4D Composite Structure:
(Onto) Logical 4D Modeling

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Overview

- RoadMap
- Motivation
  - Behavior, review
  - 4D, requirements
- 4D Solution

  Objects and behaviors

  1. in space-time
  2. within time intervals, space regions
- Summary

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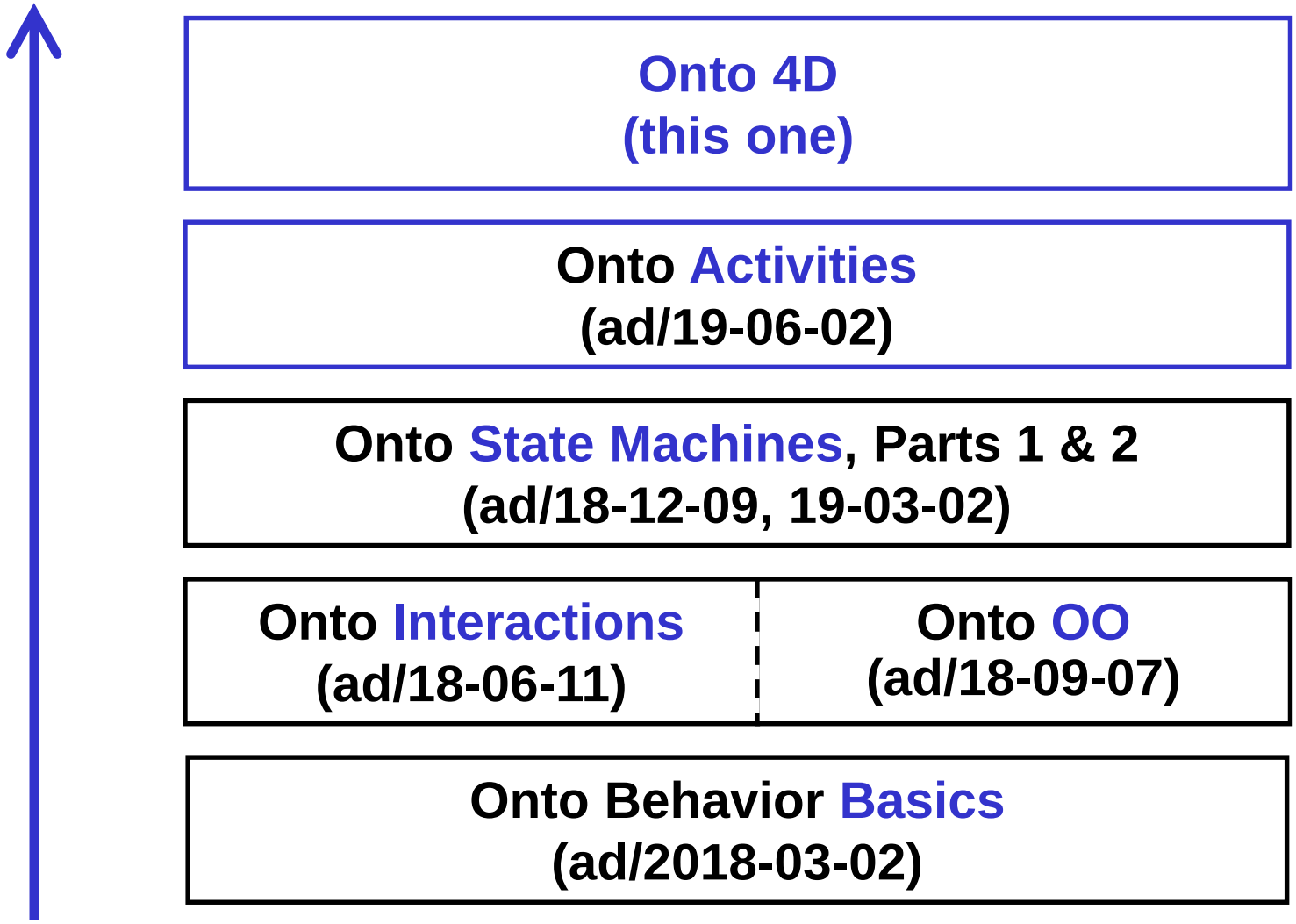
Behavior as Composite Structure



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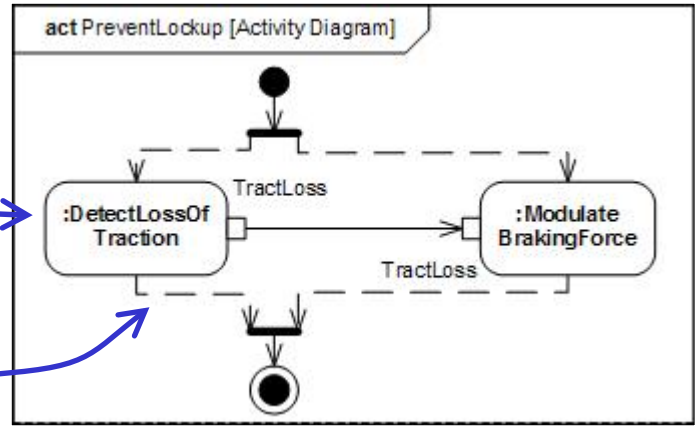
Original Problem

- **UML has three behavior diagrams.**
  - **Activity, state, interaction.**
- **Very little integration or reuse between them.**
  - **Three underlying metamodels.**
  - **Three representations of temporal order.**
- **Triples the effort of learning UML and building analysis tools for it.**

General Solution

- **Treat behaviors as assemblies of other behaviors.**
  - **Like objects are assemblies of other objects.**
- **Assembly = UML internal structure**
  - **Pieces represented by properties.**
  - **Put together by connectors.**
- **Put all behavior diagrams on the same underlying behavior assembly model.**

