Logical Modeling for Engineering

Conrad Bock

U.S. National Institute of Standards and Technology

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NIST
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Overview

- Quantative and logical Modeling
- Categories
  - As membership conditions
  - Terminology and notation
  - Kinds of conditions
  - Most common condition: Generalization
- Categories of categories
  - Subject-specific languages
- Categories of relations (and processes)
- Summary and References

Quantitative Modeling

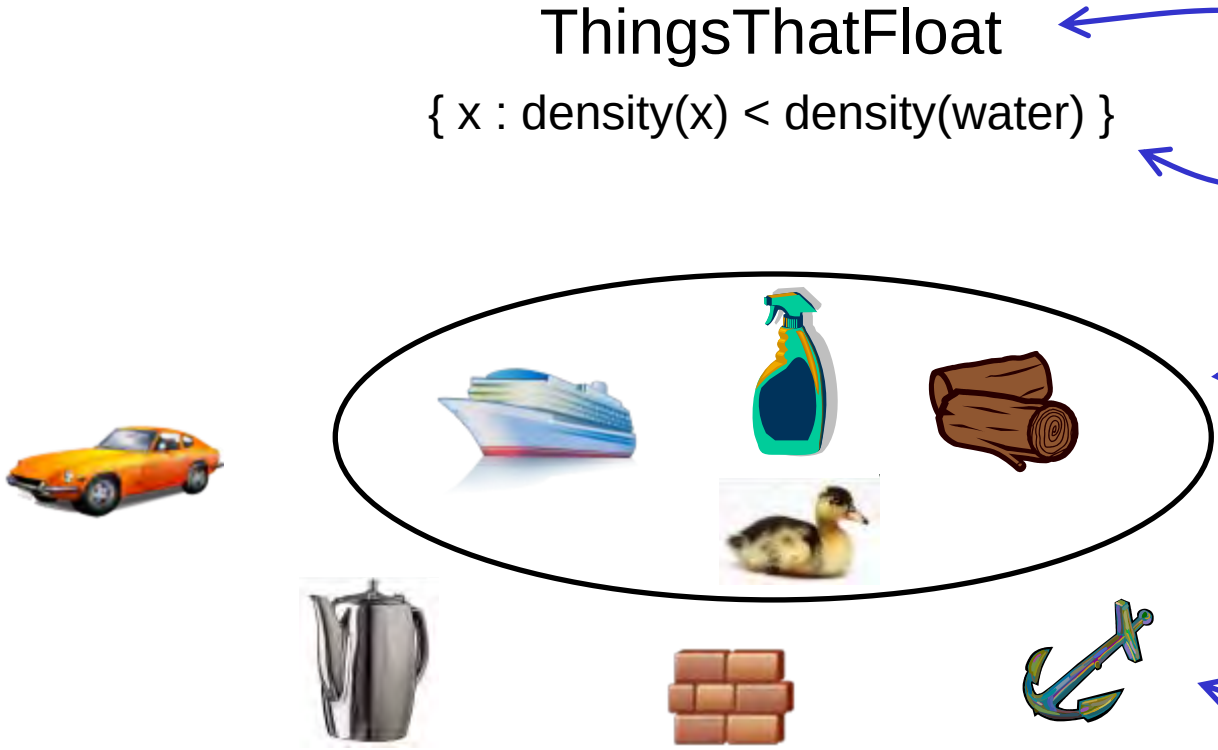
- **Quantitative modeling**
  - **Numerical formulas (equations)**
  - **Dynamic and stochastic simulations**
- **Used for:**
  - **Calculating or simulating numeric values and probabilities.**
  - **Deriving new numerical formulas.**

Logical Modeling

- **Logical modeling is about categorizing things and relations between things ...**
  - **This document is a requirement, this other one is a design, and the second satisfies the first.**
- **… and keeping these categorizations consistent.**
  - **Requirements or designs are changed, does the satisfies relation still hold?**
  - **If not, what would make it hold again?**

Categories = Conditions

- **Things "fall into" categories.**
- **Categories have conditions for what can and cannot fall into the category.**

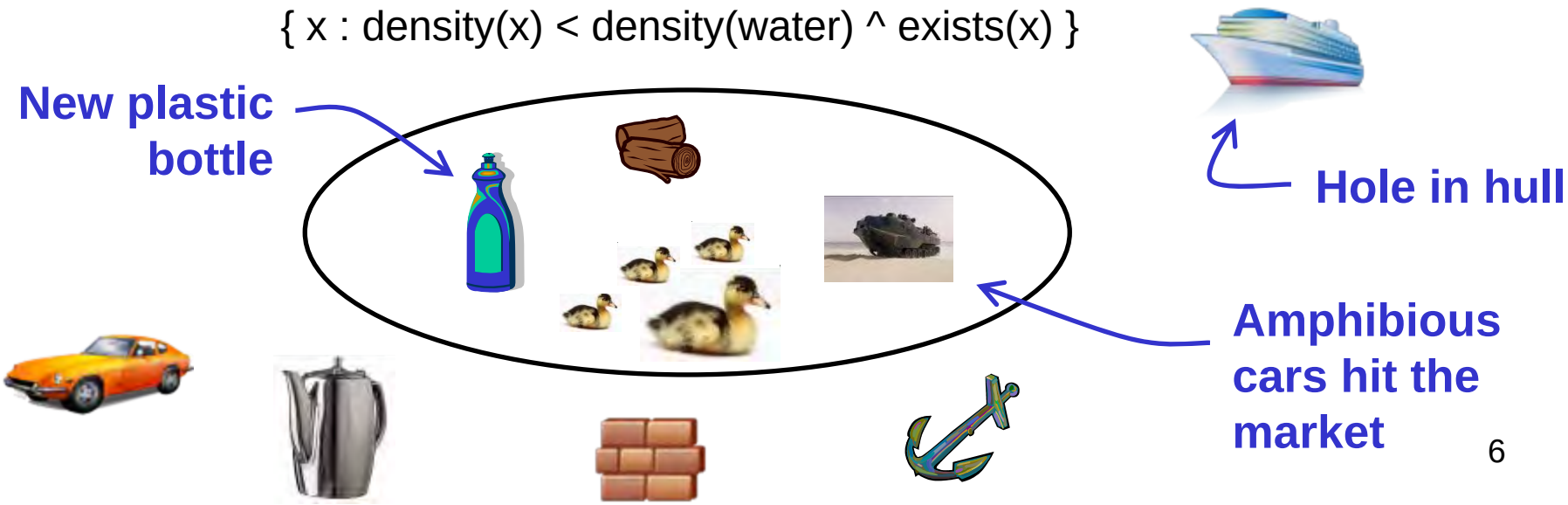


Categories Specify Sets

- **Which things fall into a category can change over time without changing the category (condition).**
  - **New things created, some things destroyed, conditions met or unmet over time.**
  - **Not true for set membership.**

ThingsThatFloat

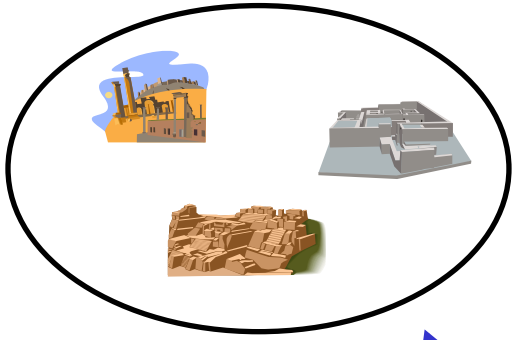
{ x : density(x) < density(water) ^ exists(x) }



Categories ~~Imply~~ Existence

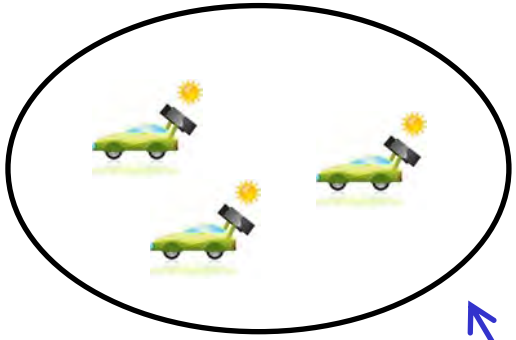
- **Conditions might only be satisfied by things from the past, future, in simulation, or not at all.**

