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You've Got a Plan?

A Domain Modelling Approach for Collaborative Product Disassembly Planning with PDDL

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IARIA

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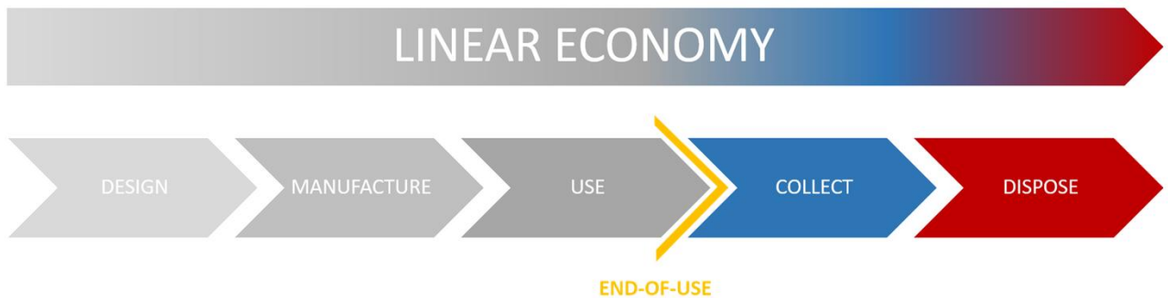
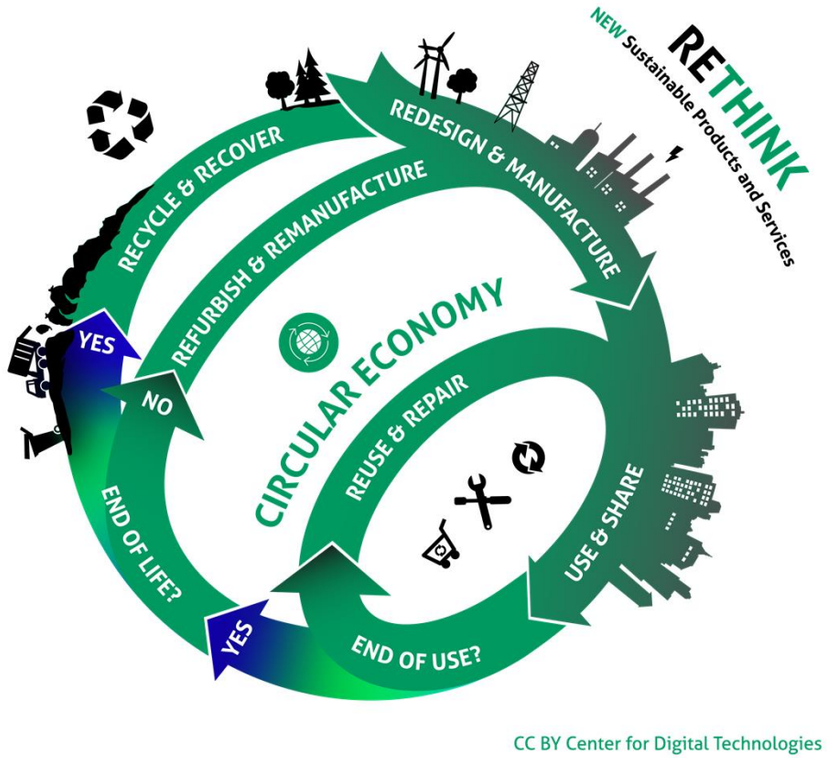
- **Research Interest:**
  - Digitized Circular Economy
  - AI-Planning Systems for Automation Processes
  - Digital Twin & Cyber-Physical Systems Design
  - Software Engineering for Robotics
- **CV:**
  - 2019: B.Sc. Energy and Raw Materials
  - 2021: M.Sc. Petroleum Engineering
  - 2021: Academic Researcher Center for Digital Technologies TU Clausthal & Ostfalia
  - 2022: Academic Researcher Institute for Software and Systems Engineering

Relevance of the Research

- Resource scarcity is increasing with every year!
- Linear Economy is still in place in industries
- Circular Economy keeps resources in a cycle
- We need a shift, from LE to CE!
- Especially production is energy and resource consuming
- Repairing, Refurbishing and Remanufacturing (3Rs) of products can mitigate these consumption
- **But how?**





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Problem Statement

- Discarding of products is nowadays easy
- On the opposite 3R operations are hard to conduct
- Reasons are, among others:
  - Economic Factors
  - Lack of skilled laborer
  - Technical obsolesces and inability to upgrade
  - Inability of companies to cope high amount and variety of used incoming products
- ➢ Automated Systems can mitigate some of those effects
- ➢ However, adaptivity is key and automated systems must be enabled to act in an adaptive manner

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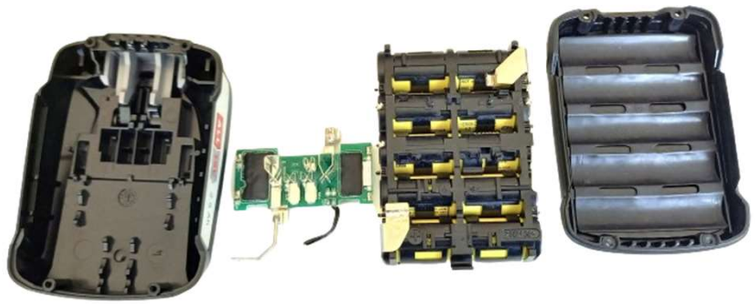
Problem Statement

So how can we enable Automated Systems to get from here…

to here and be adaptive at the same time?



