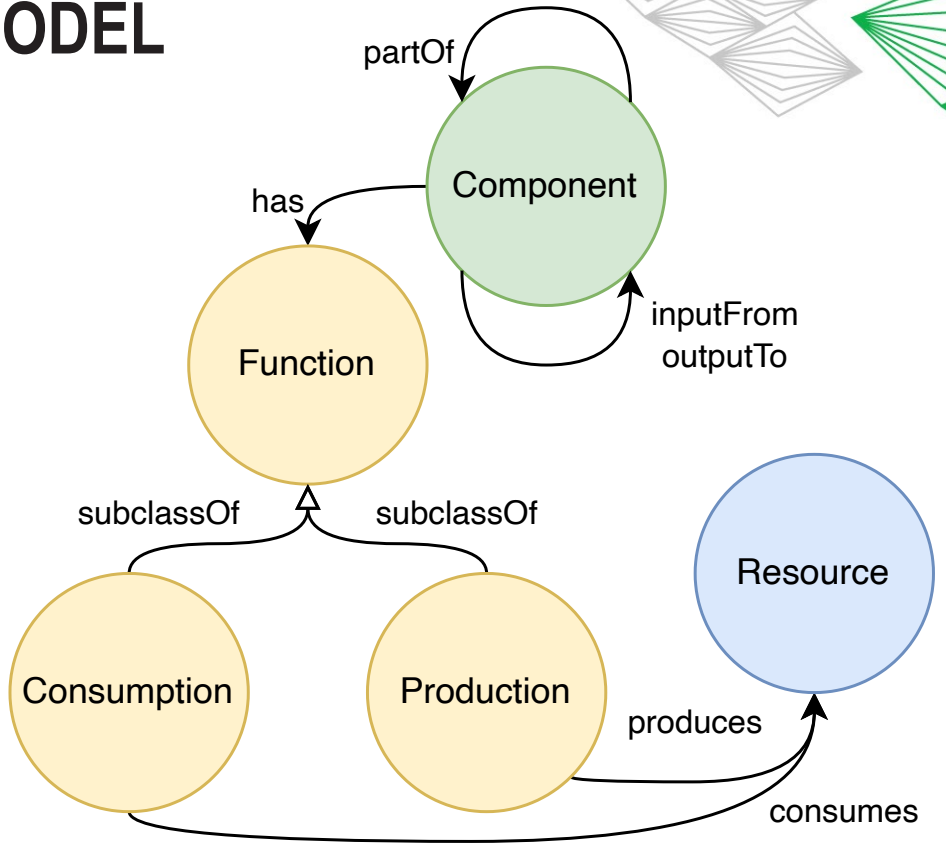
KNOWLEDGE GRAPHS

- Knowledge base with a graph structure
- Supports fact inference
  - I.e. (Driver, drives, Car) implies (Driver, has, License)
- Structured by an *ontology* (a conceptual model)
- It's all about the *instances*
  - I.e. (Charles Leclerc, drives, Ferrari SF-24 Formula 1)



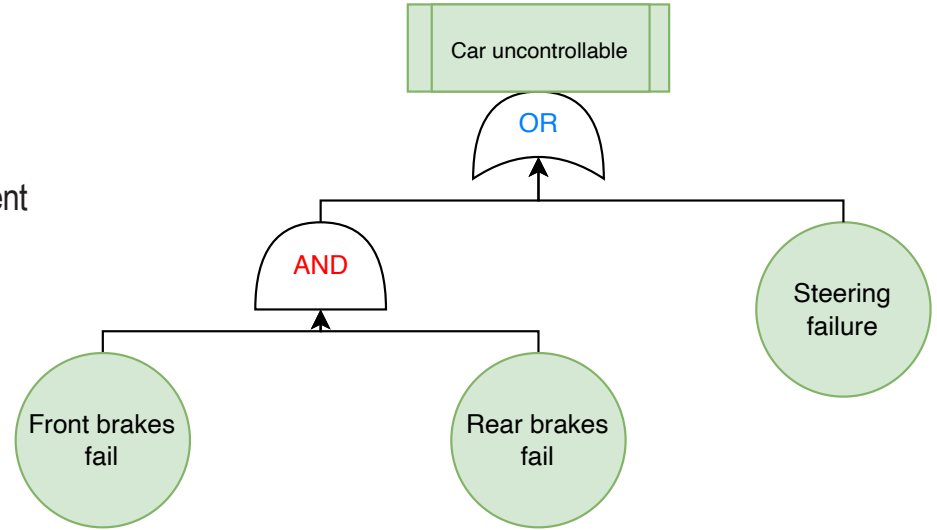
OUR CONCEPTUAL MODEL

- Describes the *domain* of CPS design
- **Minimal knowledge** assumptions
  - Compositionality
  - Functionality



FAULT TREES

- Visual causal model
- Basic Events, Gates and a Top-level Event
- Risk analysis
  - Minimal cut sets (MCS)



MCS: { *Front brakes fail*, *Rear brakes fail* }, { *Steering failure* }

OVERVIEW

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RUNNING EXAMPLE

- Lycoming O-320 aircraft engine
- Designed for reliability

A Lycoming O-320-D2A installed in a Symphony SA-160
By *Ahunt* at English Wikipedia, Public Domain
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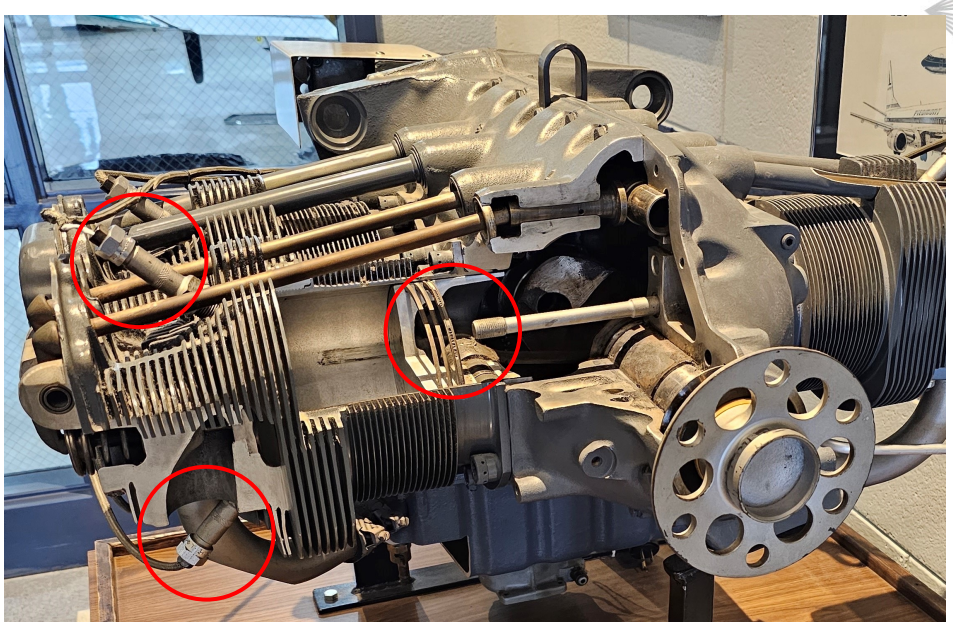
... A BETTER LOOK