Roman Cities



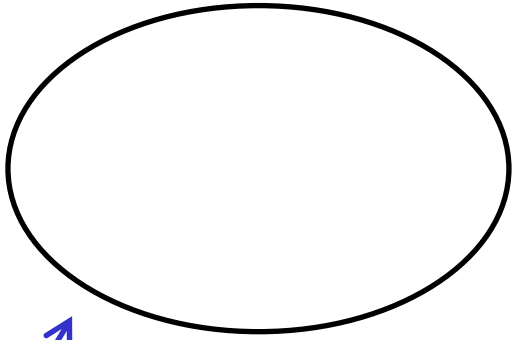
Existed in the past

Marketable Solar Cars



Might exist in the future, or in simulation

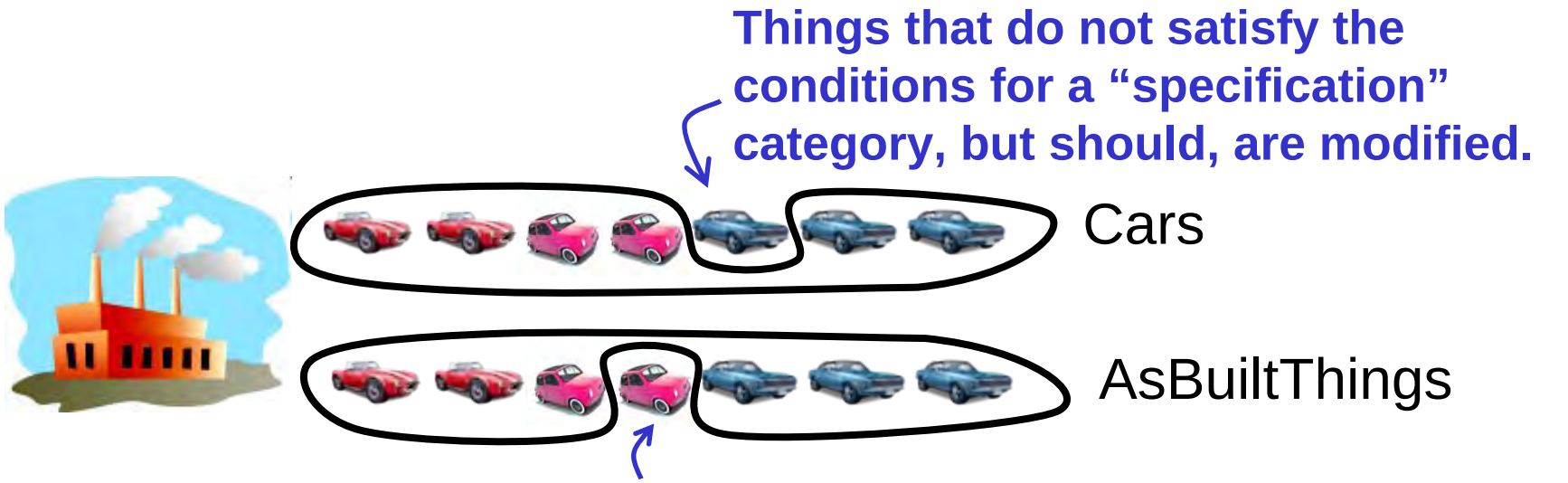
Perpetual Motion Machines



Imaginary, or will never exist

Fixed and Changing Conditions

- **When something does not fall into a category, but it should, you can:**
  - **Modify the thing**
  - **Modify the category's conditions**

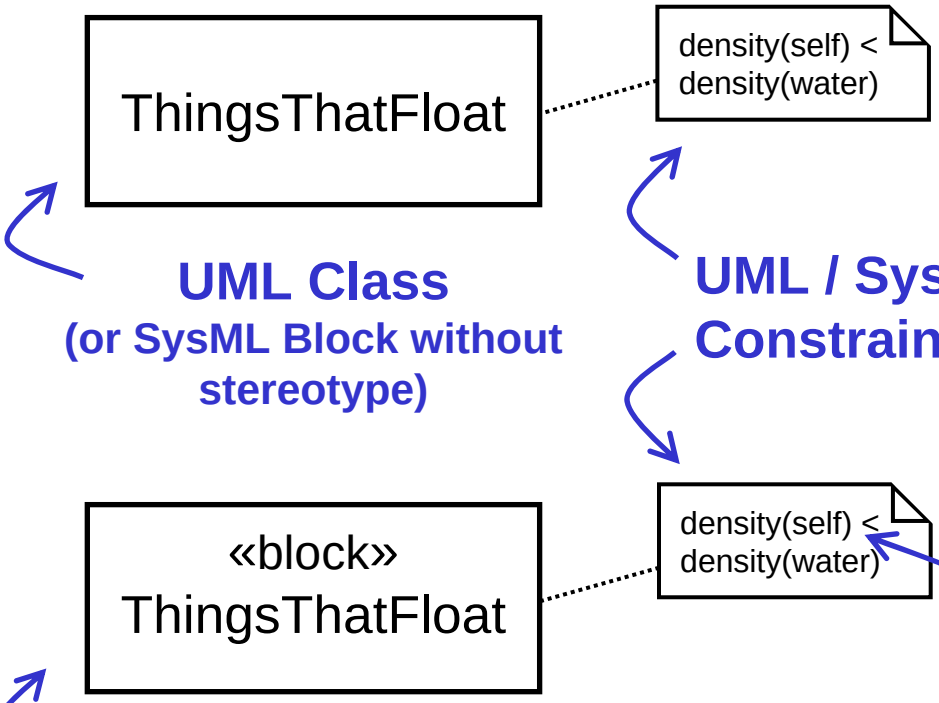


Terminology

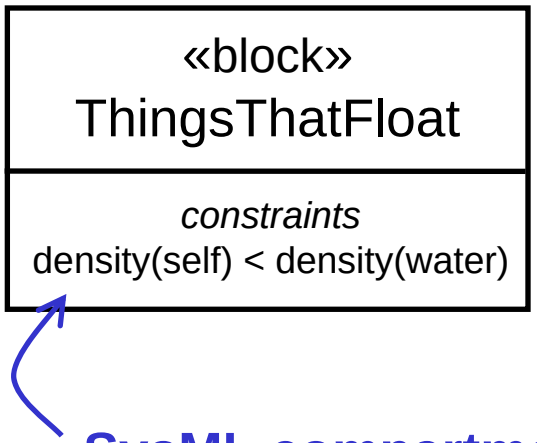
- The term “categories” is just for explanation in this presentation.
- Other terms:
  - “Classes” in the Unified Modeling Language (UML) and Web Ontology Language (OWL).
  - “Blocks” in the Systems Modeling Language (SysML), an extension of UML.
- Things falling into categories:
  - UML / SysML: “Instances” (of classes / blocks)
  - OWL: “Objects” and “Data” (interpretations of classes and datatypes)

Graphical Notation

UML & SysML:



SysML:

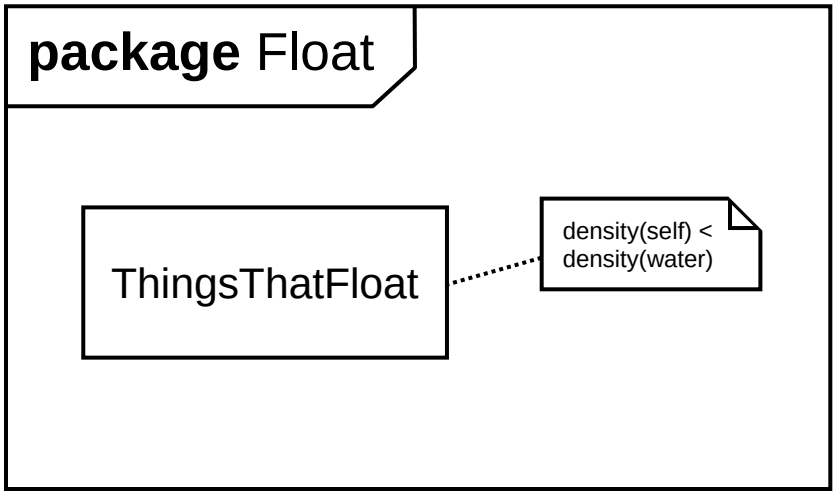


Note: Naming conventions are usually singular, easily confused with instances.