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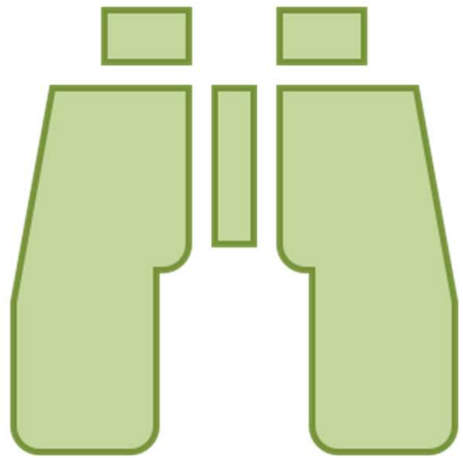
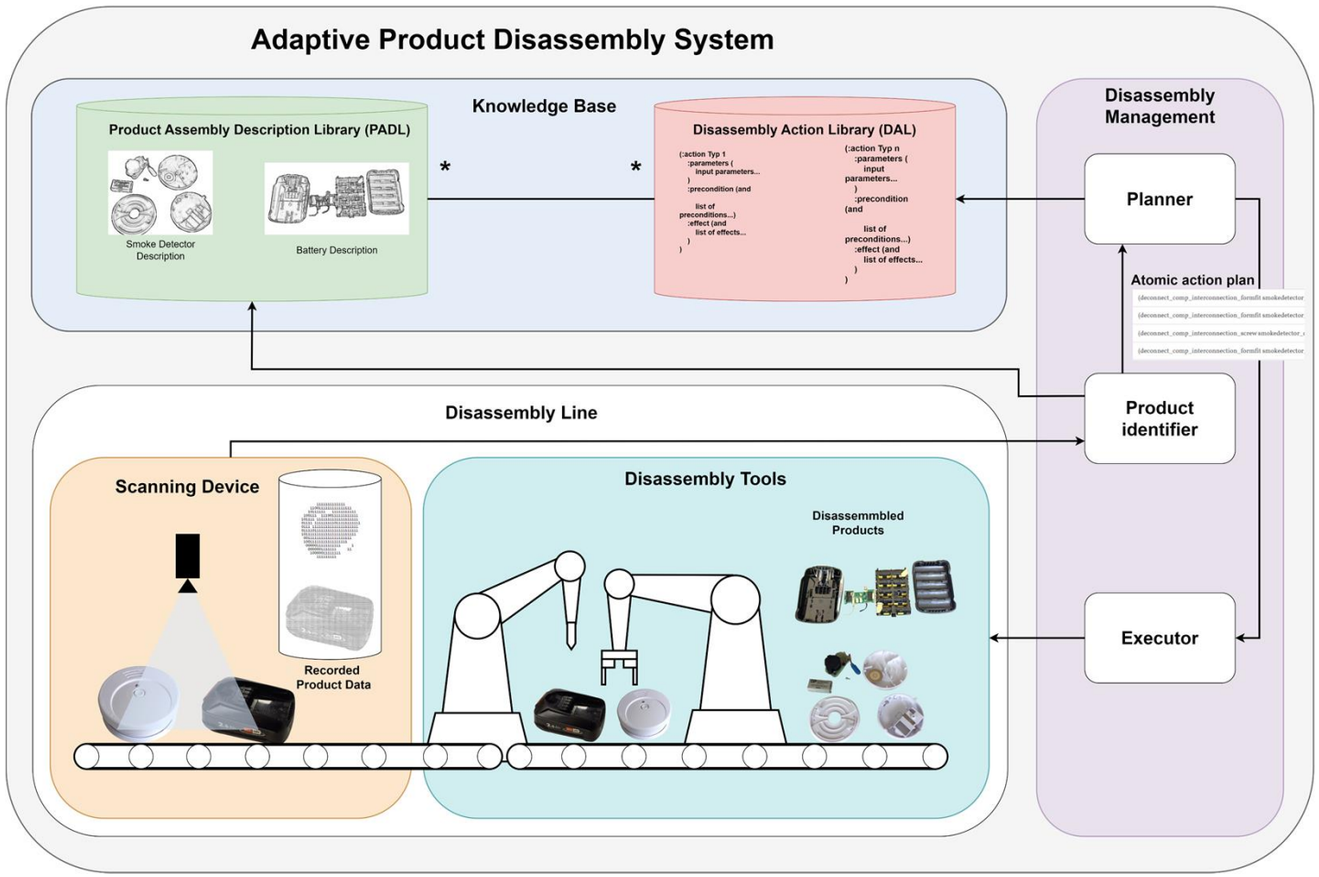
Scope of the Paper