Behaviors as Composite Structure

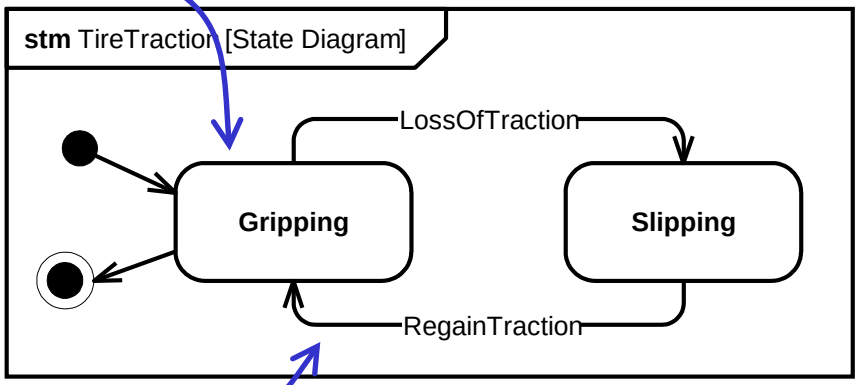


Property

Connector

Activity

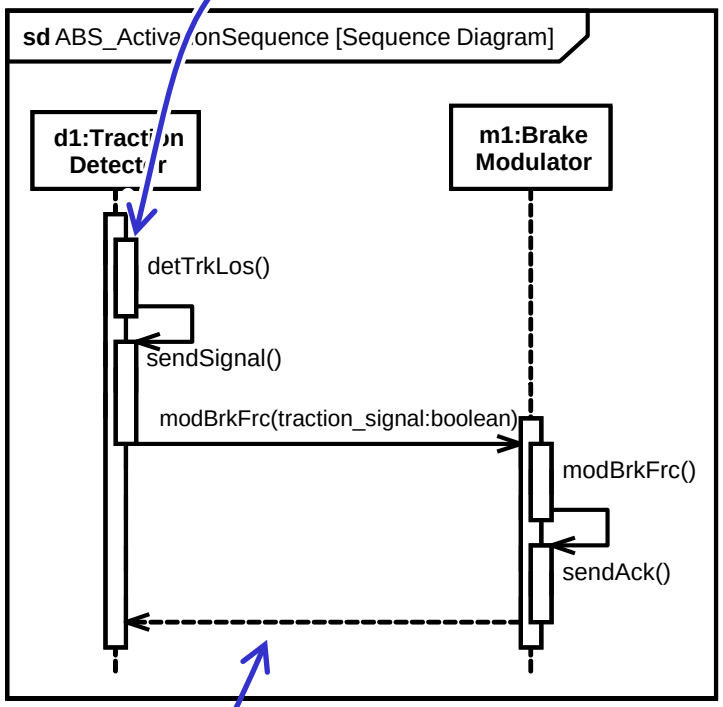
Property



Connector

State Machine

Property

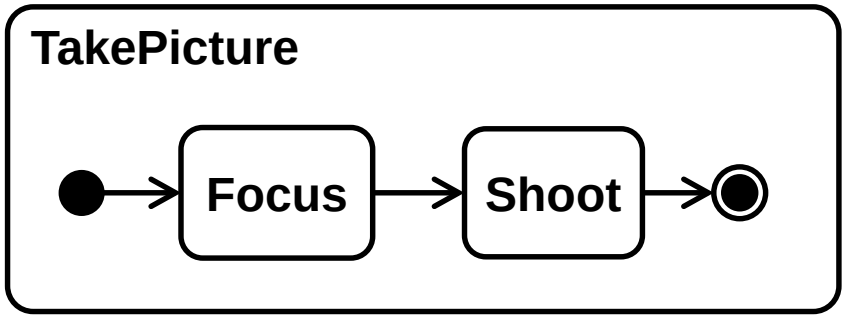


Connector

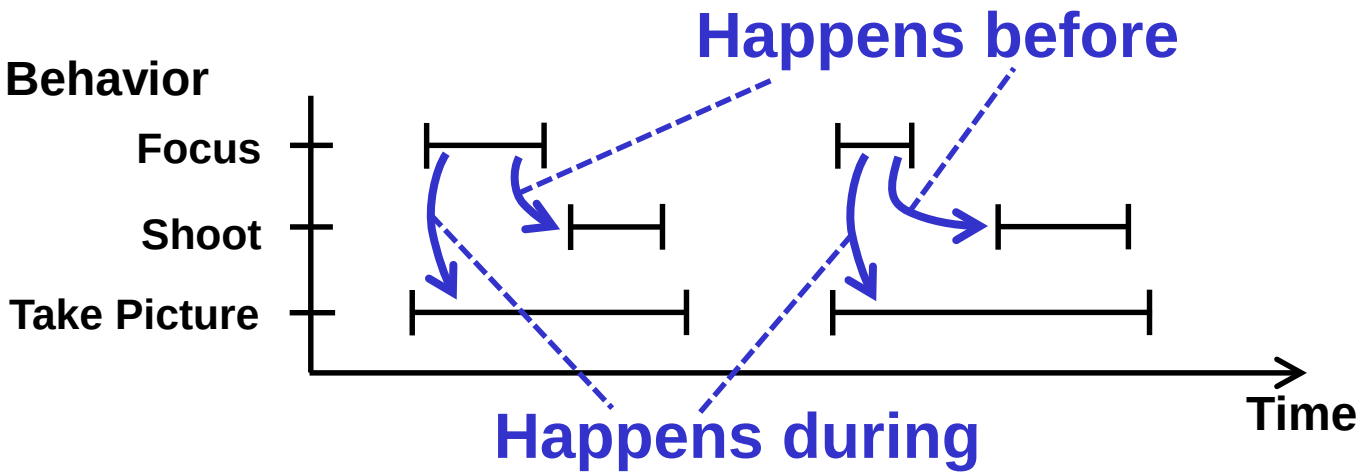
Interaction

Behavior as Timing Constraints

Model
(M1)



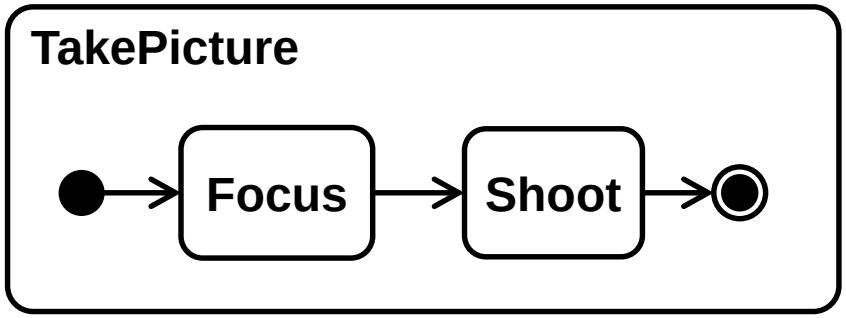
Things
Being
Modeled
(M0)



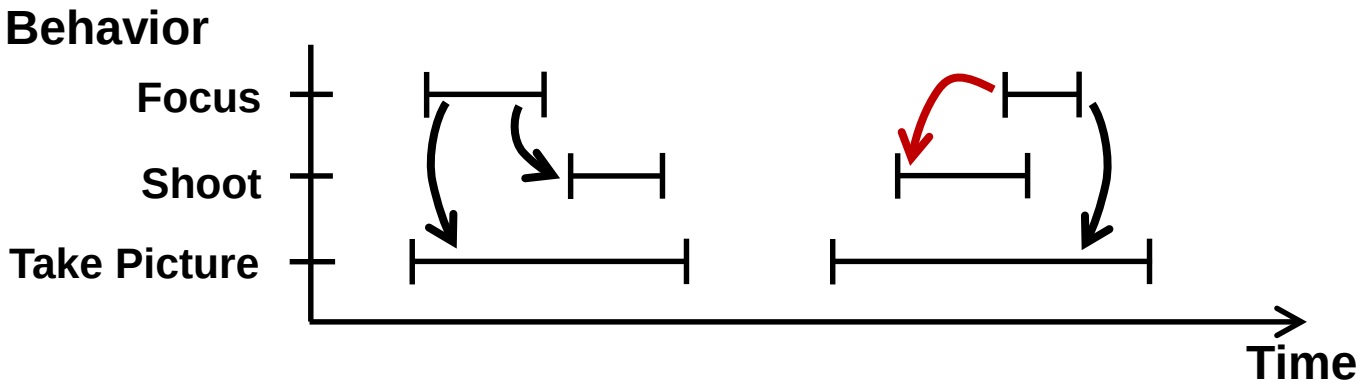
- **Behaviors model "things" happening over time.**
  - **With temporal relations (time constraints) between them.**

Behavior as Timing Constraints

Model
(M1)