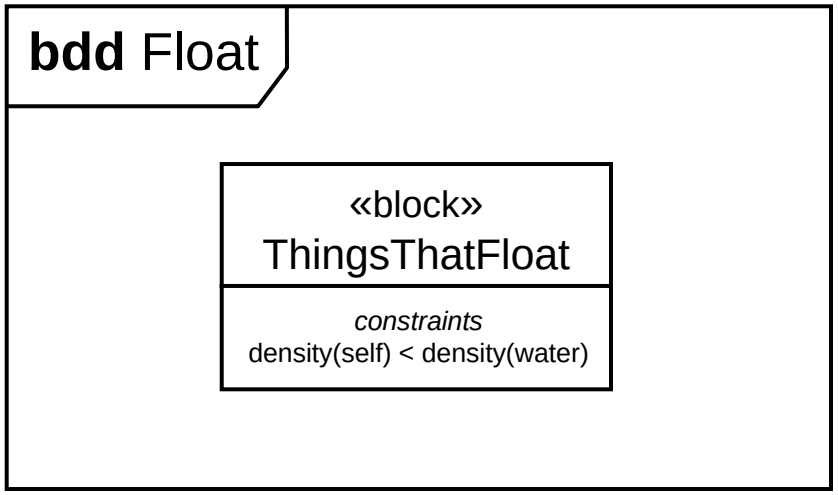
Diagrams

- **UML Classes and SysML Blocks appear in particular kinds of diagrams.**

UML Package Diagrams



SysML Block Definition Diagrams



“In” Conditions

- **Can only determine when something falls into a category, not out of it.**
  - **Any four-wheeled thing over 750kg that carries people using its own power over 100kw is a car.**
  - **If something meets the condition it is a car.**
  - **Otherwise, it might be a car or not (maybe some cars are three-wheeled).**
- **Purely *sufficient* conditions do not interact.**
  - **Each condition is sufficient separately.**

“Out” Conditions

- **Can only determine when something falls out of a category, not in it.**
  - **Cars are vehicles.**
  - **If condition is not met (something is not a vehicle), then it is not a car.**
  - **Otherwise, it might or might not be a car (some vehicles might not be cars).**
- **Purely *necessary* conditions do not interact.**
  - **Each condition negates separately.**
- **Combining necessary and sufficient can be contradictory.**

In vs Out in English

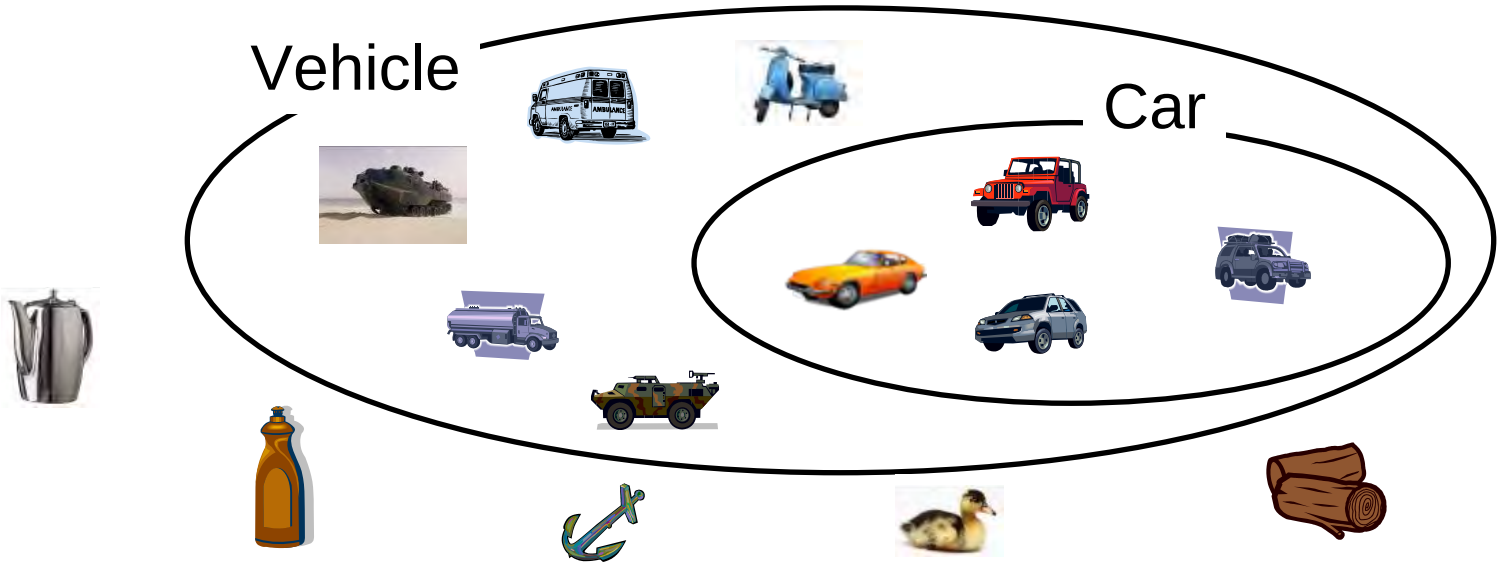
- **In English:**
  - **Sufficient (in) conditions usually have the category at the end**
  - **Necessary (out) conditions usually have the category at the beginning**
- **Any four-wheeled thing over 750kg that carries people with it own power over 100kw is a car. (sufficient / in)**
- **Cars are vehicles. (necessary / out)**
- **Sometimes sufficient conditions are incorrectly read as also necessary.**

In & Out Conditions

- **Conditions can be both sufficient (in) and necessary (out).**
  - Things must meet the condition to be in the category, otherwise they are out, no in-between.
- **Mathematical set descriptors:**
  - { x : density(x) < density(water) }
  - Things less dense than water are in the category (sufficient / in).
  - Things more dense or the same density are not in the category (necessary / out).

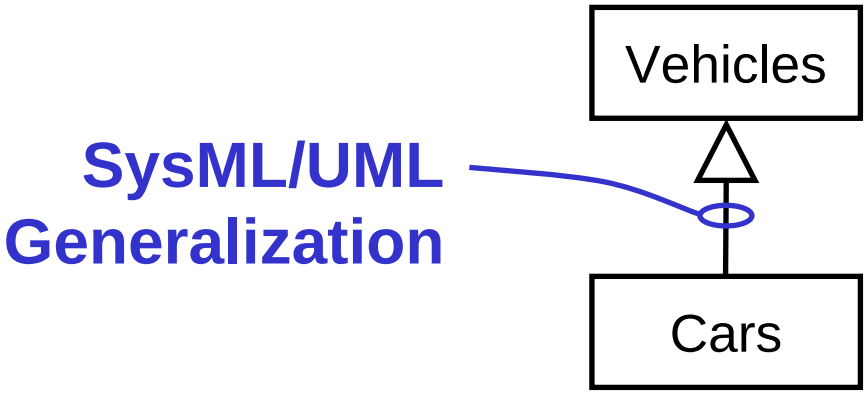
The Most Common Condition

- **Things falling into one category always fall into another.**
  - **Example: Cars are vehicles.**
  - **Cars satisfy the conditions of Vehicles.**
  - **A necessary condition for Cars, a sufficient condition for Vehicles.**