- Two central subjects:
  - Conception of a model which takes the structural hierarchy and variety of products into account
  - Implementation and Testing of an AI-based sequence Planner

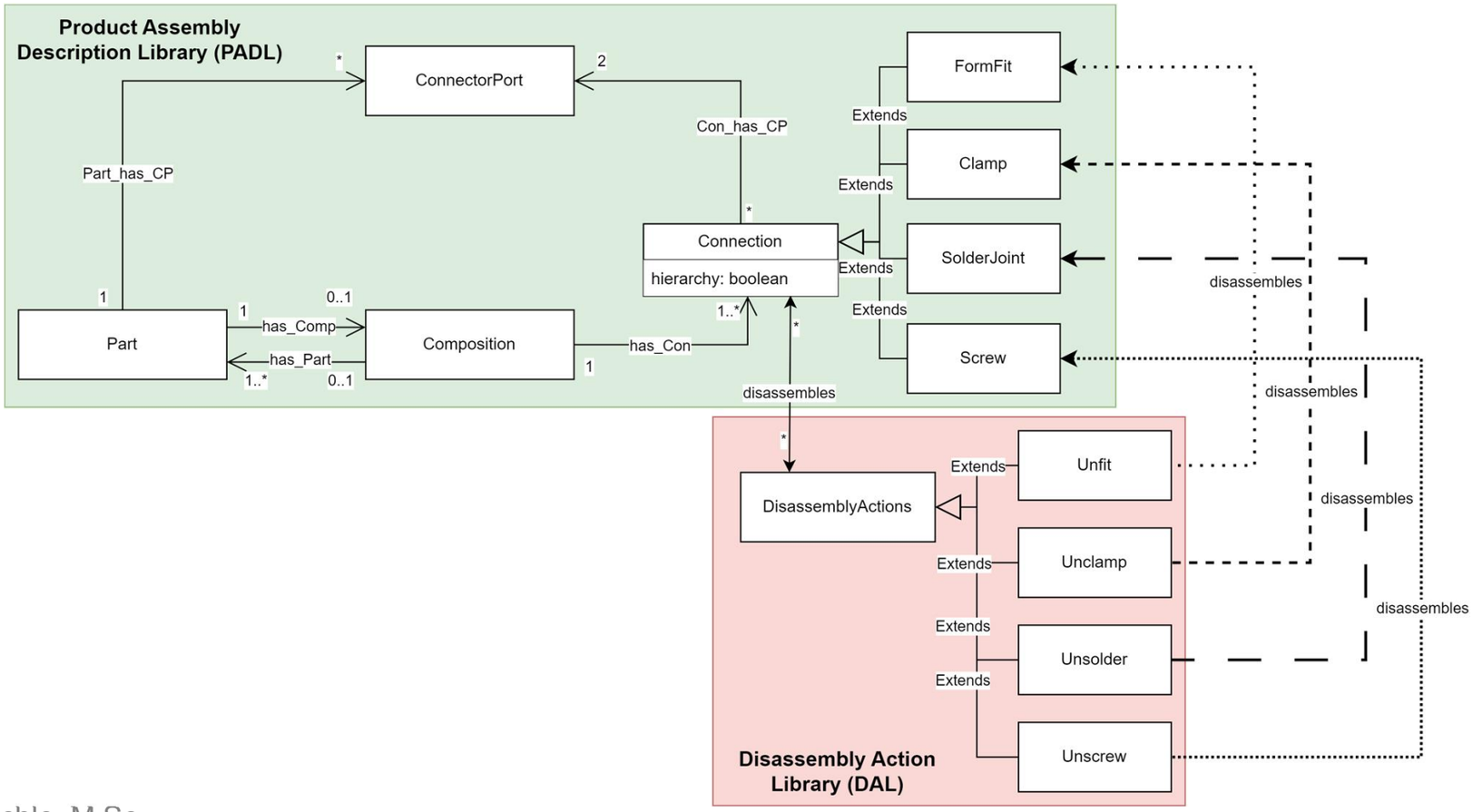
- Contribution to the research question:
  - Contribution of a meta-model, suitable to describe compositional structure in a modular and flexible way
  - Formulated PDDL-Domain derived from the meta-model to generate AI-based sequence plans for robotic disassembly systems
  - Evaluation and Testing with two product models, defined as PDDL-Problem on a Planner-based level