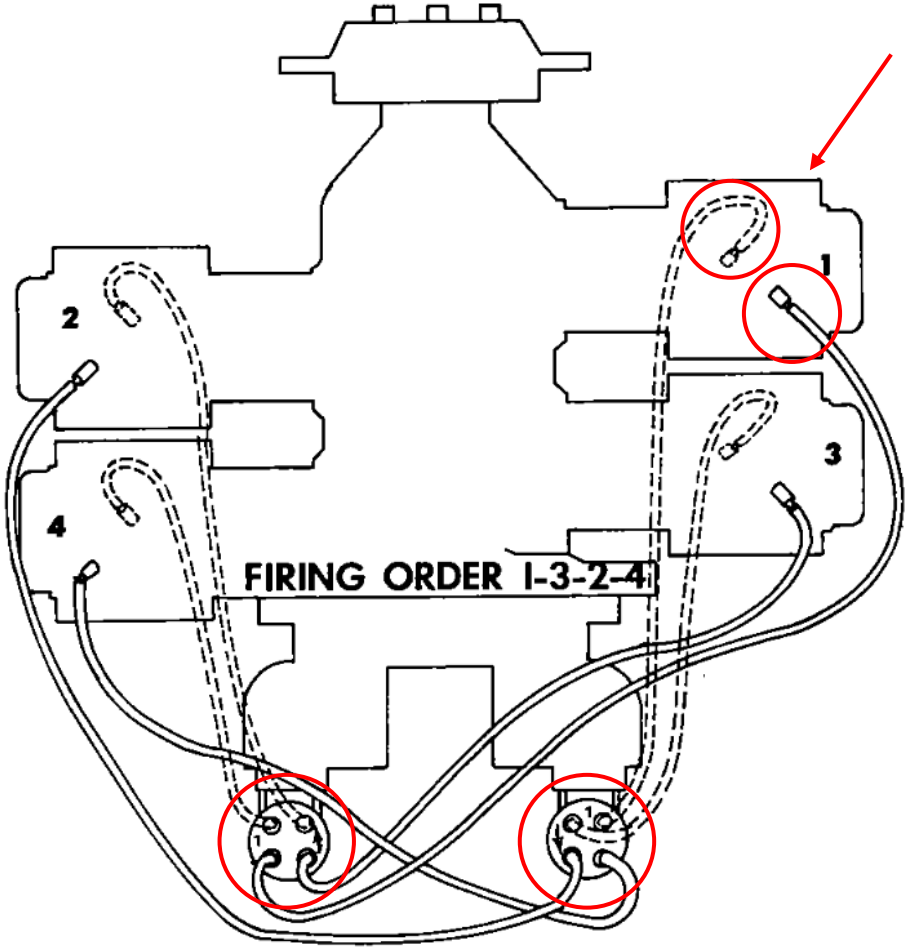
- We see that an engine consists of many components, i.e.:
  - Cylinders and pistons
  - Ignition system
  - Lubrication system
  - etc.



A Lycoming OH-320-D2A cutaway
By *KOMRADE DIMITRI,* Own work, CC BY-SA 4.0
https://commons.wikimedia.org/w/index.php?curid=133450956

THE IGNITION SYSTEM

- The simplified diagram shows:
  - Cylinders
  - Spark plugs
  - Magnetos[1]
- And interestingly
  - Two magnetos
  - Two spark plugs per cylinder

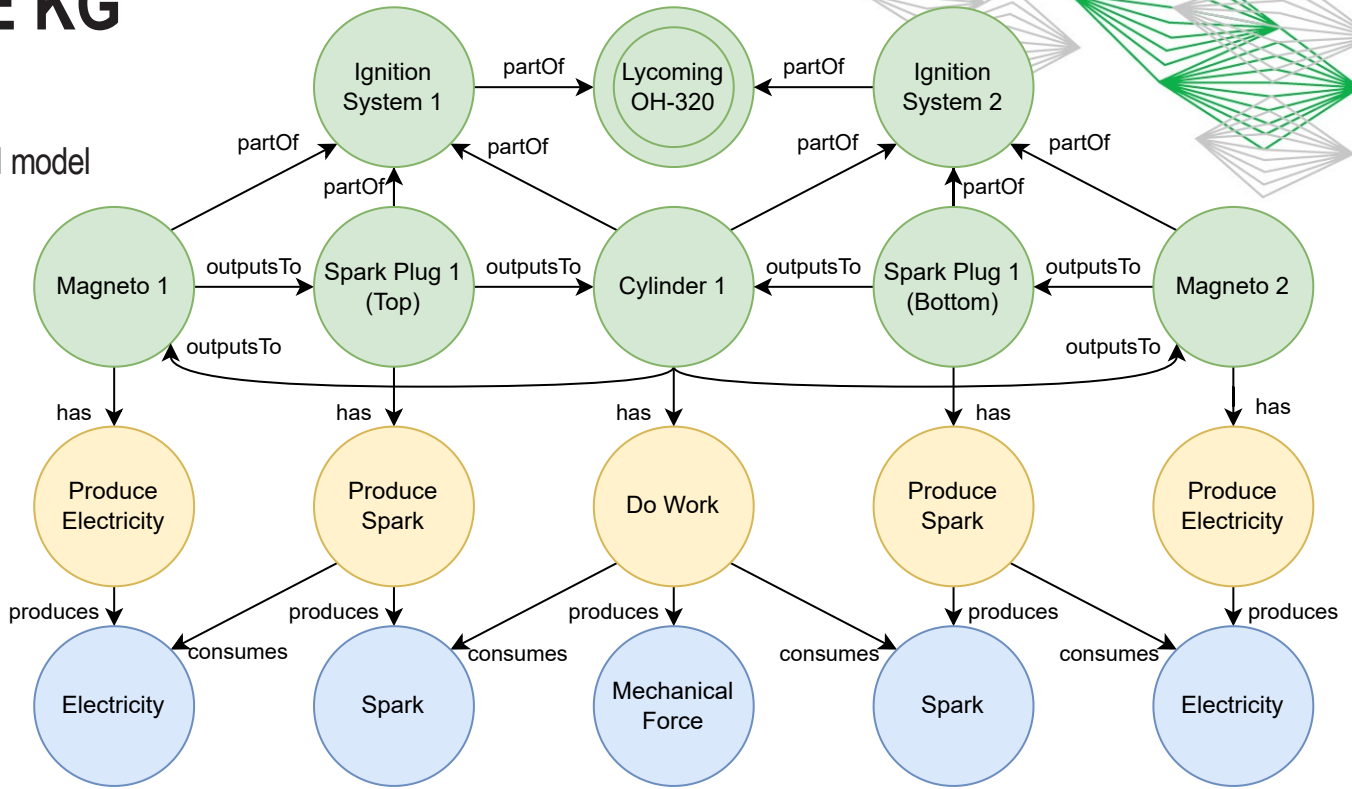


Ignition Wiring Diagram
By *Textron Lycoming, Overhaul Manual Direct Drive Engine (Part No. 60294-7)*

[1] Magnetos convert mechanical energy into high-voltage electricity.