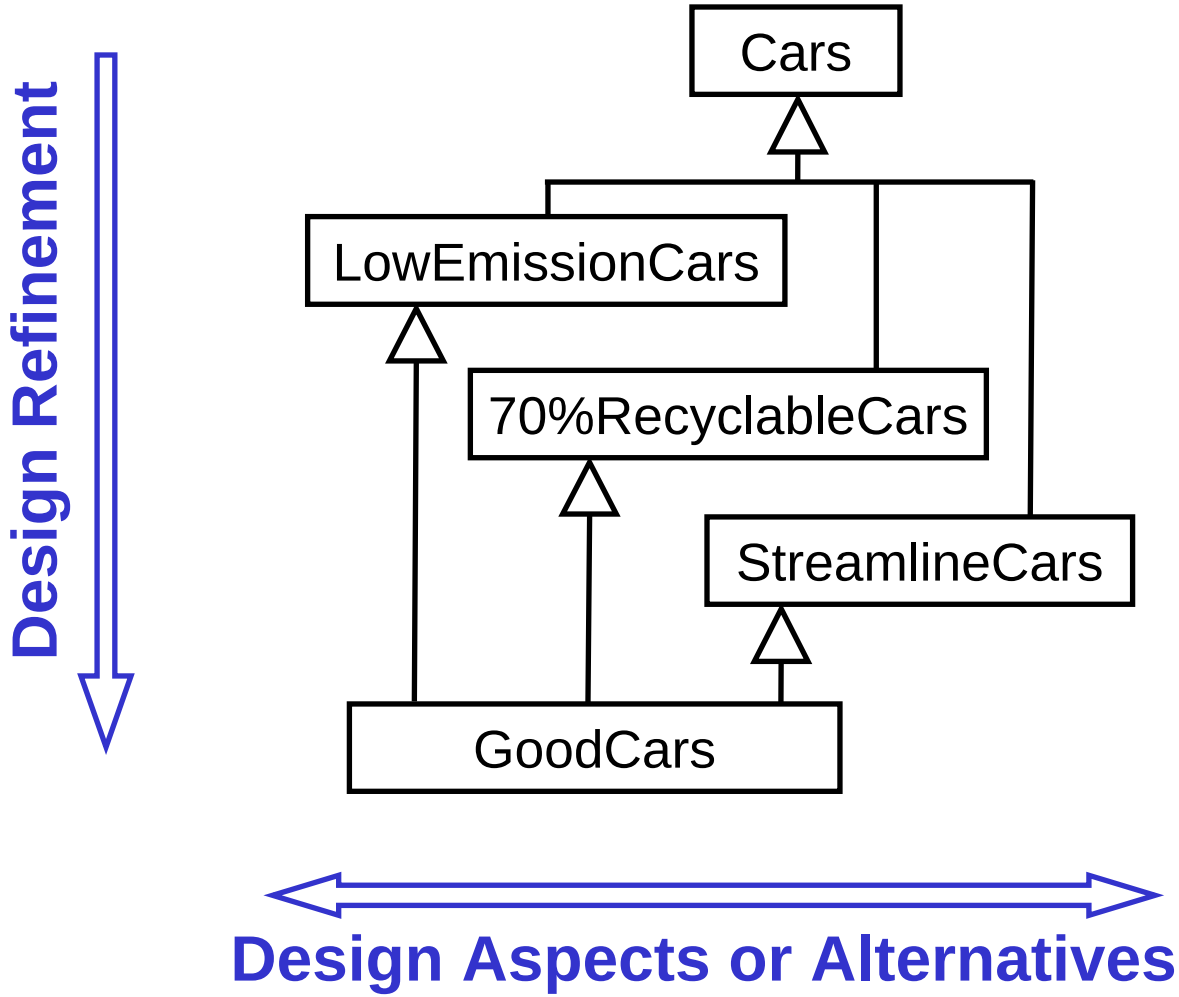
Terminology and Notation

- **The previous condition is so common it is given a name and notation in most languages.**
- **“Generalization” in UML and SysML.**
- **“Subclass” in OWL.**



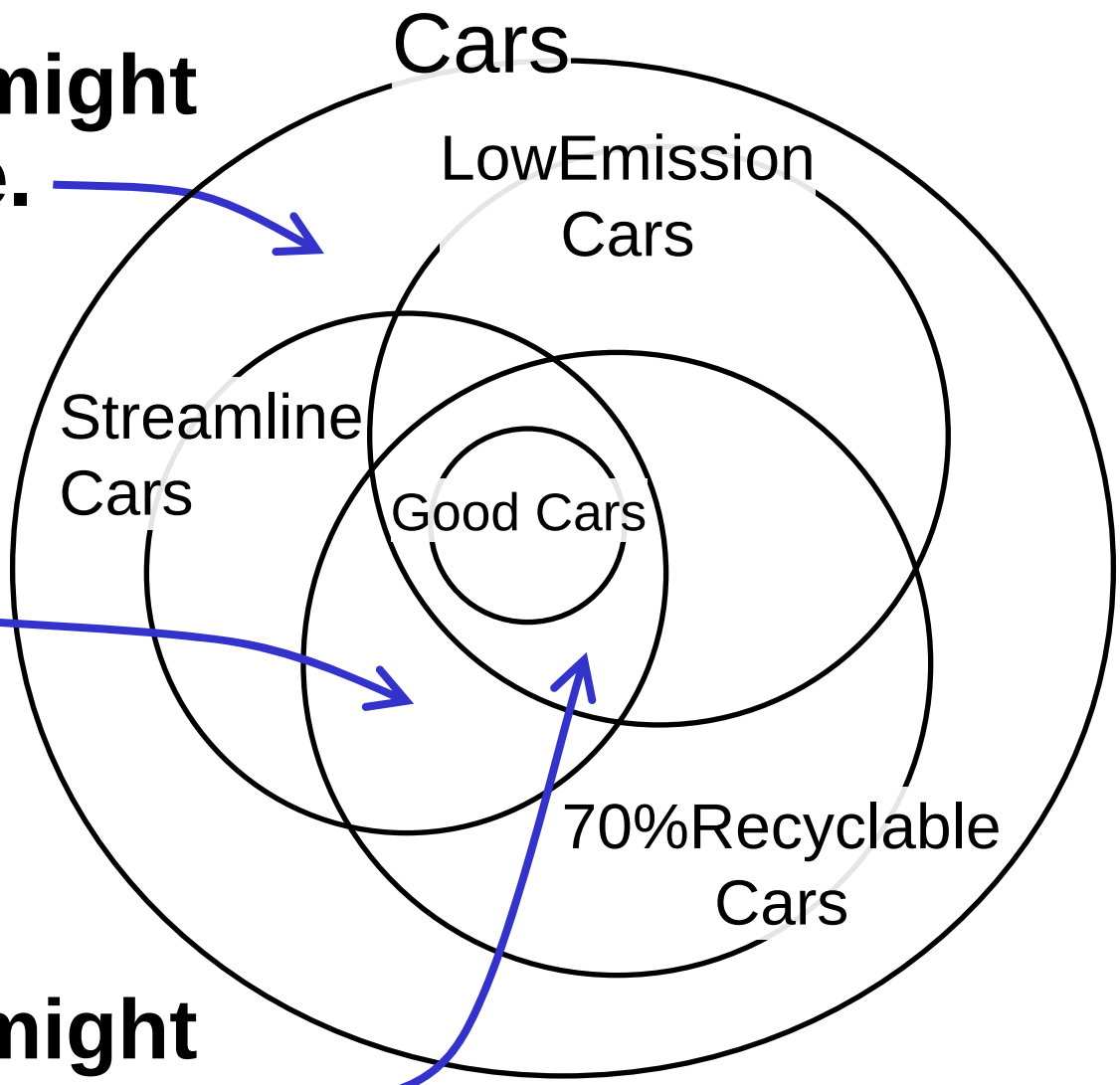
Multiple Generalization

- **Useful for reusing and combining categories.**



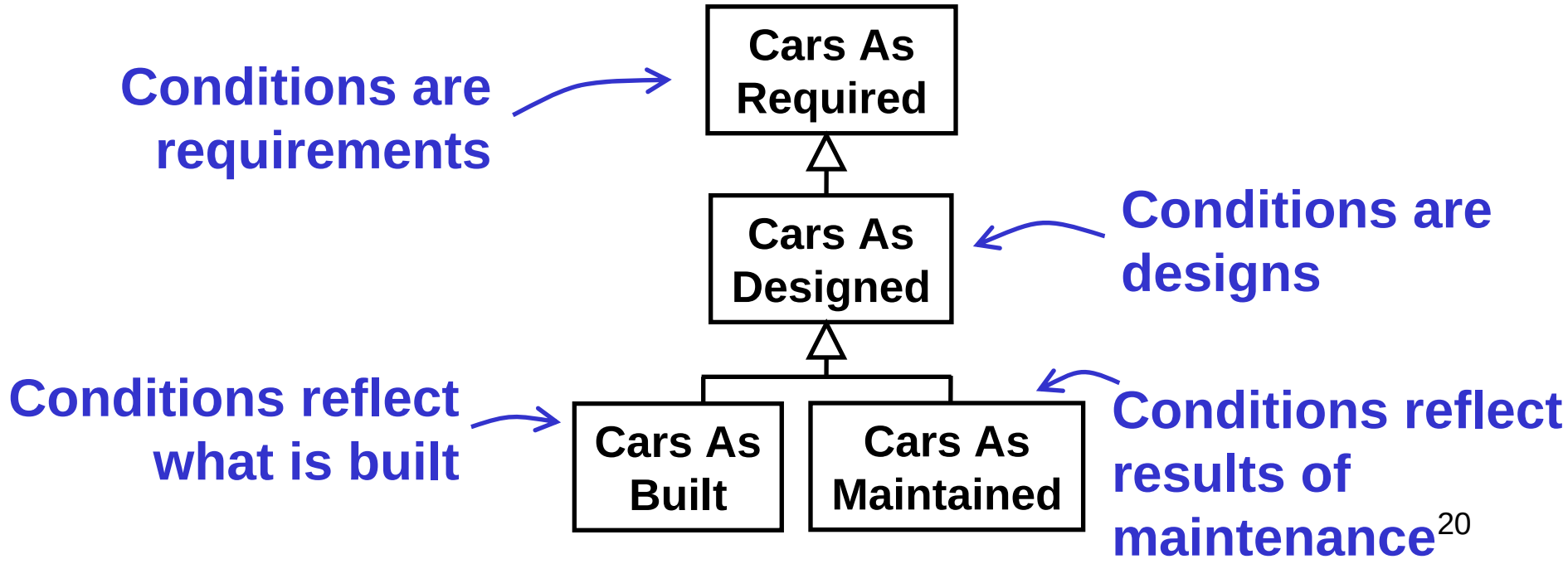
Multiple Generalization Gotchas

- **Subcategories might not be complete.**
- **Subcategories might partially overlap.**
- **Subcategories might not be an intersection.**