Overall Concept



Meta-Model



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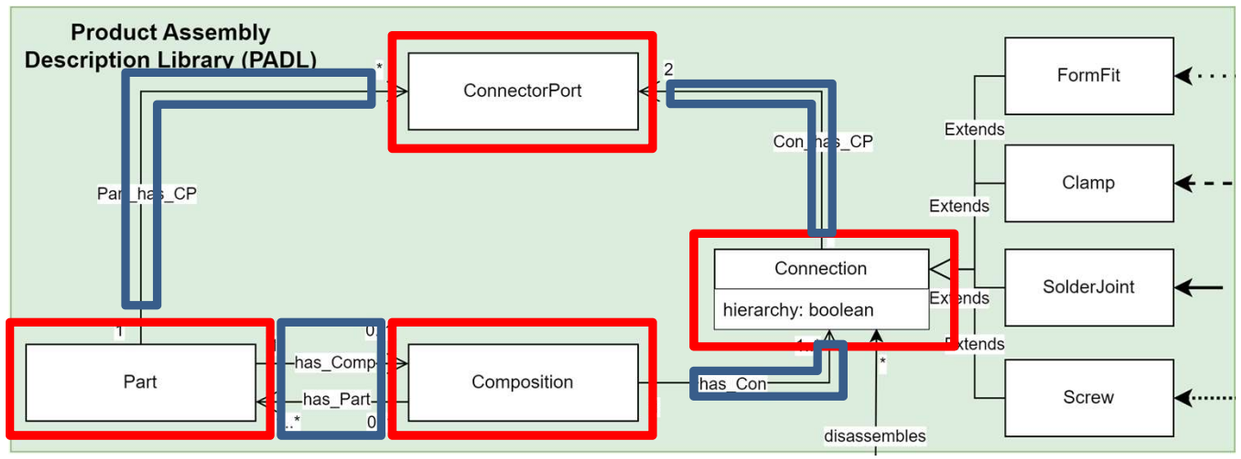
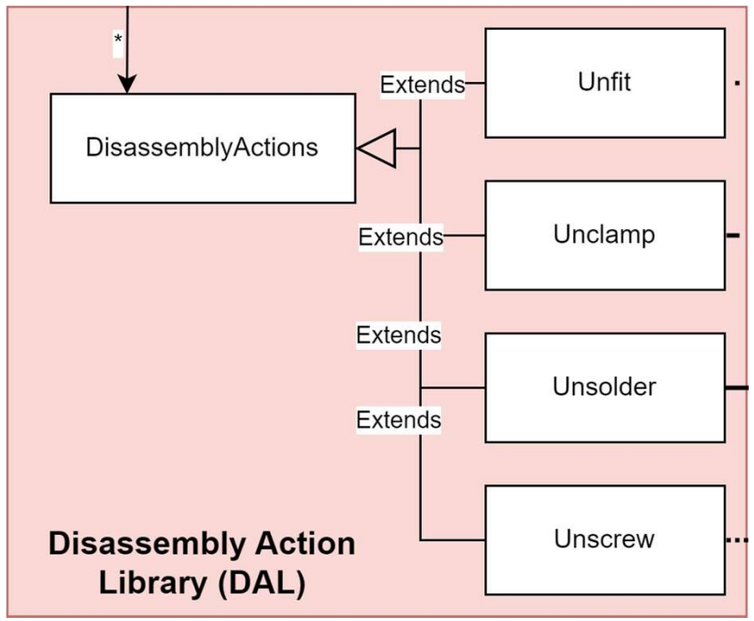
Product Assembly Description Library (PADL)

- PADL contains the general objects of our Meta-Model
- It is used to describe the compositional structure of the products
- Link establishes systematic connection between system entities
- Extensions of *Connection* act as specifications



Disassembly Action Library (DAL)

- DAL contains the model of the *DisassemblyActions,* required to disconnect the corresponding links
- Extensions enable the specification of disassembly operations