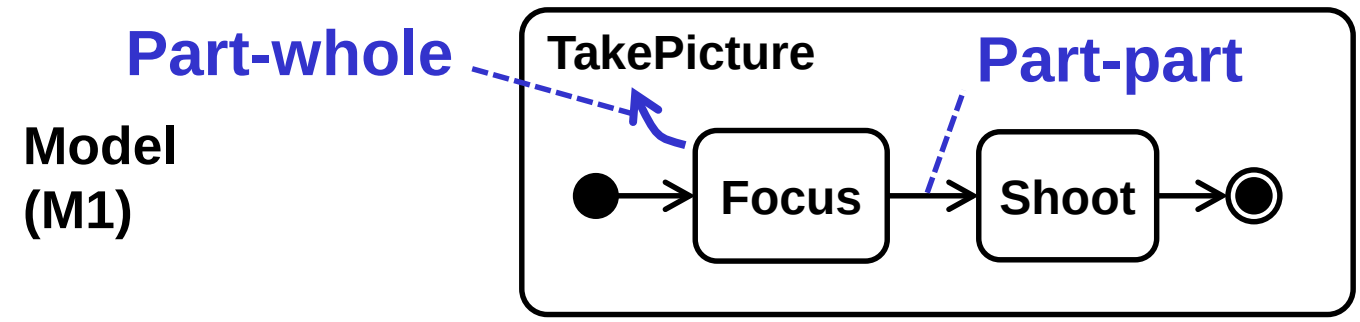


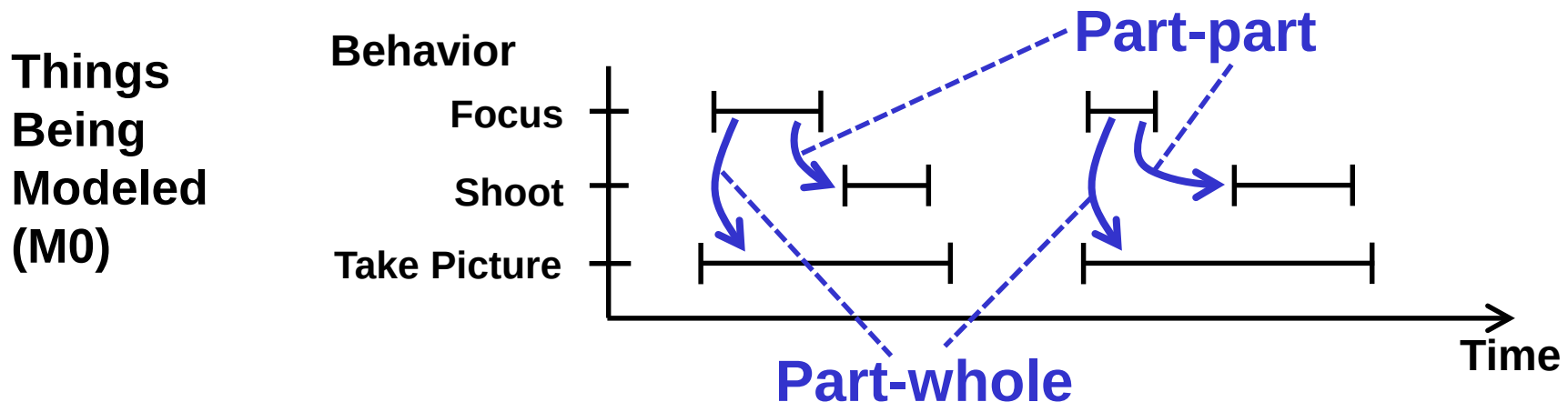
Things
Being
Modeled
(M0)



- The TakePicture occurrence on the right does not follow the behavior model.

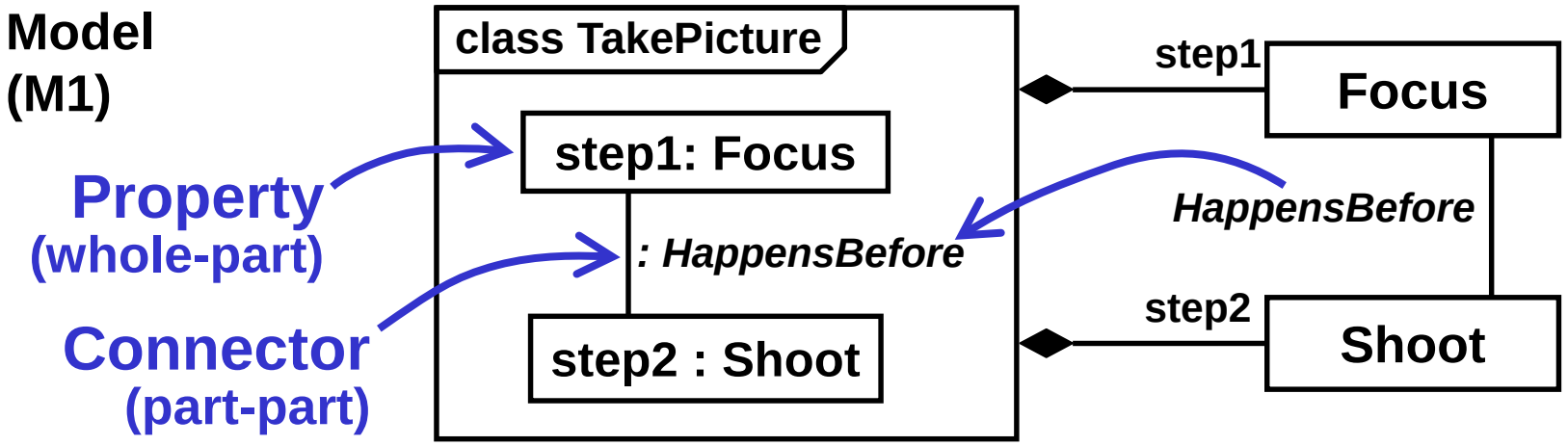
Behavior as “Composite Timing”

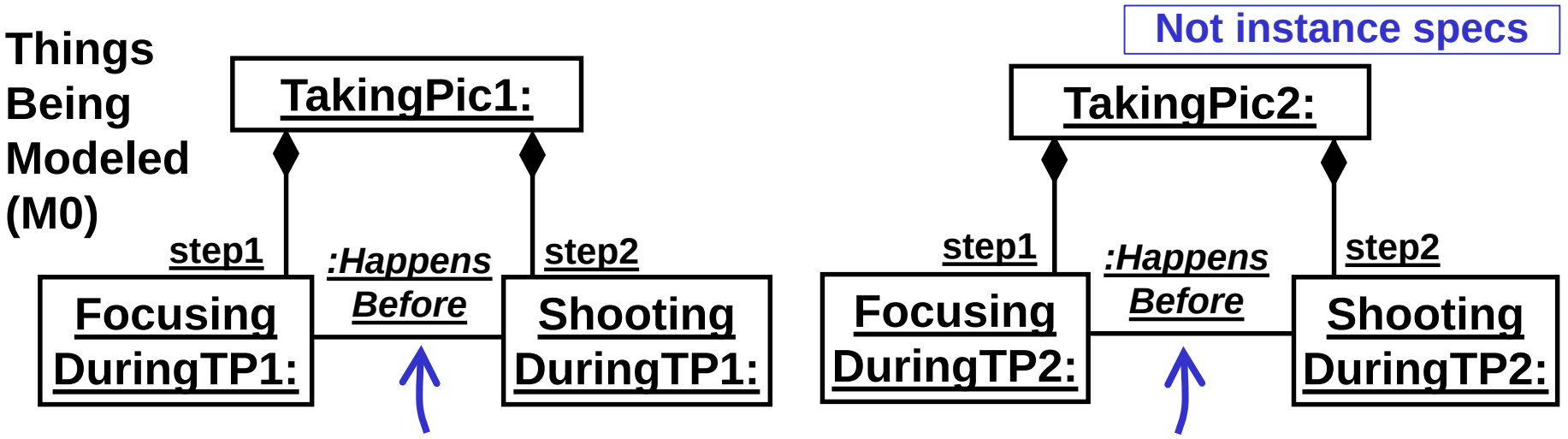




- **Composite structure relations are temporal:**
  - **Part-whole = happens during.**
  - **Part-part = happens before.**