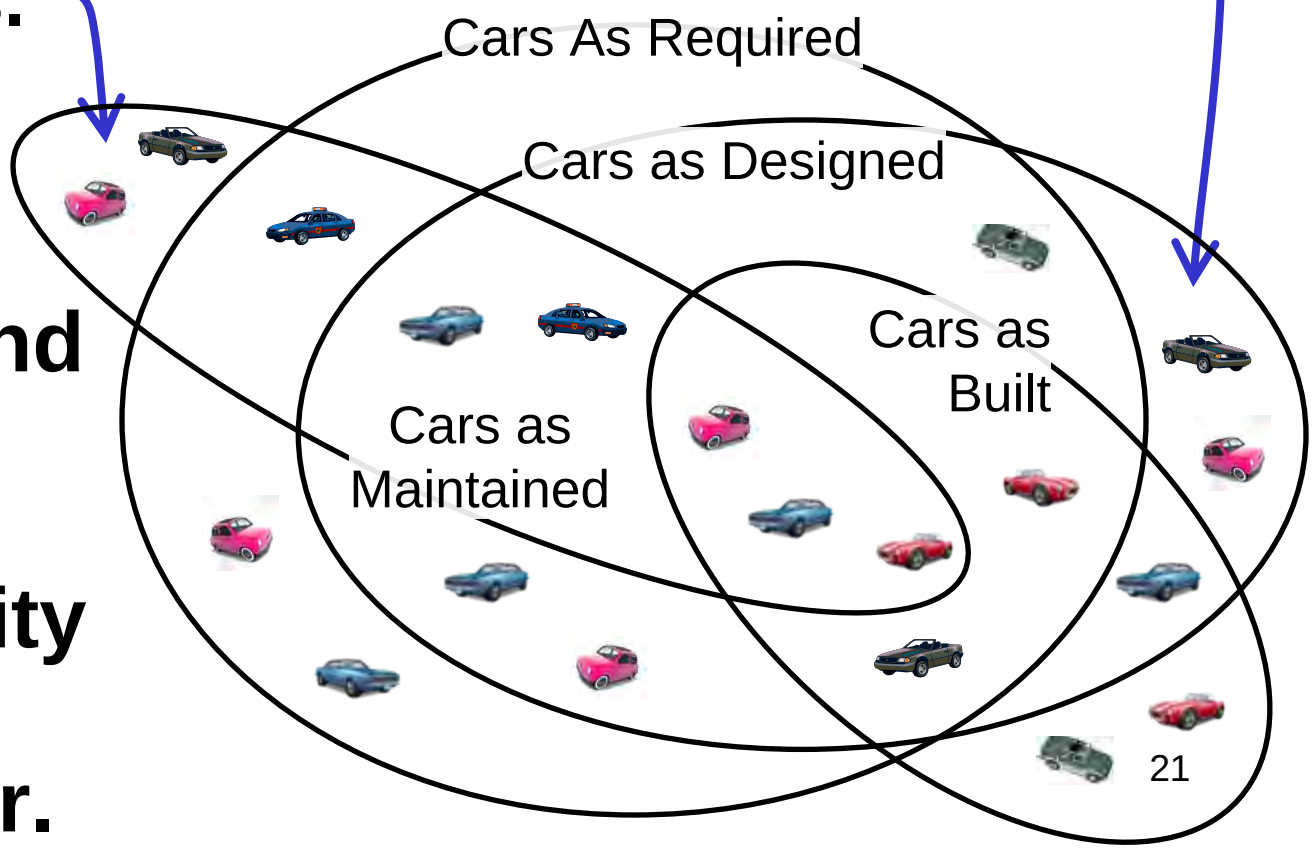
Categories in Product Lifecycles

- **In the ideal world:**
  - **Cars as built and maintained are also cars as designed.**
  - **Cars as designed are also cars meeting requirements.**



Analysis / Reasoning

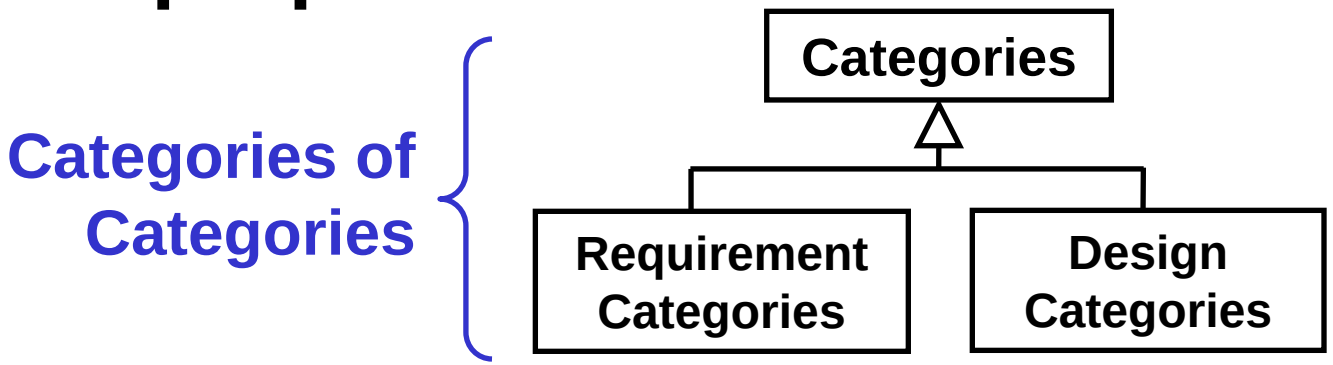
- **In the real world sometimes:**
  - **Designs do not meet requirements.**
  - **Cars are not built or maintained to designs.**

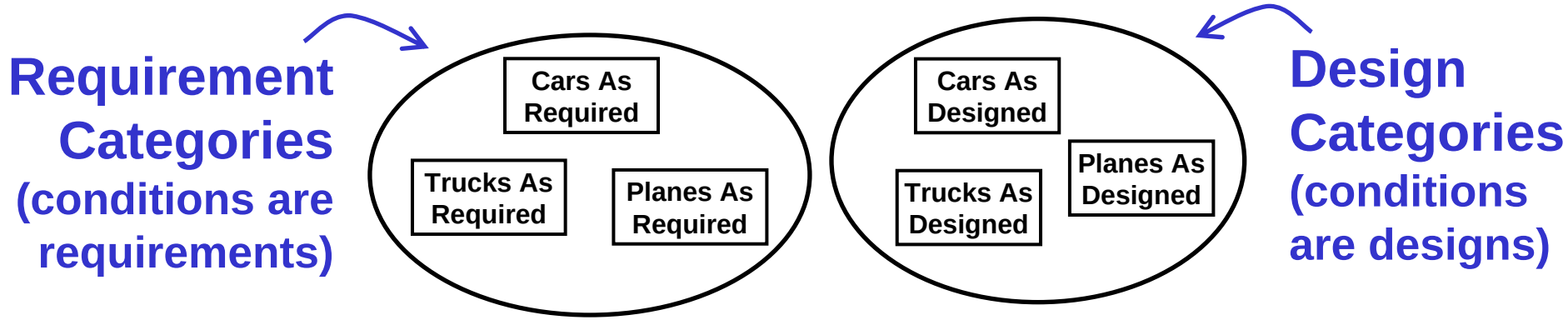


- **Analyzers and reasoners help detect the possibility of these cases earlier.**