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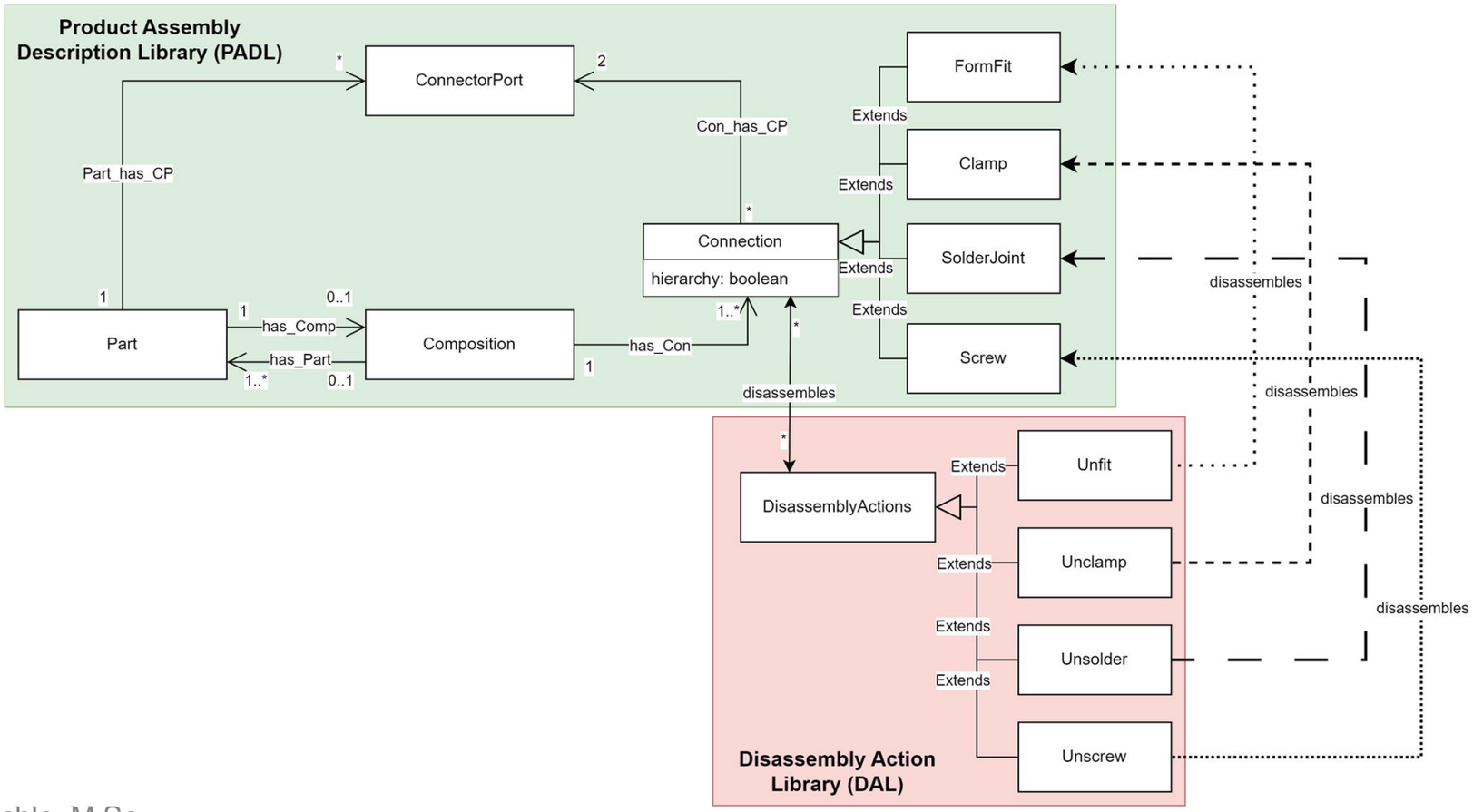
Meta-Model



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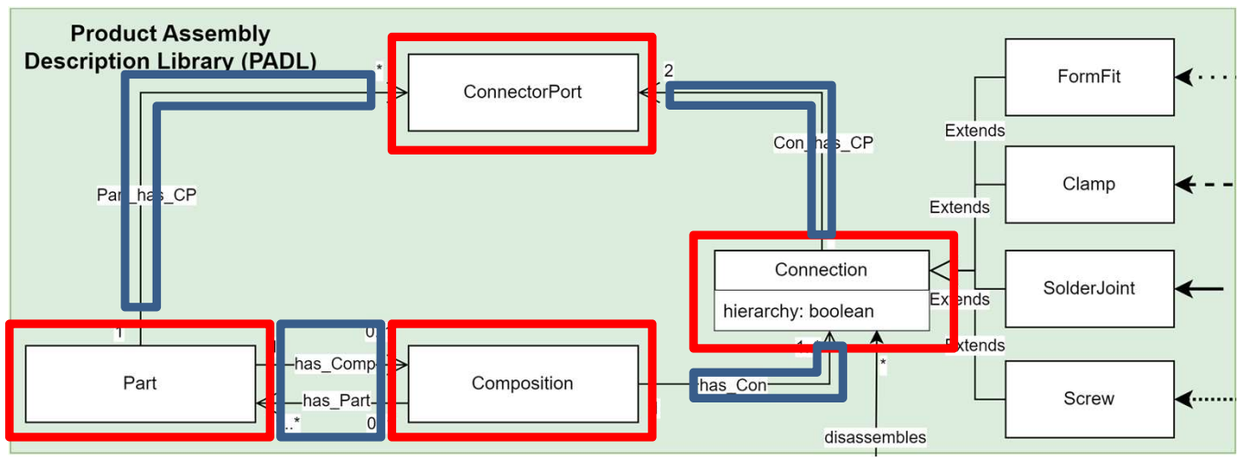
Implementation in PDDL