THE EXAMPLE KG

- Instantiates the conceptual model with the system design
- *... Unreadable*



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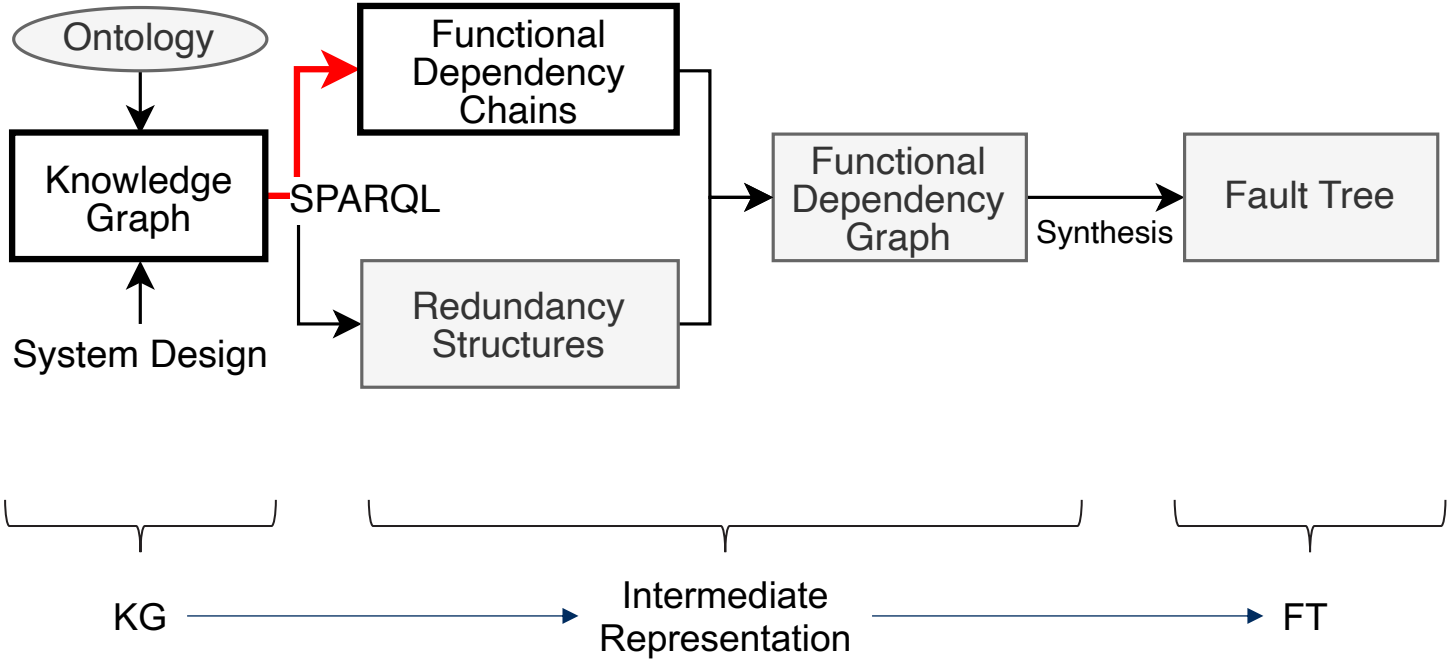
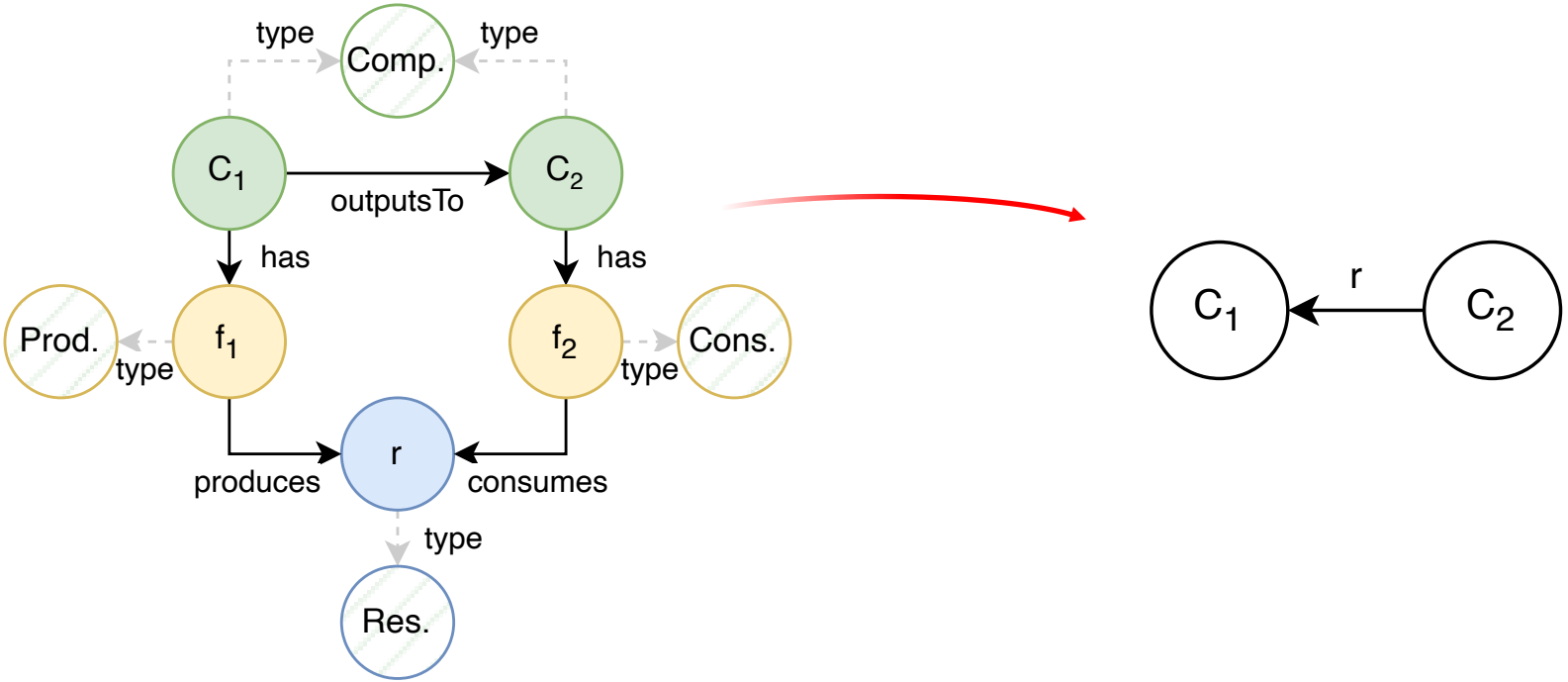
FDEP GRAPH CONSTRUCTION