Categories of Categories

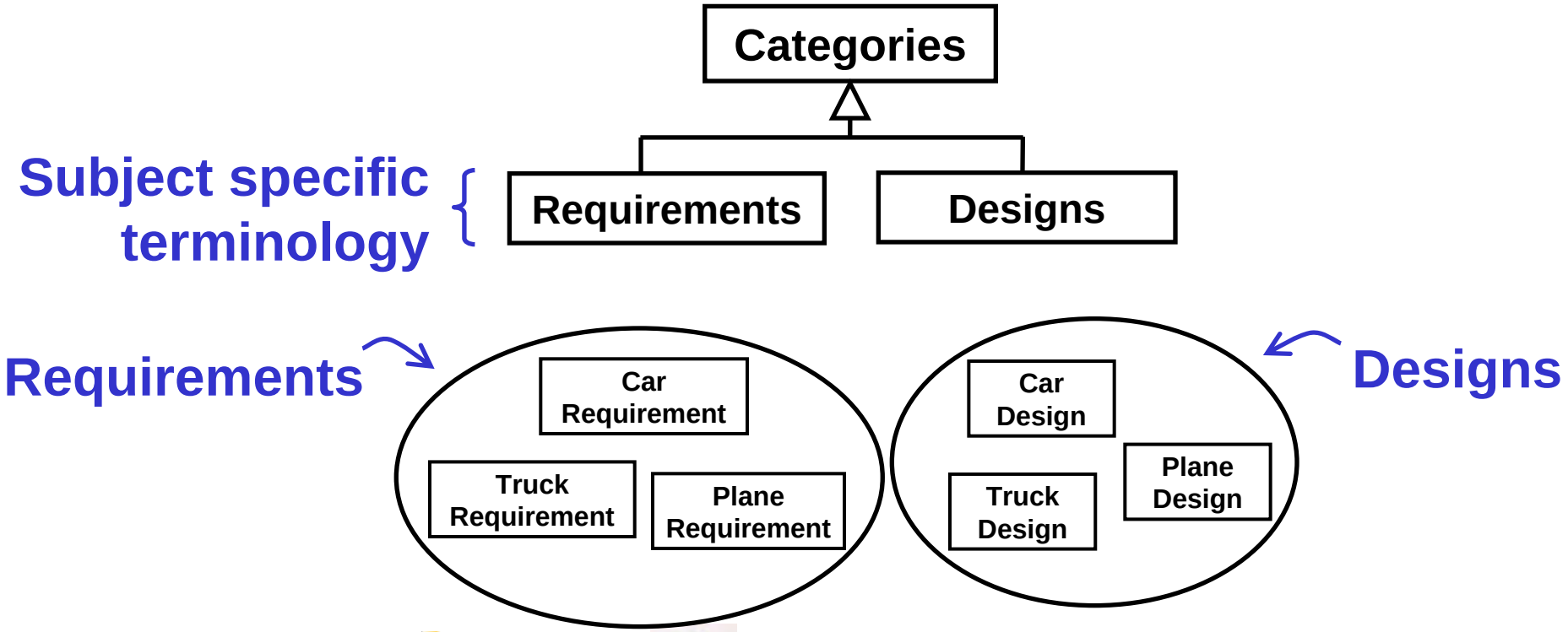
- **Distinguish categories according to purpose.**





Subject-Specific Languages

- **Use terminology of subject matter experts, rather than logic / ontology.**

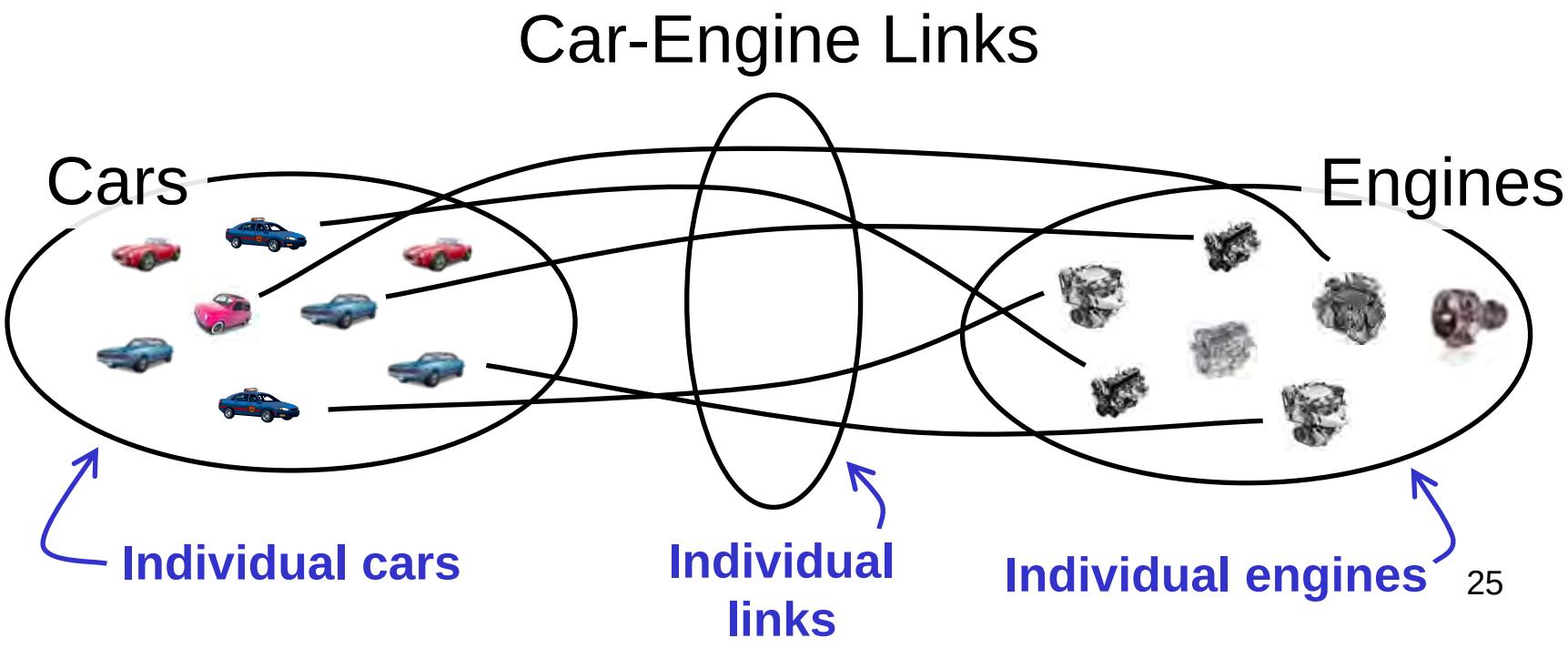


Terminology

- **The terms “categories of categories” and “subject-specific languages” are just for explanation in this presentation.**
- **Other terms:**
  - **“Metaclasses” in UML/SysML (part of “metamodeling”).**
  - **“Domain-specific languages” (common in UML community).**
  - **Not mentioned much in the OWL community, but it is partially supported with “punning”.**

Relations

- **Relations between actual things or categories:**
  - **Cars have engines.**
  - **Designs meet requirements.**

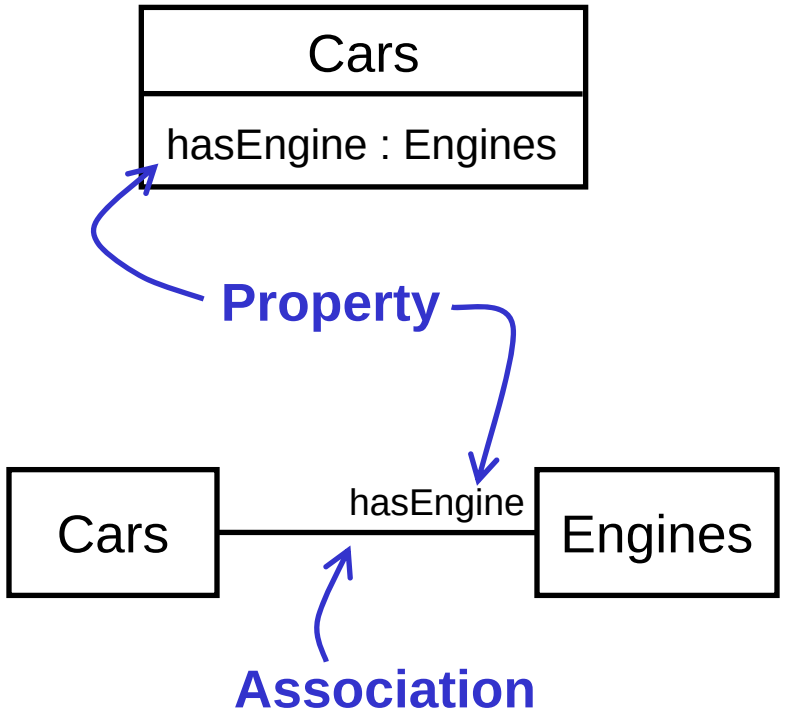


Terminology

- The term “relations” is just for explanation in this presentation.
- Other terms:
  - “Properties” in UML, SysML, and OWL.
  - “Associations” in UML
- Things falling into relation categories:
  - UML / SysML: “Links” (of associations). No term for properties, but properties have “values”.
  - OWL: Elements of set cartesian (cross) products (“pairs”, “tuples”).