- Planning Domain Definition Language (PDDL) is used to implement the model
- PDDL is a descriptive language for AI-based Planning, which allows the formulation…
  - …of the meta-model entities as types
  - …the meta-model links as predicates
  - …the *DisassemblyActions* as Actions in the Domain
- Domain contains the information for the generation of Problems, which are then solved by a Solver/Parser combination

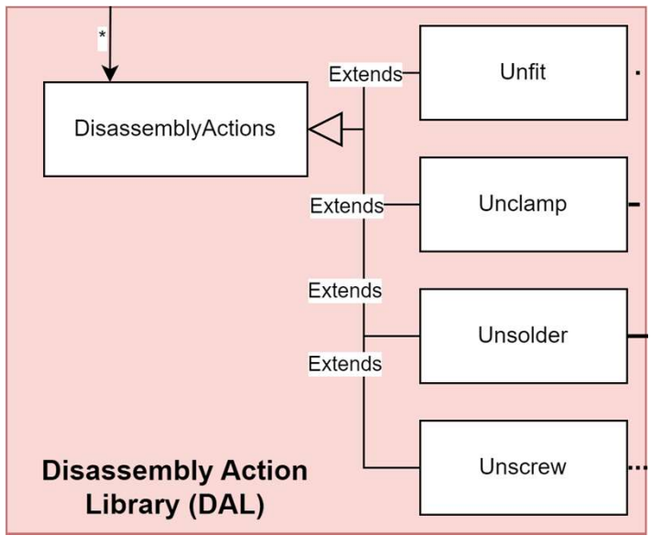
PDDL Domain – Types & Predicates




```
(:requirements :typing)
(:types
part - object
connectorport - object
connection - object
composition - object
interconnection - connection
transconnection - connection
)
```

```
(:predicates
(comp_has_cp ?part - part ?connectorport - connectorport)

(has_comp ?part – part ?composition - composition)

(has_part ?composition – composition ?part - part)

(has_con ?composition – composition ?connection - connection )

(con_has_cp ?connection – connection ?connectorport -
connectorport)
)
```

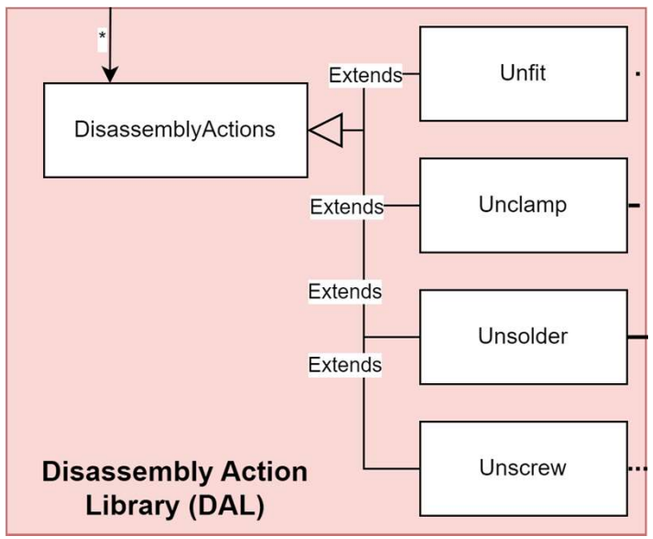
PDDL Domain - Actions




```
(:action disconnect_composition-interconnection
:parameters (
?comp - composition
?i1 - interconnection
?p1 - part
?p2 - part
?c1 - connectorport
?c2 - connectorport
 )
 :precondition (and
 (has_con ?comp ?i1)

 (forall (?deleg - transconnection)
 (not(has_con ?comp ?deleg))
 )
 (forall (?parts - part)
 (not(has_comp ?parts ?comp))
 )
 (part_has_cp ?p1 ?c1)
 (part_has_cp ?p2 ?c2)
 (has_part ?comp ?p2)
 (has_part ?comp ?p1)

 (con_has_cp ?i1 ?c1)
 (con_has_cp ?i1 ?c2)
 (not(= ?c1 ?c2))
 (not(= ?p1 ?p2))
 )
 :effect (and
 (not(has_con ?comp ?i1))
 (not(con_has_cp ?i1 ?c1))
 (not(con_has_cp ?i1 ?c2))))
```

```
(:action
disconnect_composition-transconnection
:parameters (
?comp - composition
?t1 - transconnection
?p1 - part
?p2 - part
?c1 - connectorport
?c2 - connectorport
)
:precondition (and
(has_con ?comp ?t1)
(forall (?allcomp - composition)
 (not(has_part ?allcomp ?p1))
 )
(has_comp ?p1 ?comp)
(has_part ?comp ?p2)
(part_has_cp ?p1 ?c1)
(part_has_cp ?p2 ?c2)
(not(con_has_cp ?t1 ?c1))
(not(con_has_cp ?t1 ?c2))
(not(= ?c1 ?c2))
(not(= ?p1 ?p2))
)
:effect (and
(not(has_con ?comp ?t1))
(not(con_has_cp ?t1 ?c1))
(not(con_has_cp ?t1 ?c2))
)
)
```