CHAINS OF FUNCTIONAL DEPENDENCY



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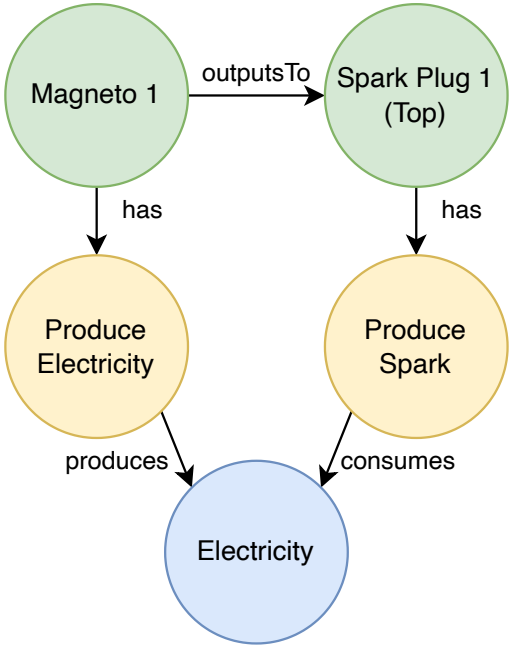
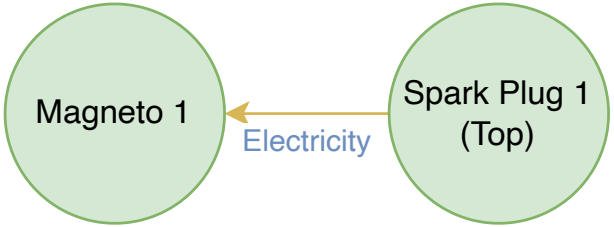
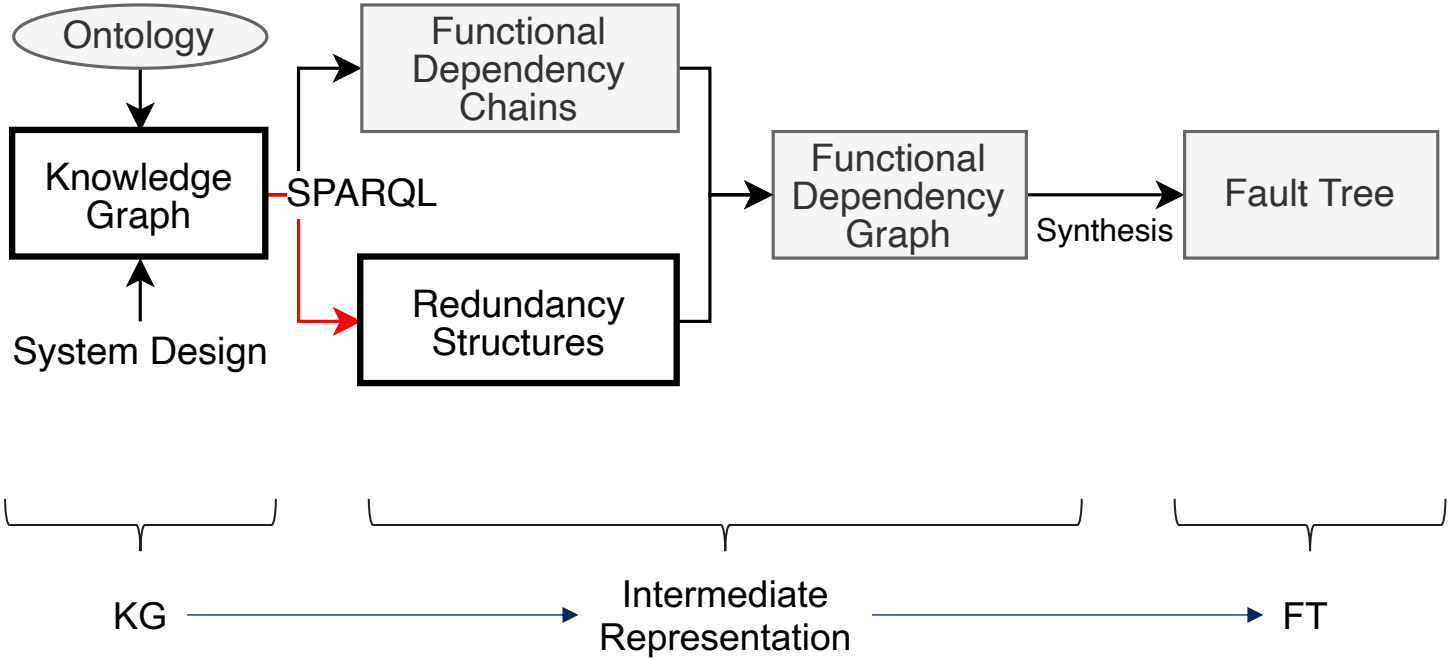
EXAMPLE