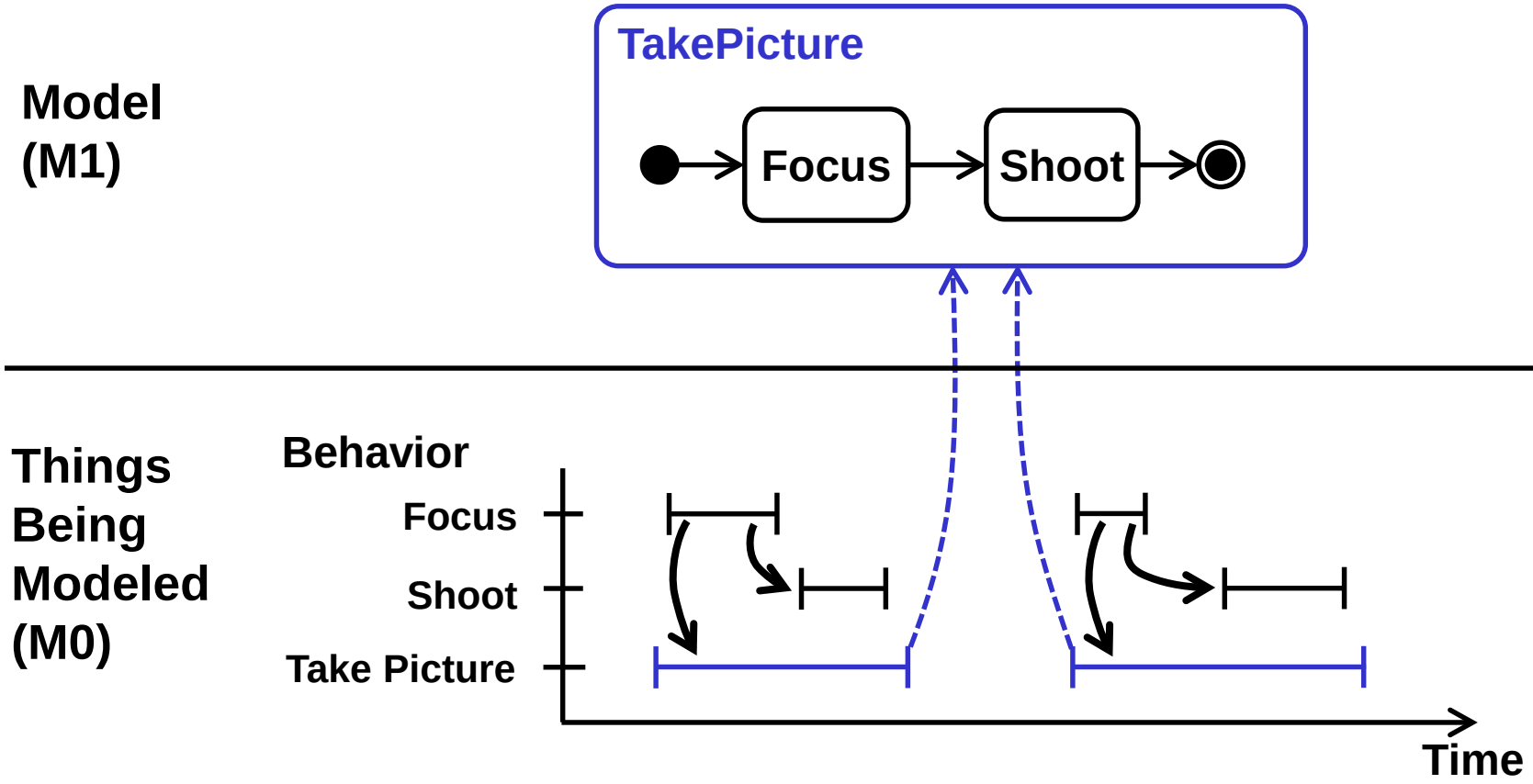
Behavior as “Composite Timing”





Focusing before shooting in same taking picture

Model and Things Being Modeled



- **Dashed arrows between M1 and M0 mean ....**

M0 → M1 Synonyms

Classified by

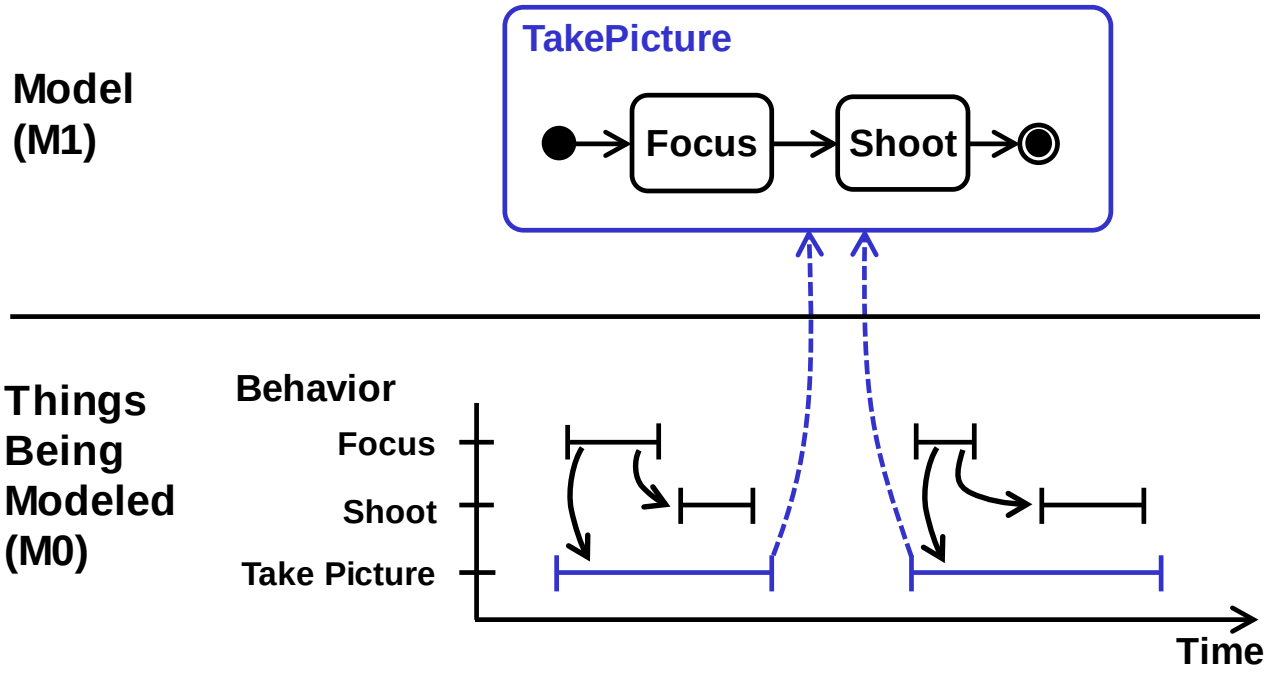
Modeled by

Specified by

Conforms to

Follows

Satisfies (logically)



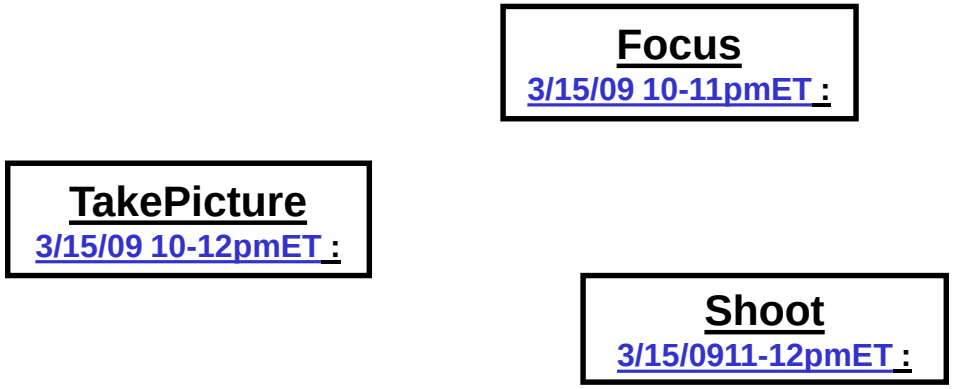
Not quite: Instance of (in the OO sense)

Not *at all* : Execution of (in the software sense)

Behavior: What's Being Modeled?