PDDL Domain - Actions




```
(:action disconnect_part-composition
:parameters (
?part - part
?comp - composition
?c1 - connectorport
?c2 - connectorport
?i1 - interconnection
)
:precondition (and
(forall (?over - composition)
(not(has_part ?over ?part))
)
(has_comp ?part ?comp)
(part_has_cp ?part ?c1)
(part_has_cp ?part ?c2)
(not(con_has_cp ?i1 ?c1))
(not(con_has_cp ?i1 ?c2))
(not(= ?c1 ?c2))
)
:effect (and
(not(has_comp ?part ?comp))
)
)
```

```
(:action
disconnect_composition-part
:parameters (
?comp - composition
?part - part
?c1 - connectorport
?c2 - connectorport
?i1 - connection
?i2 - connection
)
:precondition (and
(part_has_cp ?part ?c1)
(part_has_cp ?part ?c2)
(has_part ?comp ?part)
(forall (?links - connection)
(not(has_con ?comp ?links)
)
)
(not(con_has_cp ?i1 ?c1))
(not(con_has_cp ?i2 ?c2))
(not(= ?c1 ?c2))
(not(= ?i1 ?i2))
)
:effect (and
(not(has_part ?comp ?part))
)
)
```

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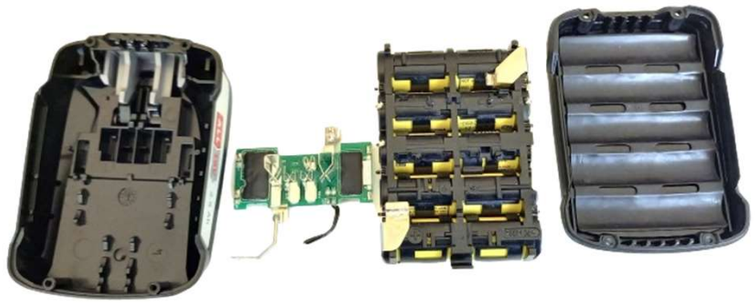
Problem Statement

Can we now get from here…

to here with our automated system?



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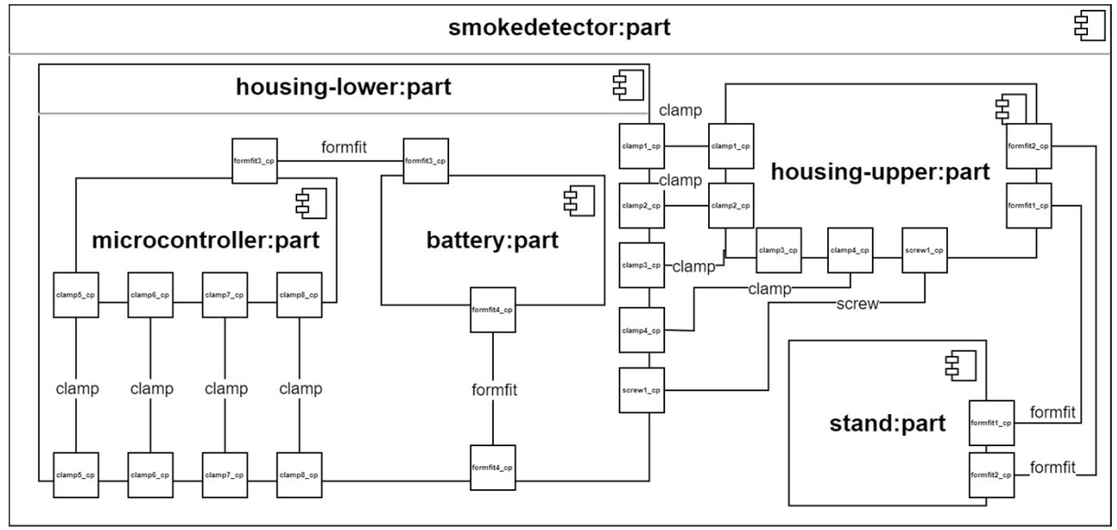
Test Scenario

- PDDL implementation was tested with two different Use-Cases on a planning base:
  - Smoke detector
  - Power Tool Battery
- Problems were drafted as Composition Structure Diagrams
- Composition Structure Diagrams captures the assembled state, that is used to define the initial state of the Problem



Results

- Solving was carried out via the tool: https://editor.planning.domains/
- As Solver, out of the standard implementation solvers, the BFWS Solver with an ff Parser was the most suitable option
- Plans were generated by the solver according to the Composition Structure Diagrams
- Application of different specified Actions were conducted in accordance to the preconditions

	Smoke Detector	Power Tool Battery
Total time:	1.05921 sec.	1.24214 sec.
Nodes generated during search:	332	429
Nodes expanded during search:	312	169
Plan found with cost:	15	25