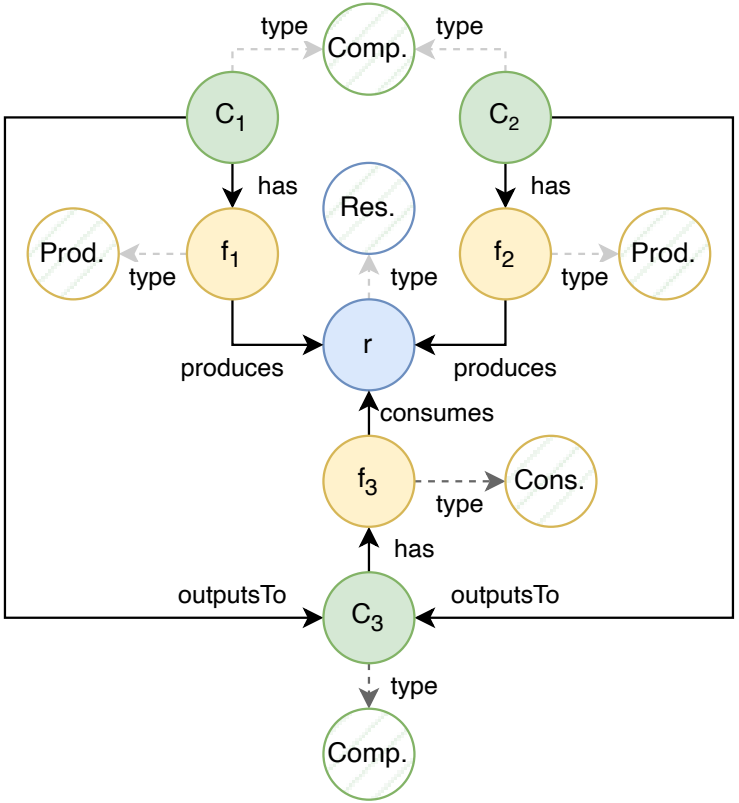
SPARQL

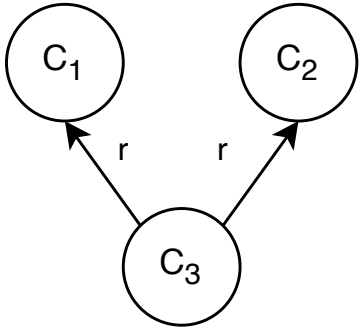


FDEP GRAPH CONSTRUCTION



REDUNDANCY STRUCTURES





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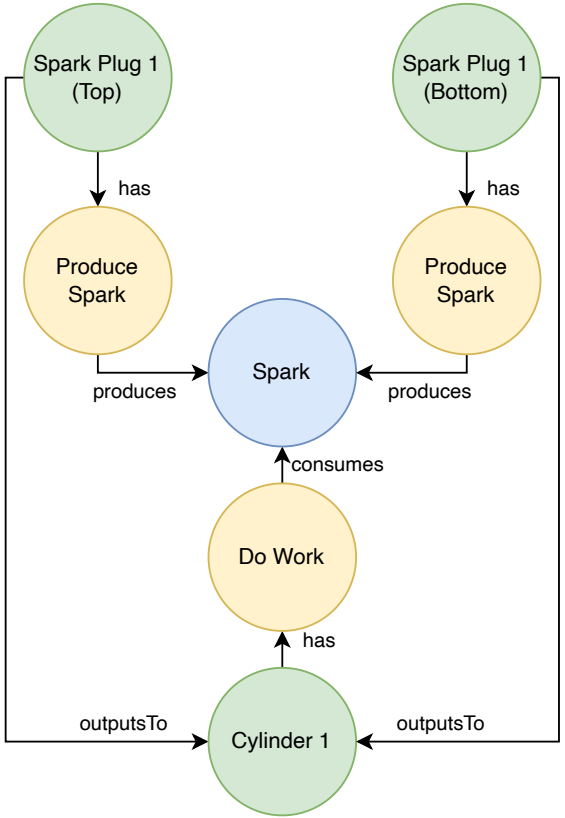
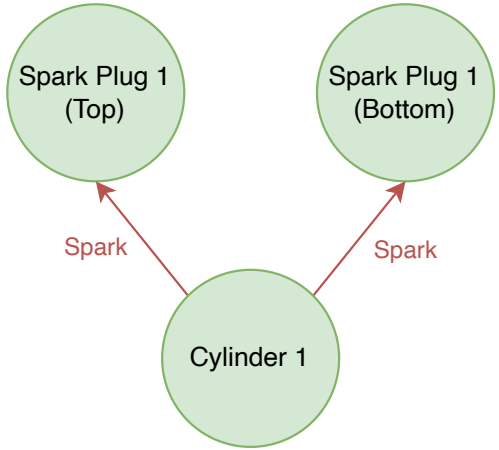
EXAMPLE