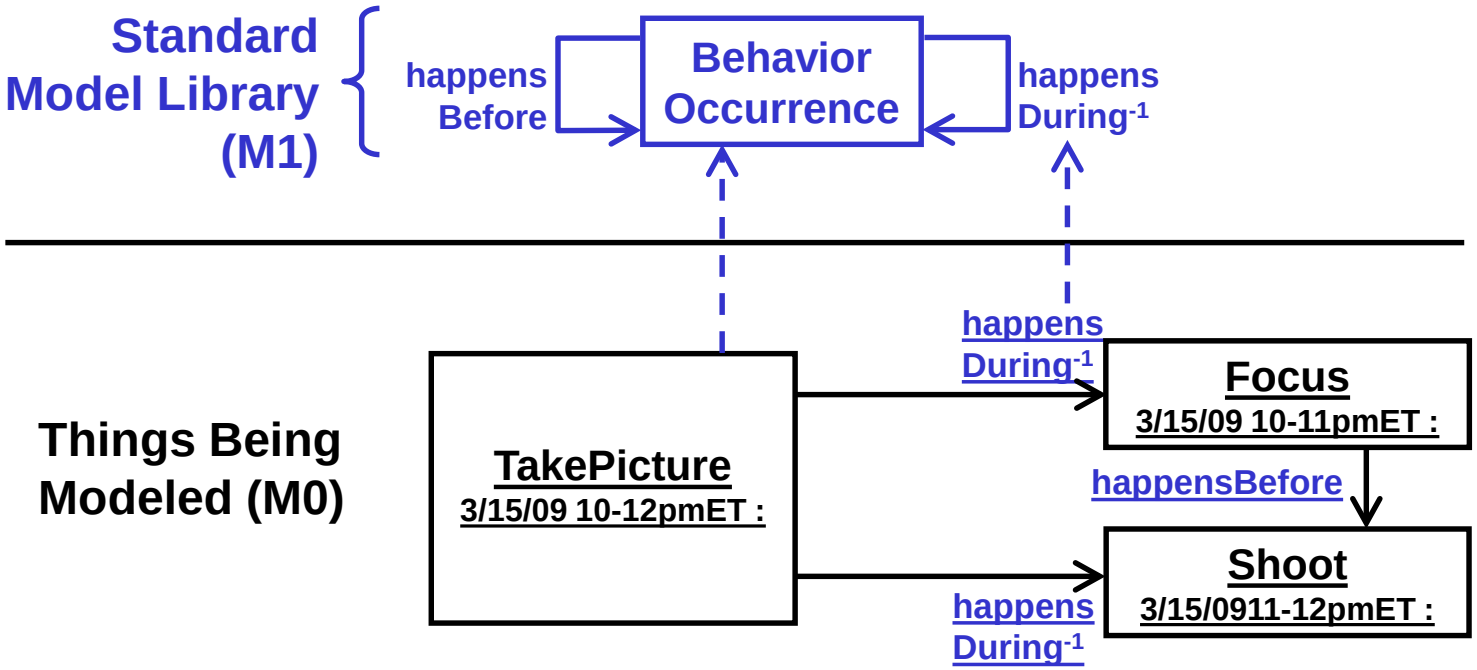
Real, Simulated, or Desired Things Being Modeled (M0)

Not instance specs.



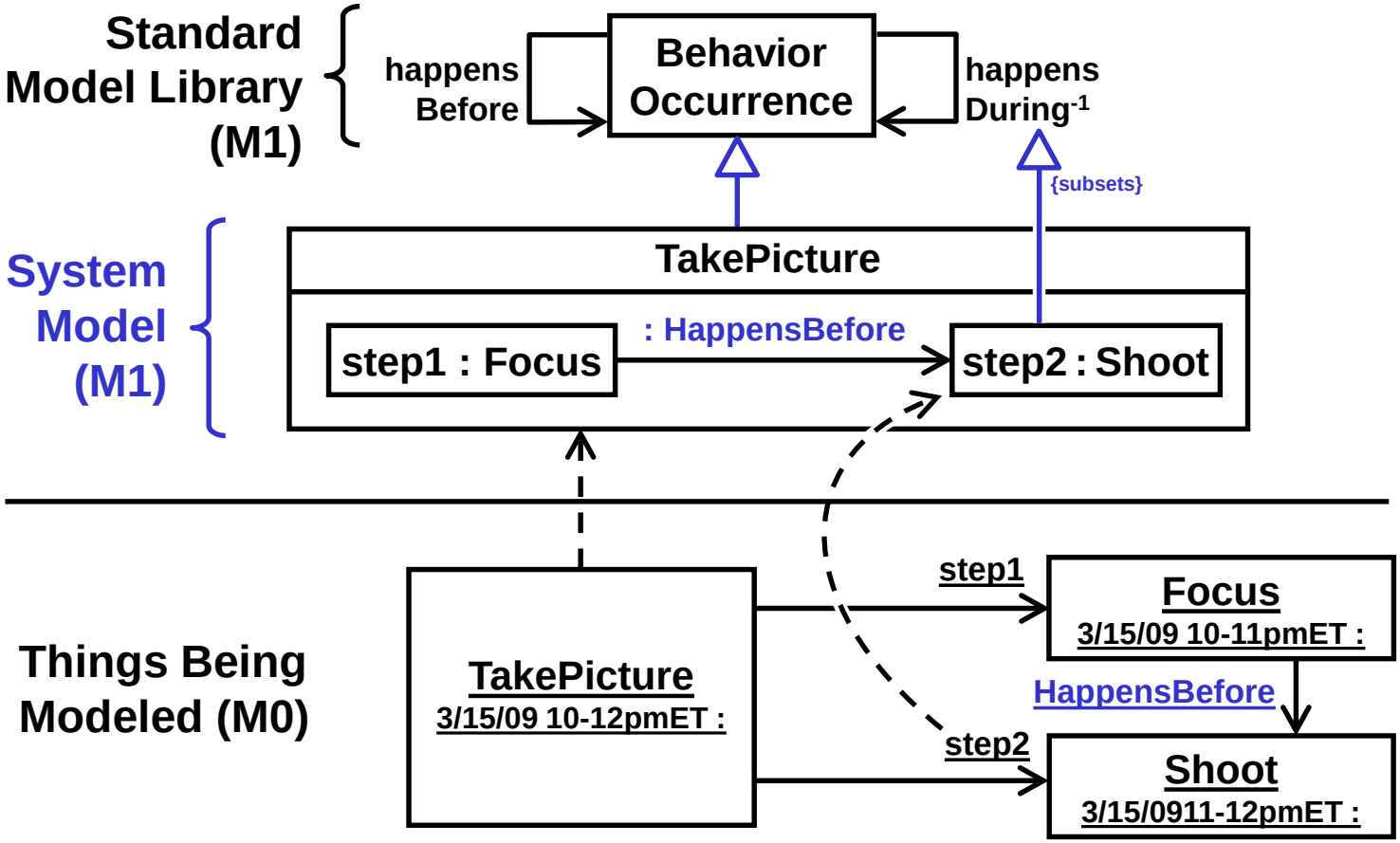
- **"Things" that occur in time**
  - **Eg, taking a picture, focusing, etc.**
  - **Not "behaviors", "actions", etc.**

Behavior: What's in Common?



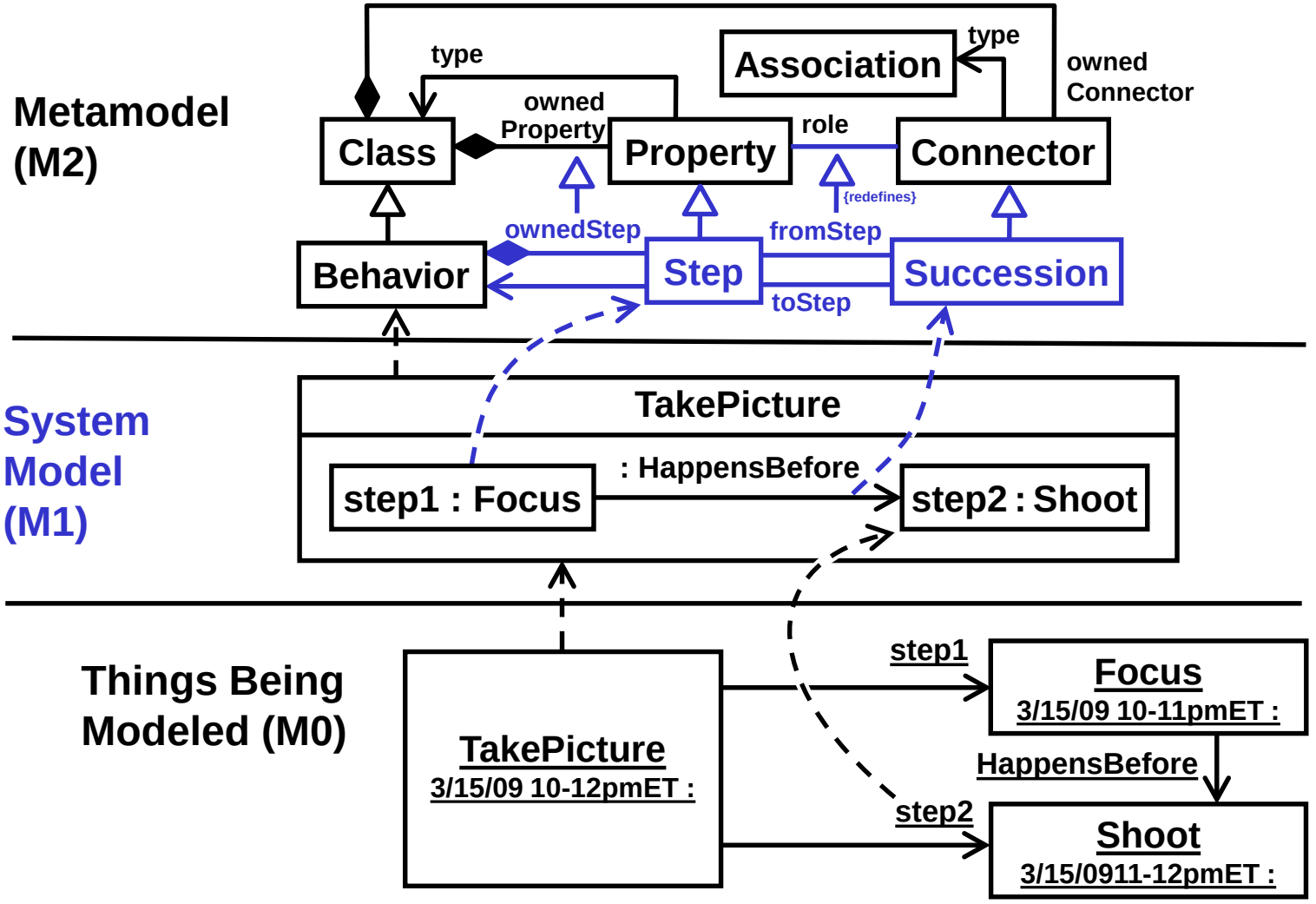
- They happen before or during each other.
  - Construct M1 library for this.
  - Use it to classify things being modeled.