Graphical Notation

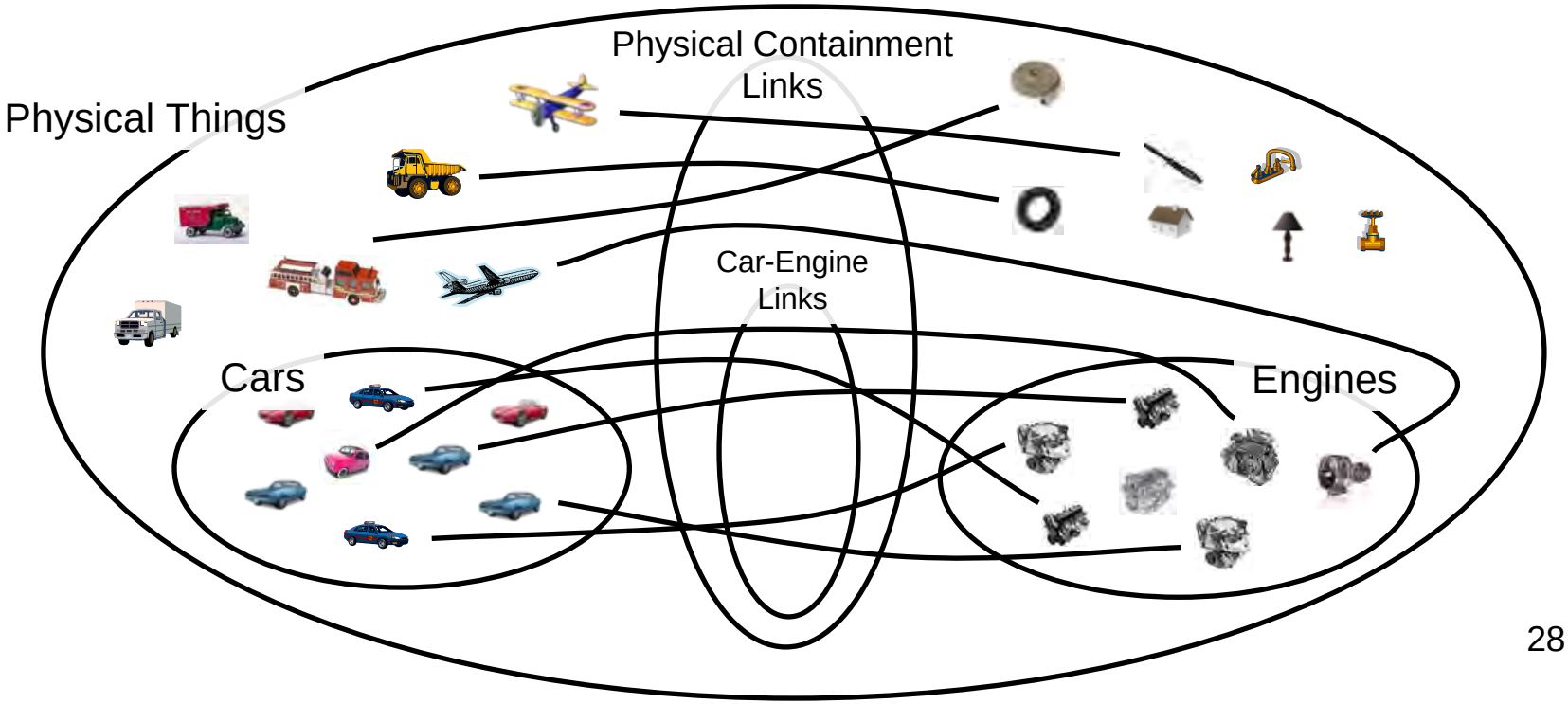
UML & SysML:



SysML applies the «block» stereotype to UML Classes.

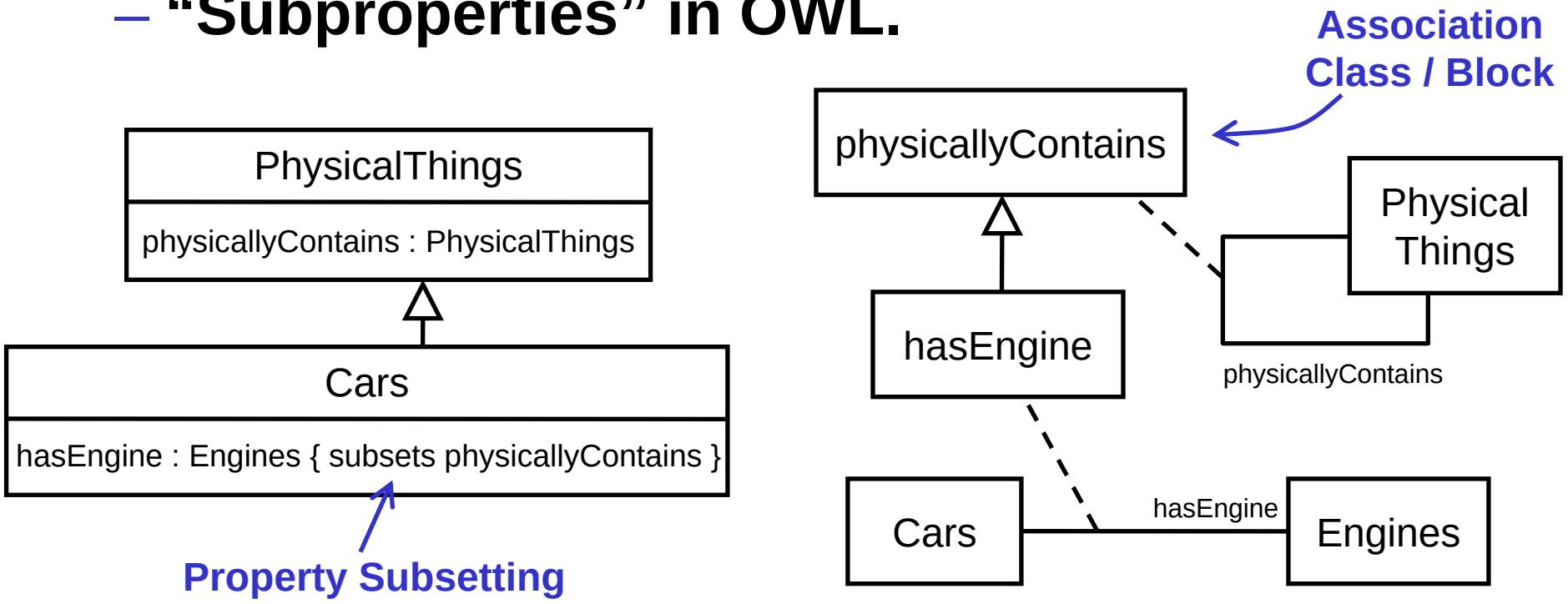
Generalization of Relations

- **Links falling into one relation category always fall into another.**
  - **Example: Car-engine links are physical containment links.**



Terminology and Notation

- **The term “generalization of relations” is just for explanation in this presentation.**
- **Other terms:**
  - **“Property Subsetting” or “Association Generalization” in UML and SysML.**
  - **“Subproperties” in OWL.**