SPARQL



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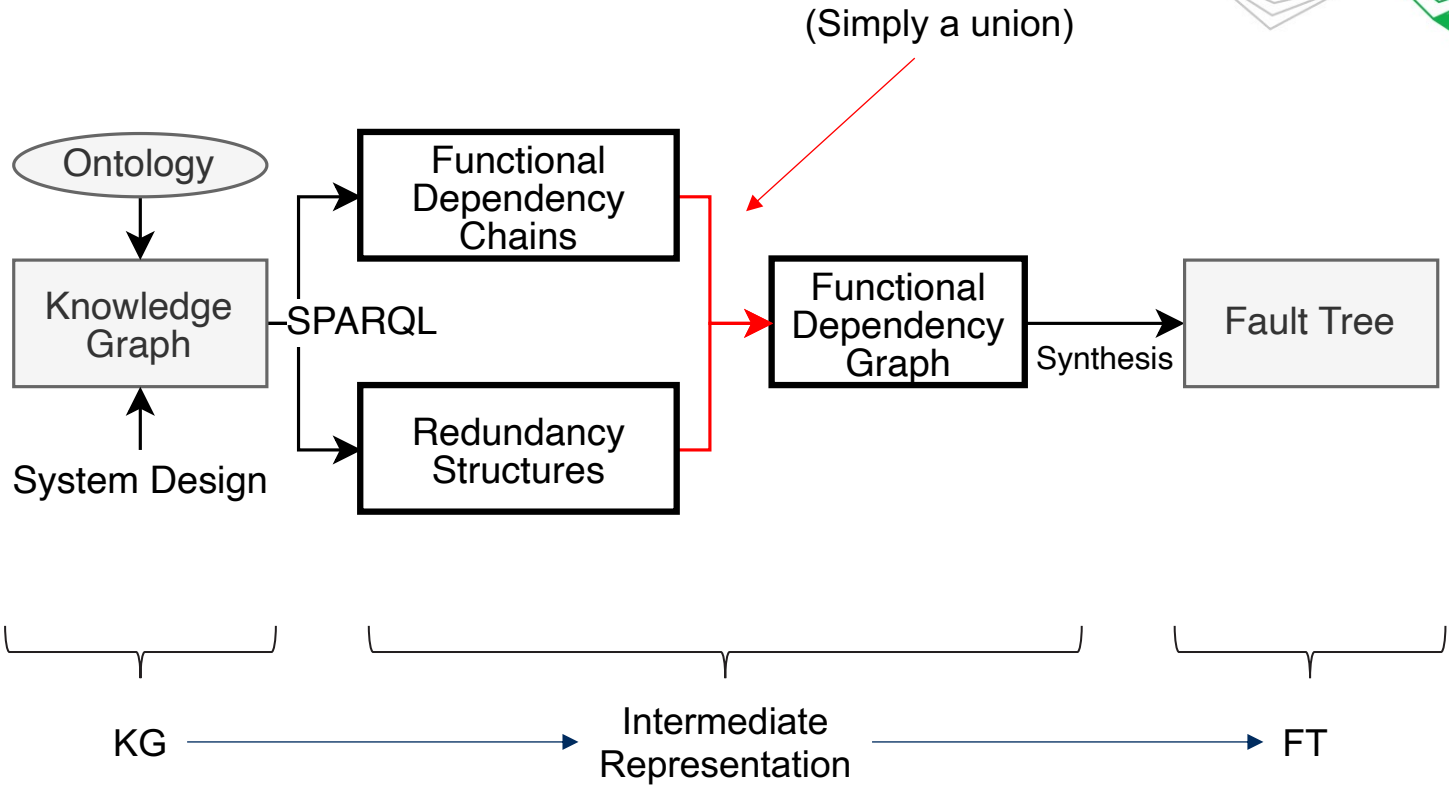
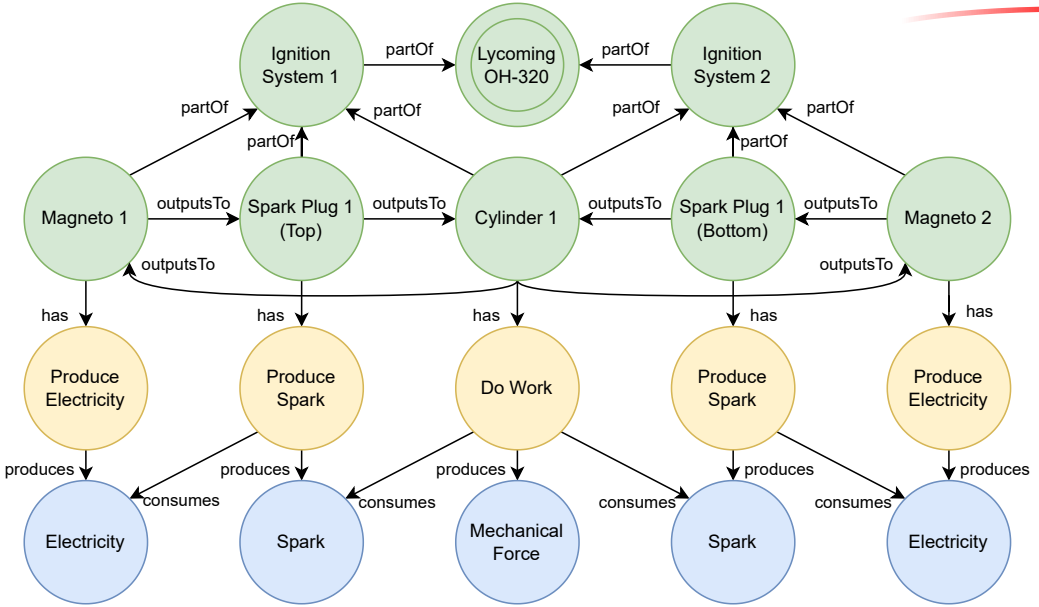
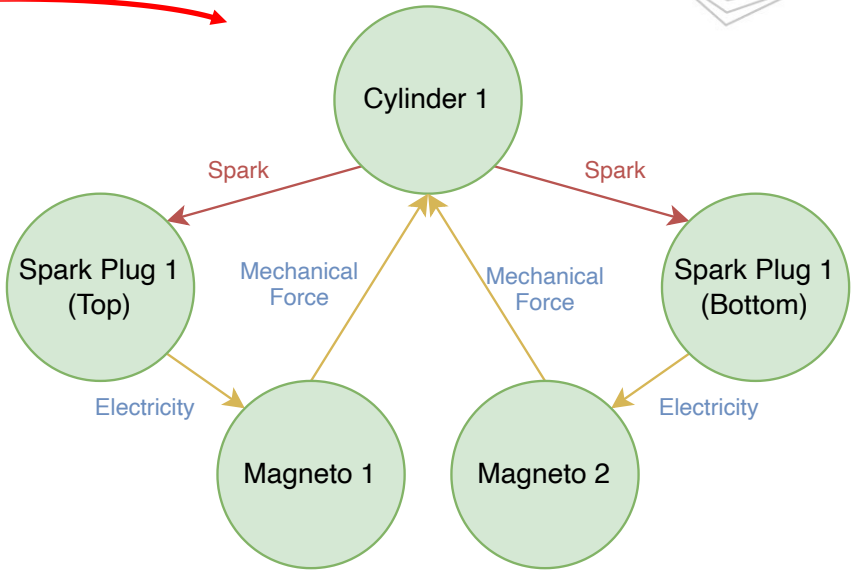
FDEP GRAPH CONSTRUCTION