Behavior: Use Library



- **Specialize library classes and subset/redefine library properties.**

Behavior: Too repetitive at M1?

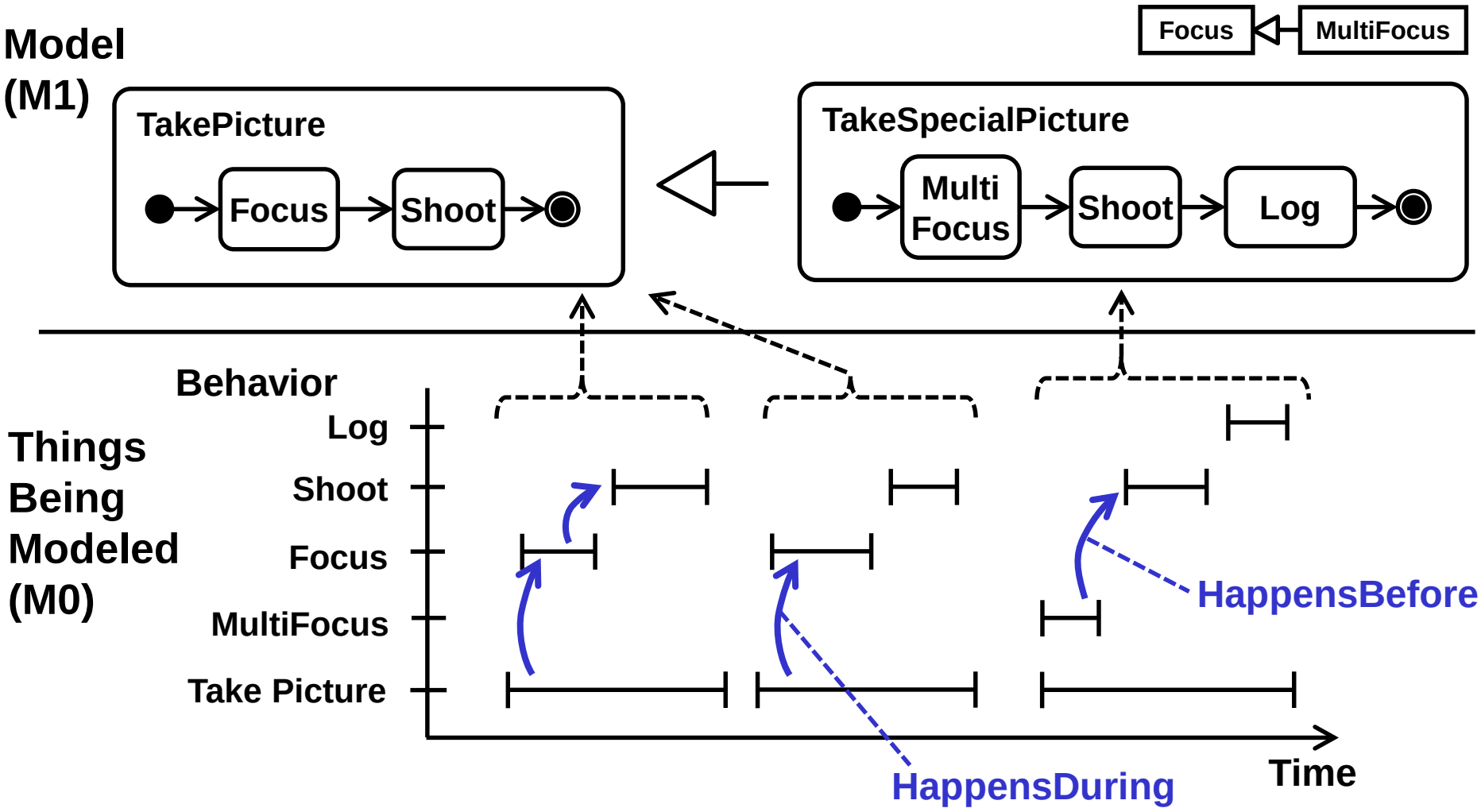


- **Capture M1 patterns in M2 elements.**
  - **Tools apply patterns automatically.**

Benefits: Original Problem

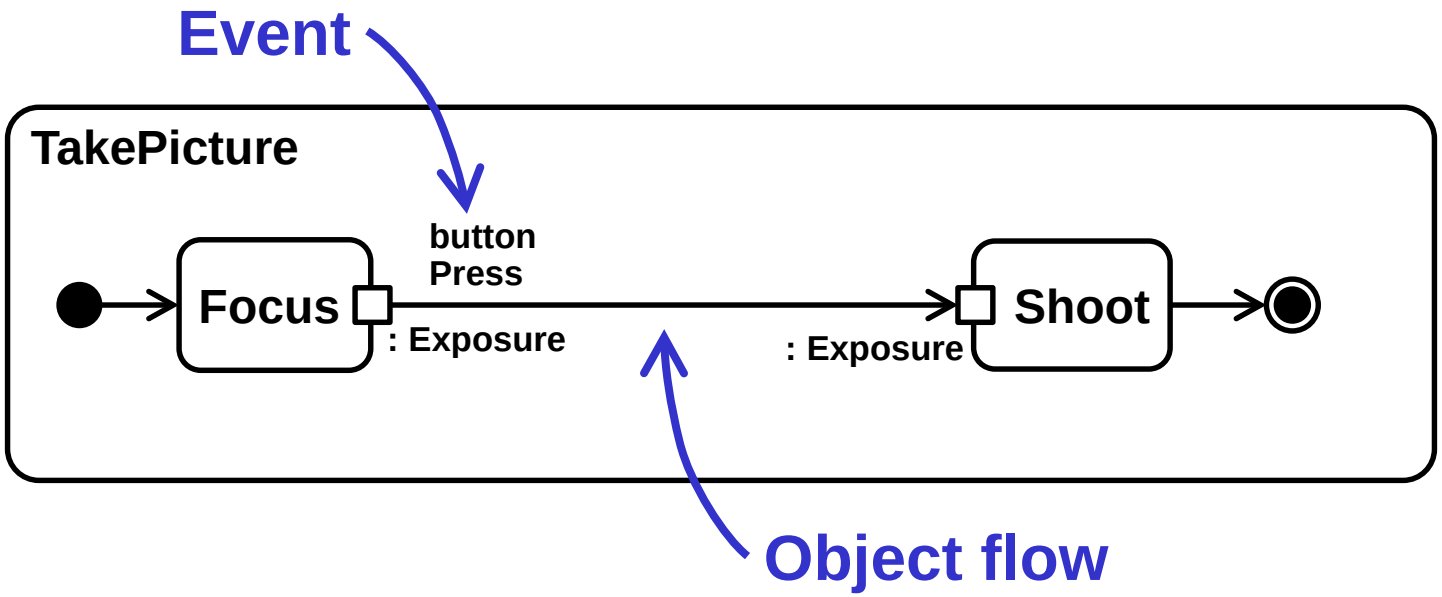
- **Flexibility in using metamodels**
  - **Add metaelements as needed to simplify library usage.**
- **Many metaelements become synonyms**
  - **Application / method / diagram-specific terminology sharing same semantics.**
  - **M2 actions, states, etc, => M1 happensDuring**
- **Learning UML and building analysis tools for it is easier**
  - **Due to shared semantics for variety of modeling language terminology.**