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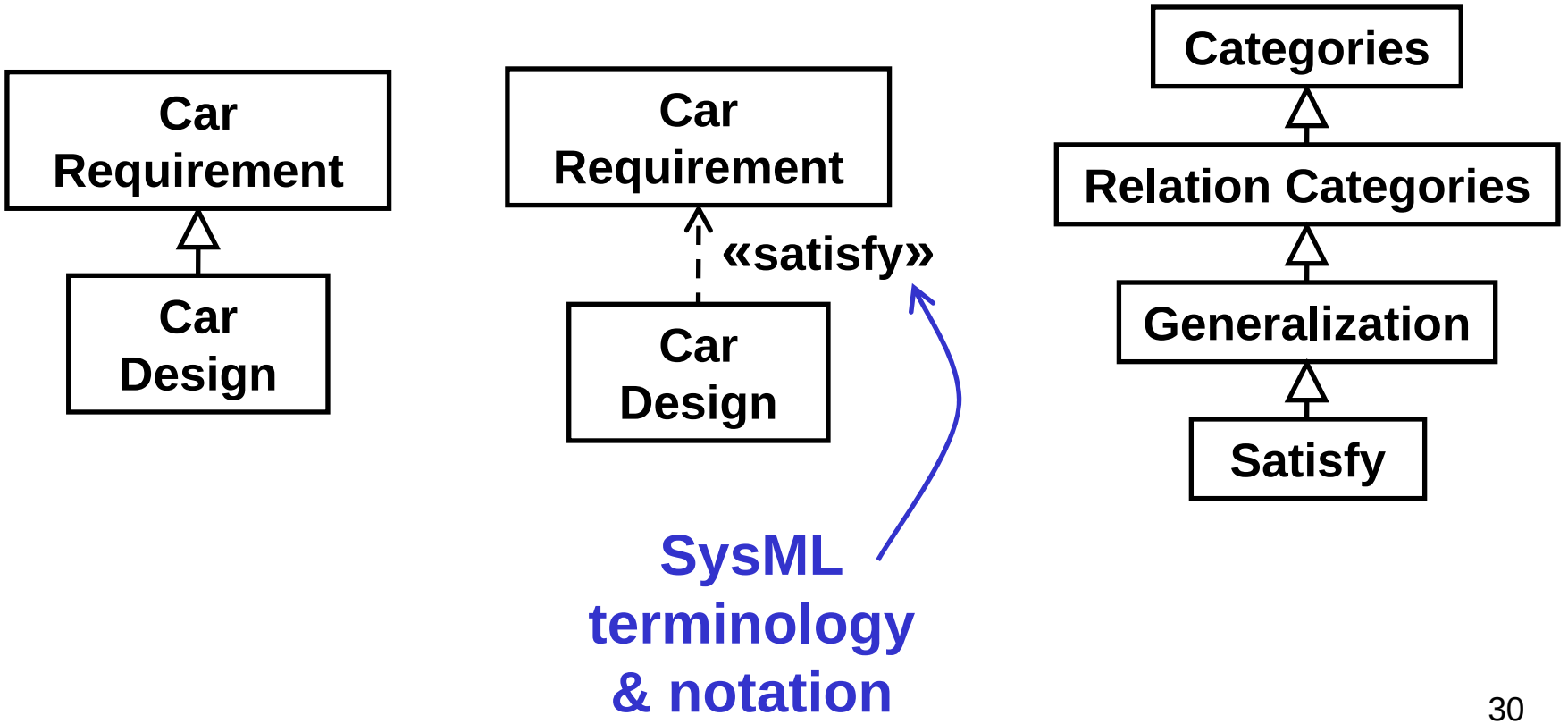
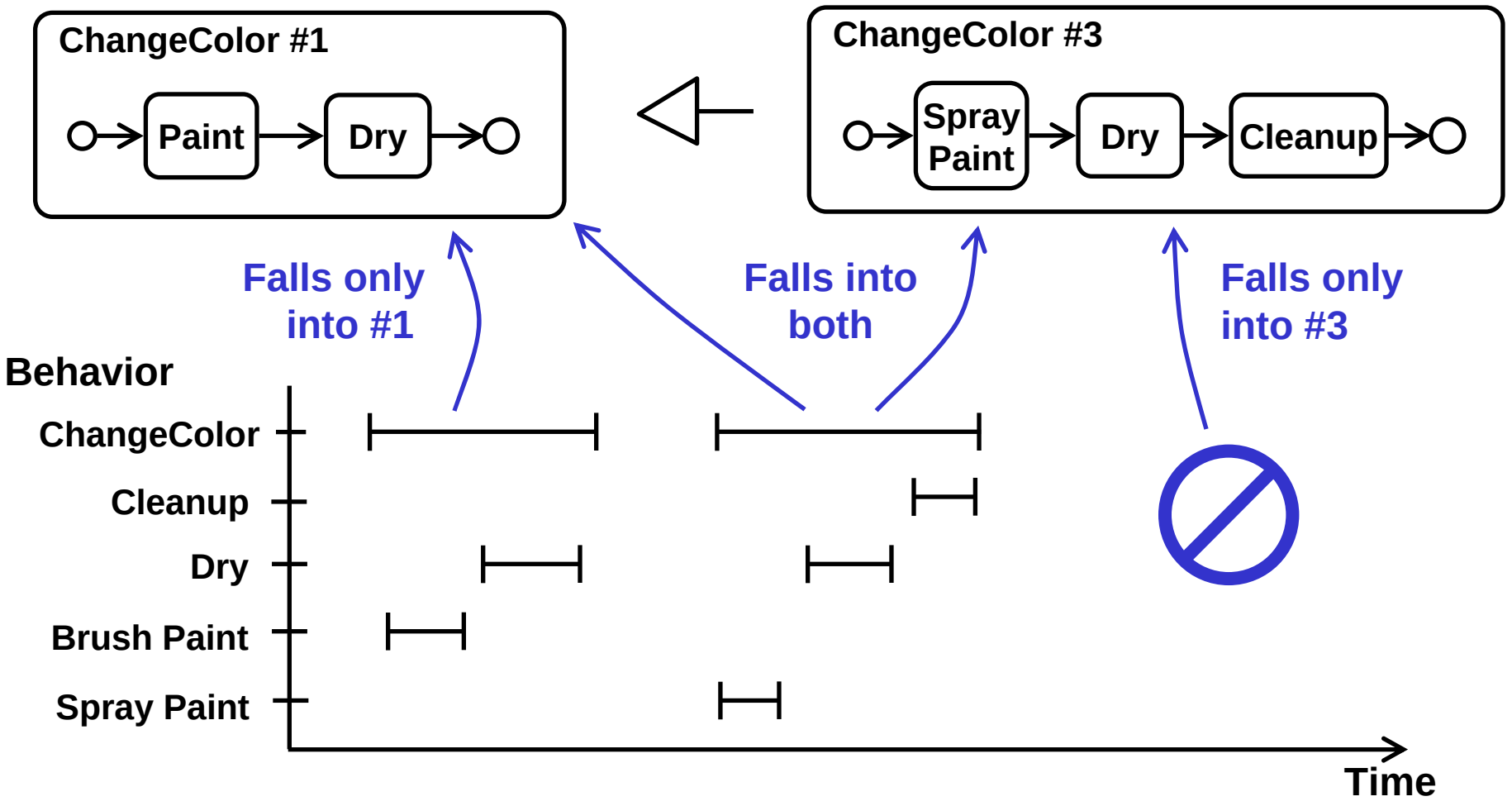


Other Logical Constructs

UML/SysML	OWL
Property / Association Multiplicity	Property Cardinality
Property Redefinition	Property Restriction
UML Composite Structure, SysML Internal Block Diagram	Role Composition
SysML Association Participant Properties and Internal Block Connector Properties	

Logical Process Modeling

- **Categorizing occurrences.**



Summary

- Logical modeling is about categories.
- Categories = conditions specifying sets.
  - Independent of things falling into them.
  - In/out (sufficient/necessary) conditions.
  - Common condition: Generalization.
- Relation as categories of links.
- Categories of categories to define subject-specific languages.
- Various terminologies and notations.
- Applicable to product and process modeling.

References

- **UML: http://omg.org/spec/UML**
- **SysML: http://omg.org/spec/SysML**
  - **1.3: http://doc.omg.org/ptc/2011-08-09**
- **OWL: http://w3.org/TR/owl2-overview**
- **"Ontological Product Modeling for Collaborative Design," Bock, Zha, Suh, Lee, Advanced Engineering Informatics, 24:4, pp510-524, 2010, http://nist.gov/manuscript-publication-search.cfm?pub_id=822748.**
- **"Ontological Behavior Modeling," Bock, Odell, Journal of Object Technology, 10:3, pp1-36, 2011, http://www.jot.fm/contents/issue_2011_01/article3.html.**
- **Other material: conrad dot bock at nist dot gov.**