EXAMPLE





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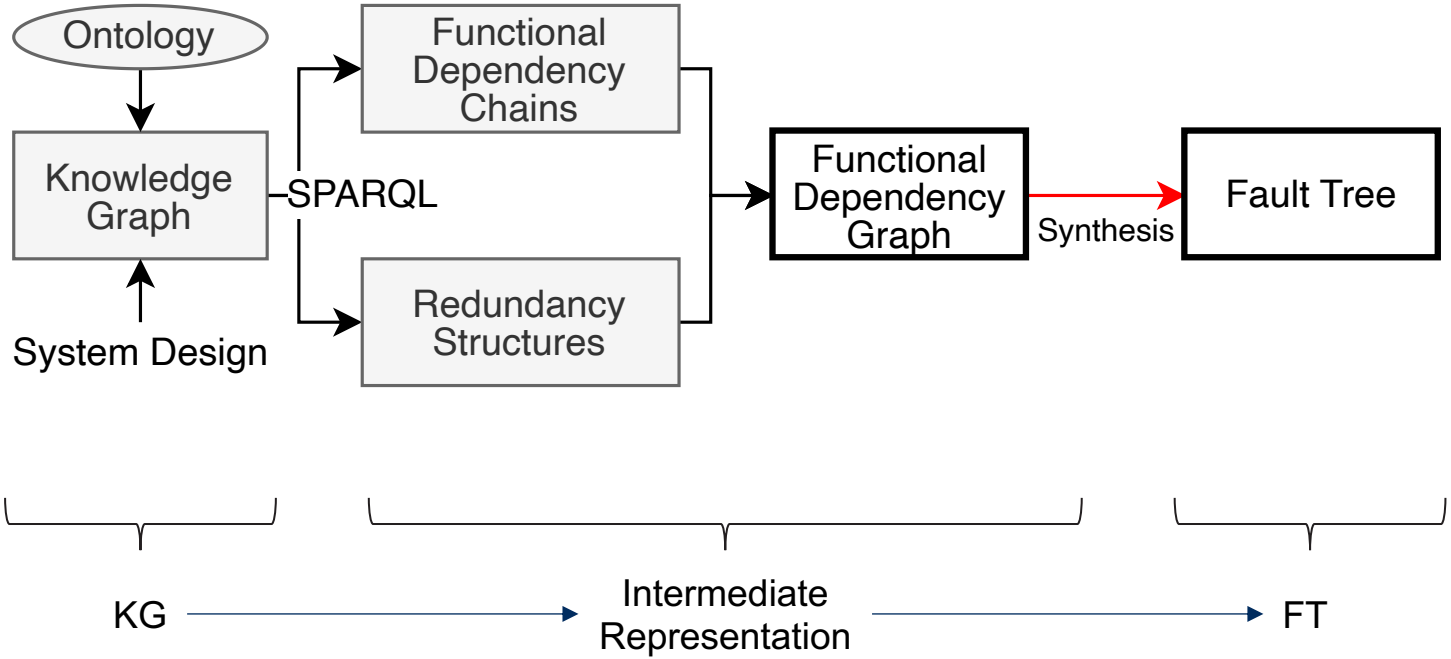
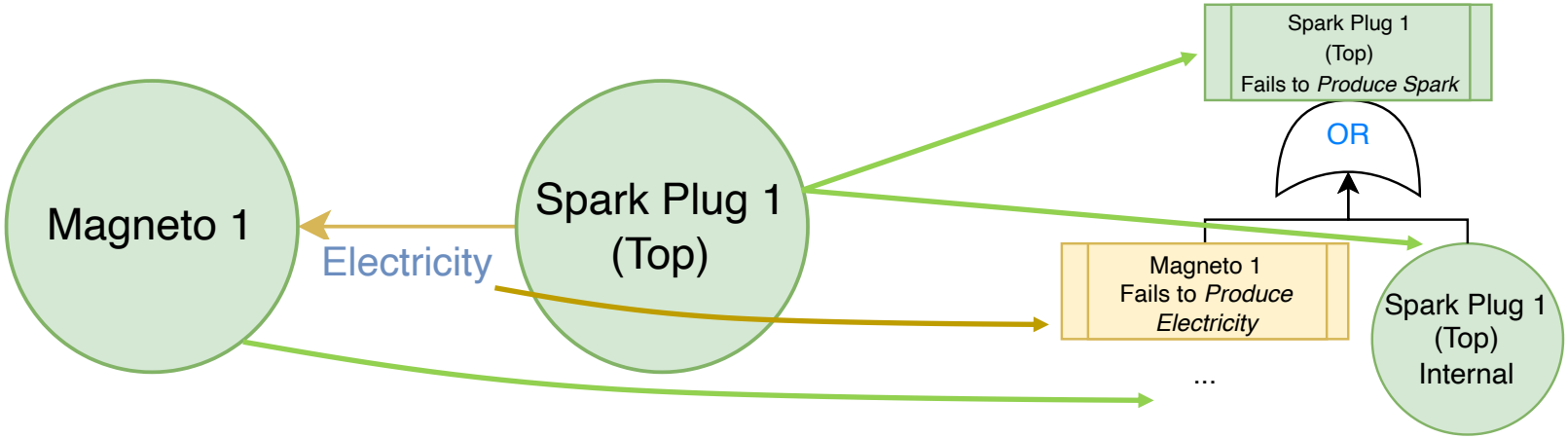
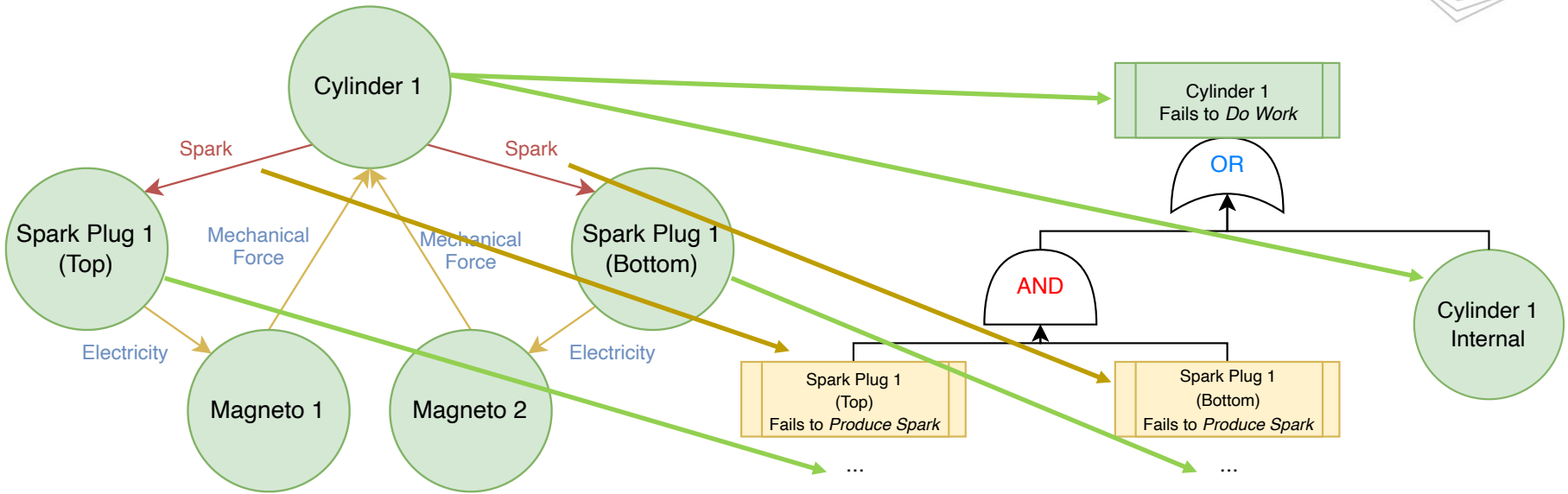
FAULT TREE SYNTHESIS