Benefits: Expressiveness



- **Constraints are inherited in UML**
  - **including temporal constraints.**

Benefits: Expressiveness



- **Combine activity and state machines.**
  - **States and actions happen during their "containing" occurrences, ordered in time.**

Benefits: Modeled Semantics

- **UML semantics is written in free text**
  - **Specifying an execution procedure for activities and state machines:**

> Tokens are *offered* to an ActivityEdge by the source ActivityNode of the edge. Offers propagate through ActivityEdges and ControlNodes, according to the rules associated with ActivityEdges (see below) and each kind of ControlNode (see sub clause 15.3) until they reach an ObjectNode (for object tokens) or an ExecutableNode (for control tokens and some object tokens as specified by modelers, see ObjectNodes in sub clause 15.4). Each kind of ObjectNode (see sub clause 15.4) an
> *accepte*
> Activity
> which a

> The processing of Event occurrences by a StateMachine execution conforms to the general semantics defined in Clause 13. Upon creation, a StateMachine will perform its initialization during which it executes an initial compound transition prompted by the creation, after which it enters a *wait point*. In case of StateMachine Behaviors, a wait point is represented by a stable state configuration. It remains thus until an Event stored in its event pool is dispatched. This Event is evaluated and, if it matches a valid Trigger of the StateMachine and there is at least one enabled Transition that can be triggered by that Event occurrence, a single StateMachine *step* is executed. A step involves executing a compound transition and terminating on a stable state configuration (i.e., the next wait point). This cycle then repeats until either the StateMachine completes its Behavior or until it is asynchronously terminated by some external agent.

  - **and trace classification in interactions:**

> Clause 13, Common Behaviors, describes the general semantics of the execution of Behaviors. Interactions are kinds of Behaviors that model emergent behaviors, as defined in sub clause 13.1. As discussed in sub clause 13.2.3, the execution of a Behavior results in an execution trace. Such a trace is a sequence of event occurrences, which, in this clause, will be denoted <e1, e2, . . . , en>. Each event occurrence may also include information about the values of all relevant objects at the point of time of its occurrence.
> The semantics of an Interaction are expressed in terms of a pair [P, I], where P is the set of valid traces and I is the set of invalid traces. P ! I need not be the whole universe of traces. Two Interactions are equivalent if their pairs of trace-sets are equal. The semantics of each construct of an Interaction (such as the various kinds of CombinedFragments) are

- **Model in standard libraries.**

Benefits: Classification Semantics

- **Standard execution models for UML (fUML, etc)**
  - **Procedures that create a behavior occurrence**
    - **Conforming to a UML model.**
  - **Don't tell whether**
    - **An existing behavior occurrence conforms.**
    - **Tools are producing correct occurrences**
- **Classification does the opposite**
  - **Tells whether an existing behavior occurrence conforms to a model.**
  - **Doesn't say how to create an occurrence.**
    - **Execution engines and reasoners do this.**
  - **Enables semantic conformance testing.**

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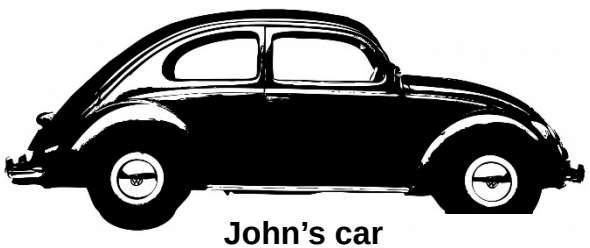
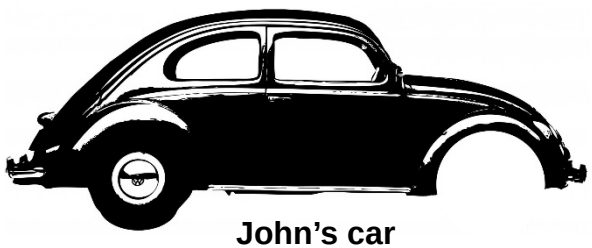
“3D/4D” Modeling Defined

- **“3D” = objects at an instant in time.**
  - **But no particular one (the “current” one).**
- **“4D” = objects as single entities extending over time.**
  - **Can be “sliced” up into intervals, including instants.**
- ***Not actually about physical space*.**
  - **Includes behaviors treated like objects.**
  - **Better name: Snap / Span (Smith).**

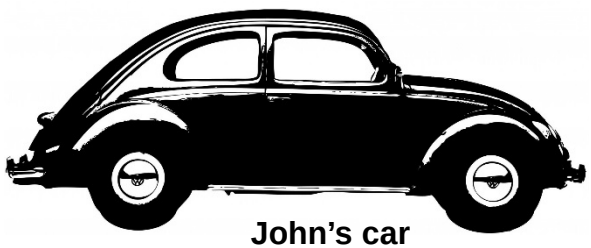
“3D” (Snap)