Conclusion

- Definition of a Meta-Model allows the description of product assemblies and the according disassembly environment
- Disassembly planning is conducted via PDDL and showed, how such systems can generate sequence-based disassembly plans
- However, model has certain Limitations:
  - Condition is not regarded as a factor
  - Cost-based considerations have not played a part in the selection of actions
- Future Outlook:
  - Implement identified limitations into the Meta-Model and the according PDDL System
  - Test planner-based disassembly structure on Robot system with defined interfaces

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References

- [1] J. Bach´er, Y. Dams, T. Duhoux, Y. Deng, T. Teittinen, and L. F. Mortensen, “Electronic products and obsolescence in a circular economy,” Eionet Report - ETC/WMGE, no. 3, 2020.
- [2] Y. Sitaramaiah and M. K. Kumari, “Impact of electronic waste leading to environmental pollution,” Journal of Chemical and Pharmaceutical Sciences, no. JCHPS Special Issue 3, 2014.
- [3] M. A. Khan, S. Mittal, S. West, and T. Wuest, “Review on upgradability - A product lifetime extension strategy in the context of product service systems,” Journal of Cleaner Production, no. 204, pp. 1154–1168, 2018.
- [4] X. Zhang, L. Zhang, K. Y. Fung, B. R. Bakshi, and K. M. Ng, “Sustainable product design: A life-cycle approach,” Elsevier Chemical Engineering Science, no. 217, 2020.
- [5] N. Roskladka, A. Jaegler, and G. Miragliotta, “From “right to repair” to “willingness to repair”: Exploring consumer’s perspective to product lifecycle extension,” Journal of Cleaner Production, no. 432, 2023.
- [6] G. Foo, S. Kara, and M. Pagnucco, “Challenges of robotic disassembly in practice,” 29th CIRP Life Cycle Engineering Conference, no. 29, pp. 513–518, 2022.
- [7] K. Wegener, W. H. Chen, F. Dietrich, K. Dr¨oder, and S. Kara, “Robot Assisted Disassembly for the Recycling of Electric Vehicle Batteries,” The 22nd CIRP conference on Life Cycle Engineering, no. 22, pp. 716–721, 2015.
- [8] S. L. Soh, S. K. Ong, and A. Y. C. Nee, “Design for Disassembly for Remanufacturing: Methodology and Technology,” Procedia CIRP 15, no. 15, pp. 407–412, 2014.
- [9] M. M. L. Chang, S. K. Ong, and A. Y. C. Nee, “Approaches and Challenges in Product Disassembly Planning for Sustainability,” The 27th CIRP Design, no. 27, pp. 506–511, 2017.
- [10] A. J. D. Lambert, “Disassembly sequencing: a survey,” International Journal of Production Research, no. 41, pp. 3721– 3759, 2003.
- [11] C. Heemskerk, L. Reijers, and H. Kals, “A Concept for Computer-Aided Process Planning of Flexible Assembly,” CIRP Annals, vol. 39, no. 1, pp. 25–28, 1990, ISSN: 0007- 8506.
- [12] E. Pednault, “ADL: Exploring the middle ground between STRIPS and the situation calculus,” International Conference on Principles of Knowledge Representation and Reasoning, no. 1, pp. 324–332, 1989.
- [13] K. Erol, J. A. Hendler, and D. Nau, “UMCP: A Sound and Complete Procedure for Hierarchical Task-network Planning,” Conference on Artificial Intelligence Planning Systems (AIPS), no. 2, pp. 249–254, 1994.
- [14] D. McDermott, M. Ghallab, A. Howe, et al., “PDDL-The Planning Domain Definition Language,” Tech Report CVC TR- 98-003/DCS TR-1165, 1998.
- [15] T. Hoebert, D. Neubauer, M. Merdan, W. Lepuschitz, Thalhammer, and M. Vincze, “ROS-driven Disassembly Planning Framework incorporating Screw Detection,” International Conference on Electrical Engineering, Computing Science and Automatic Control (CCE), no. 20, 2023.
- [16] Y. Zhang, H. Zhang, W. Zhigang, S. Zhang, H. Li, and M. Chen, “Development of an Autonomous, Explainable, Robust Robotic System for Electric Vehicle Battery Disassembly,” IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM), pp. 409–414, 2023.
- [17] S. U. Lee, A. Hofmann, and B.Williams, “A Model-Based Human Activity Recognition for Human–Robot Collaboration,” IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 736–743, 2019.
- [18] C. Deiters, “Description and consistent composition of building blocks for the architectural design of software systems,” Ph.D. dissertation, University of Technology Clausthal, Clausthal-Zellerfeld, GER, 2015.
- [19] S. Herold, “Architectural Compliance in Component-Based Systems - Foundations, Specification, and Checking of Architectural Rules,” Ph.D. dissertation, University of Technology Clausthal, Clausthal-Zellerfeld, GER, 2011.