FAULT TREE SYNTHESIS



FAULT TREE SYNTHESIS



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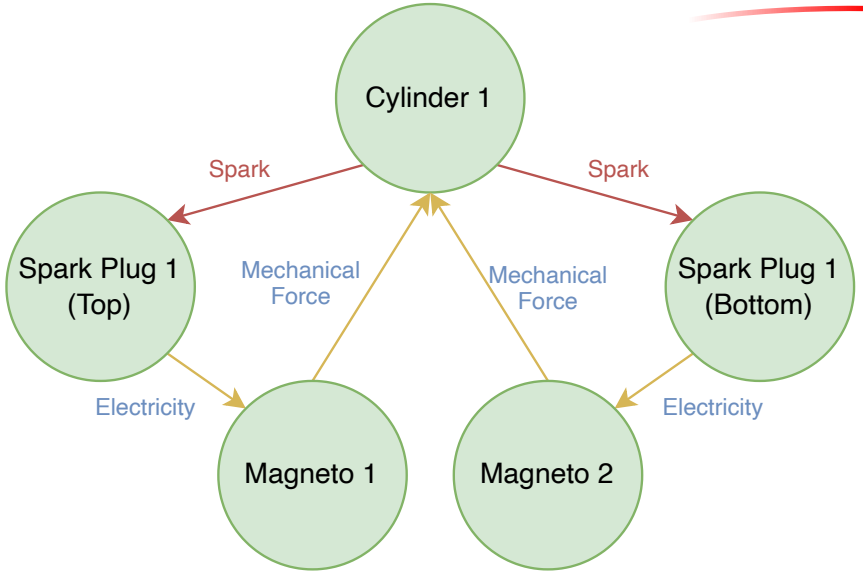
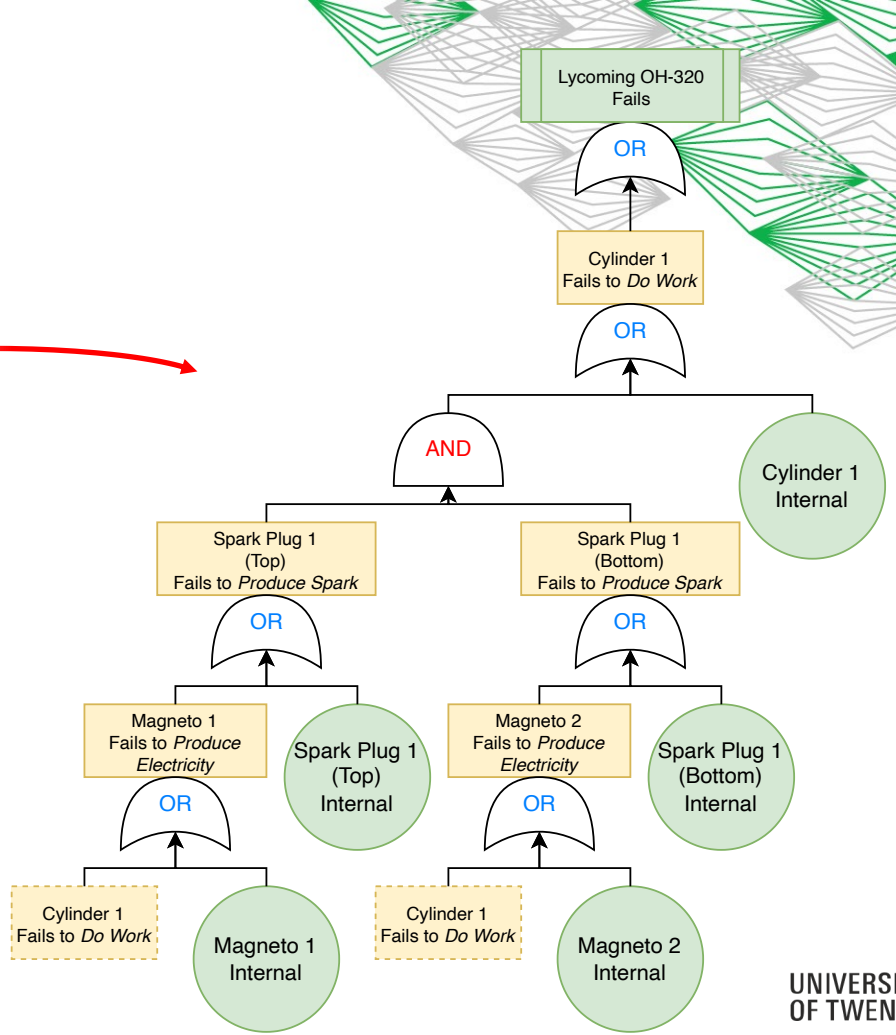
EXAMPLE





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RISK ANALYSIS

A Lycoming O-320-D2A installed in a Symphony SA-160
By *Ahunt* at English Wikipedia, Public Domain
https://commons.wikimedia.org/w/index.php?curid=8015248

Our engine fails if:

- **Just** *Cylinder 1* fails
- **Both** *spark plugs* fail
- **Both** *magnetos* fail
- The *top spark plug* **and** *magneto 2* fail
- The *bottom spark plug* **and** *magneto 1* fail

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- Methodology Overview
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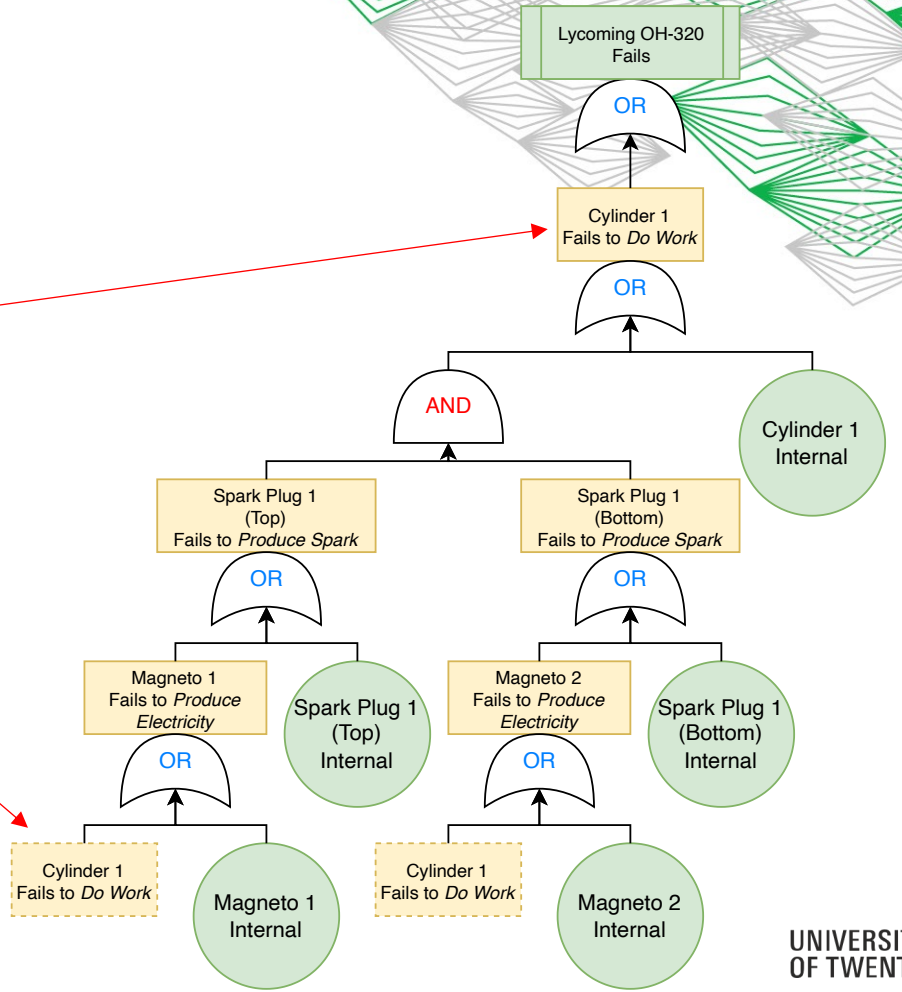
- **Limitations and Future Work**

LIMITATIONS

- Cycles are hard!
- No dynamic behavior
- No quantity specifications
  - Flow rates, units, multiplicity
  - Failure probability



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FUTURE WORK

- A stronger ontology:
  - Grounded in a Foundational Ontology (UFO)
  - Quantified, explicit requirements
  - Dynamic system model
  - Failure probabilities of components
- How do we get the system design into the knowledge graph?
- More models!