John’s car



John’s car

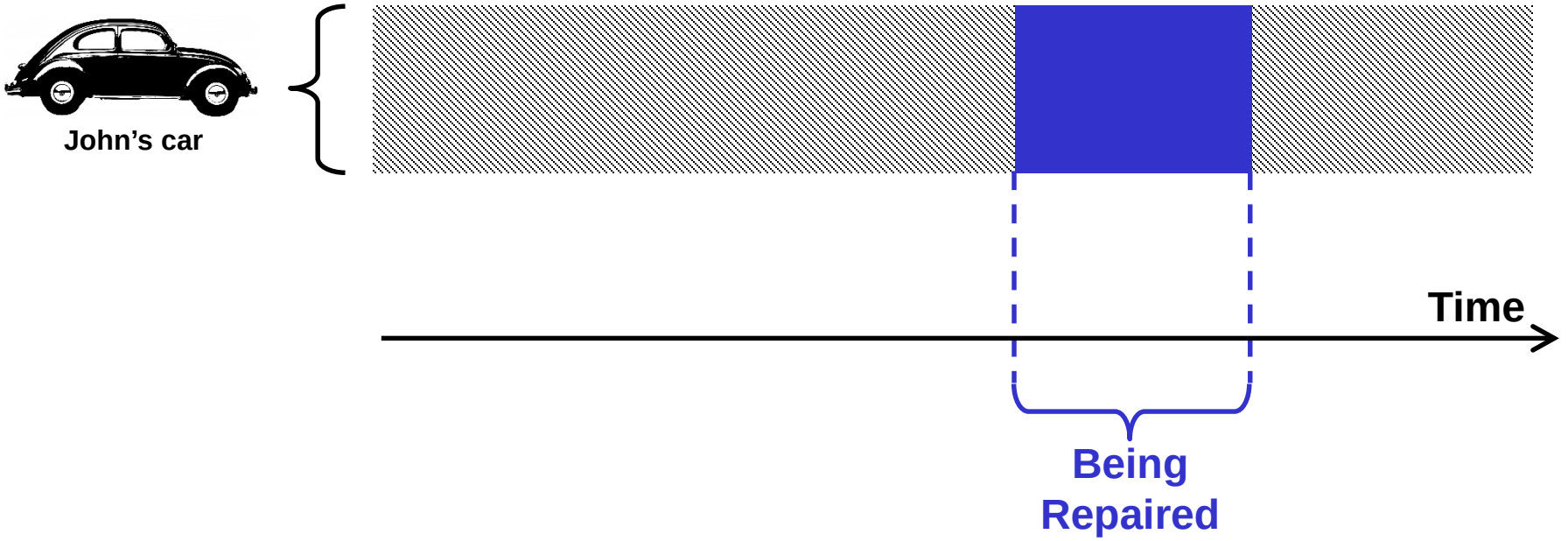


John’s car

Time

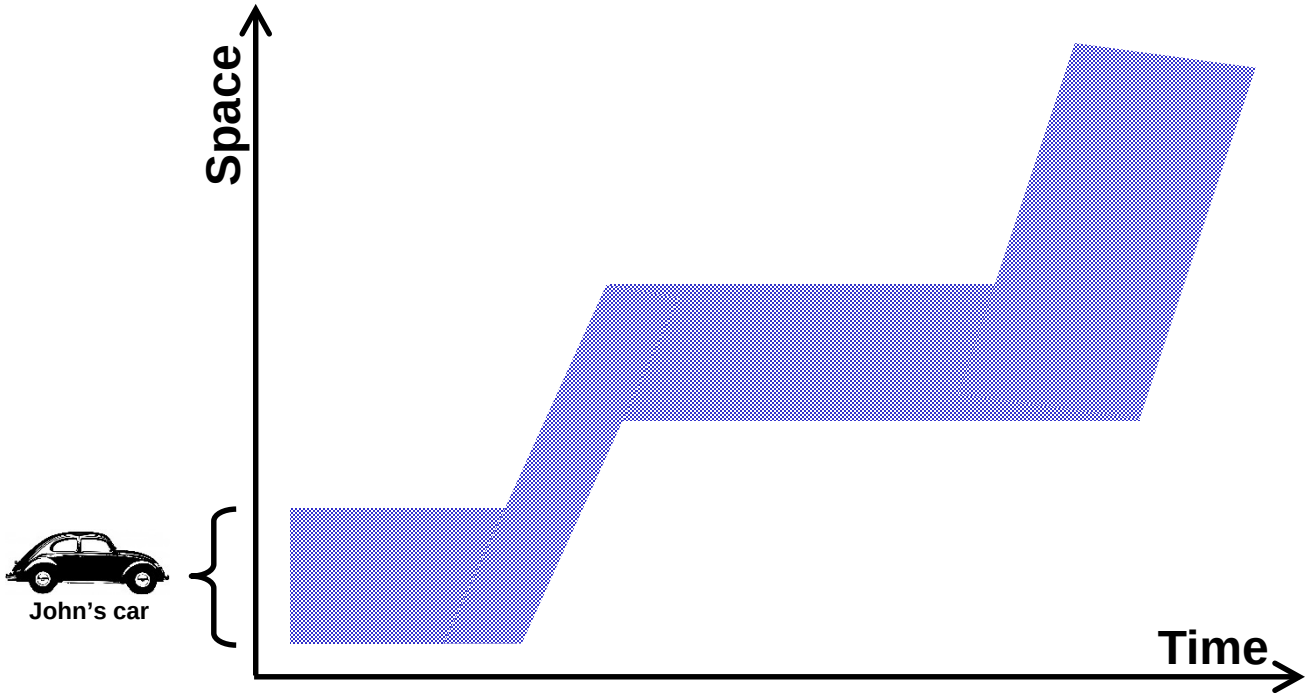
- **Object “repeated” over time.**

“4D” (Span)



- **One object “through” time.**

4D (space-time)



- **An object "moves through" time in the same way as space.**
  - **Horizontal = car is stationary**

Adapted from Matthew West, Developing High Quality Data Models, Morgan Kaufmann, 2011.

“3D / 4D” / 4D Compared

- **“4D” is more general than “3D”.**
  - **“4D” covers all instants in an object lifetime, including the “current” one.**
- **“3D” can’t easily model:**
  - **Characteristics of objects over some of their lifetimes (including particular instants).**
  - **Can’t aggregate over time (eg, number of owners a car has had).**
- **4D is more general than “4D”**
  - **4D includes space.**

UML: Not much “4D”

- **Instance specifications**
  - **“Snapshots” can’t be related to same instance.**
  - **Don’t represent any particular instance, or any.**
- **State invariants**
  - **State machines and interactions.**
    - **On SM state or interaction fragment**
  - **Left to constraint language.**
    - **Holds for duration of state or interaction fragement**
  - **Can’t aggregate over time.**
  - **SM and interaction models aren’t related.**
    - **Just happen to have the same name.**

4D Requirements

1. **Treat objects and behaviors as existing in time and space together.**
   - **Behaviors in space of objects involved in them.**
2. **Specify objects and behaviors over**
   - **(Sub) intervals of time and regions of space.**

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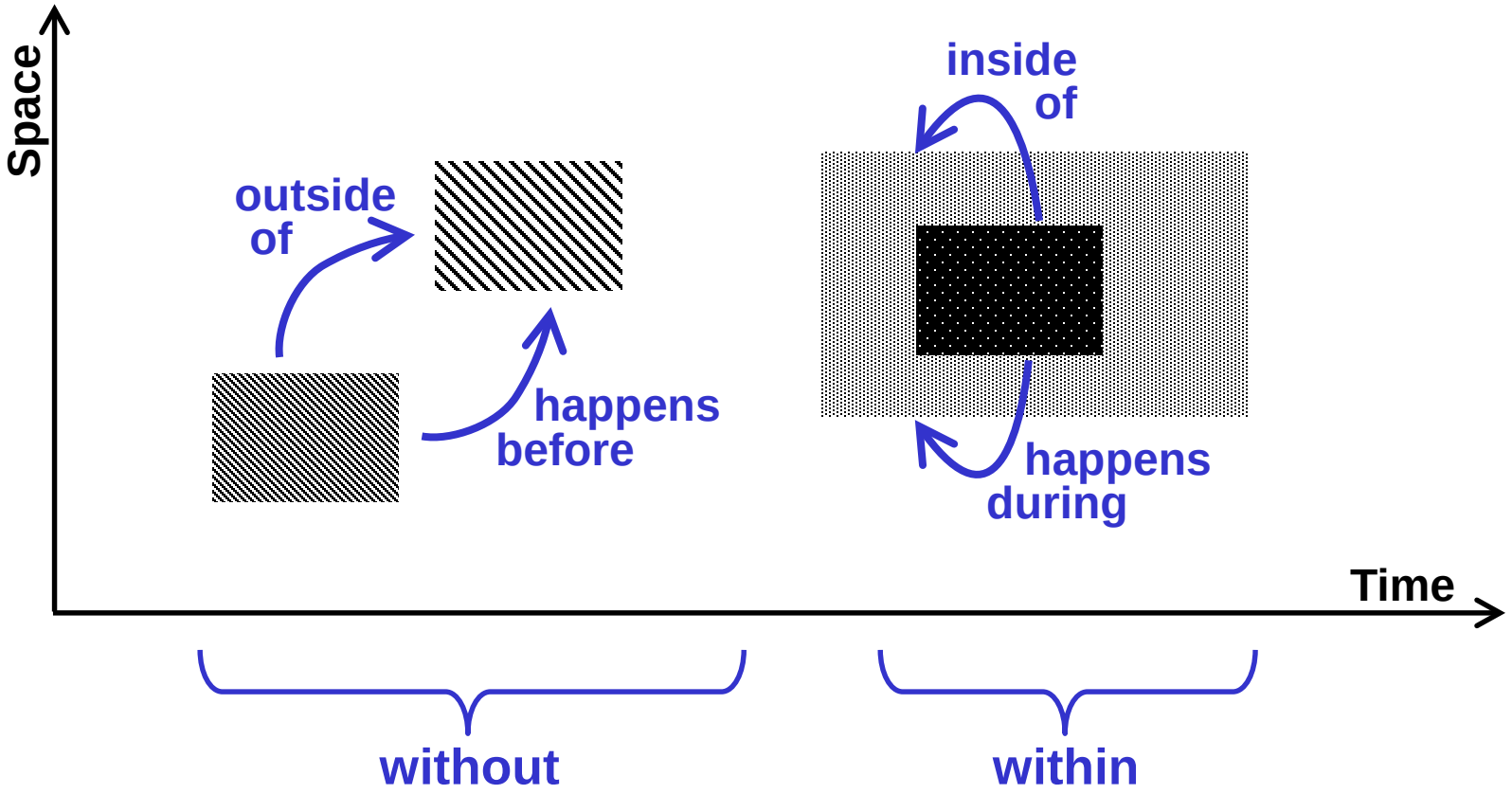
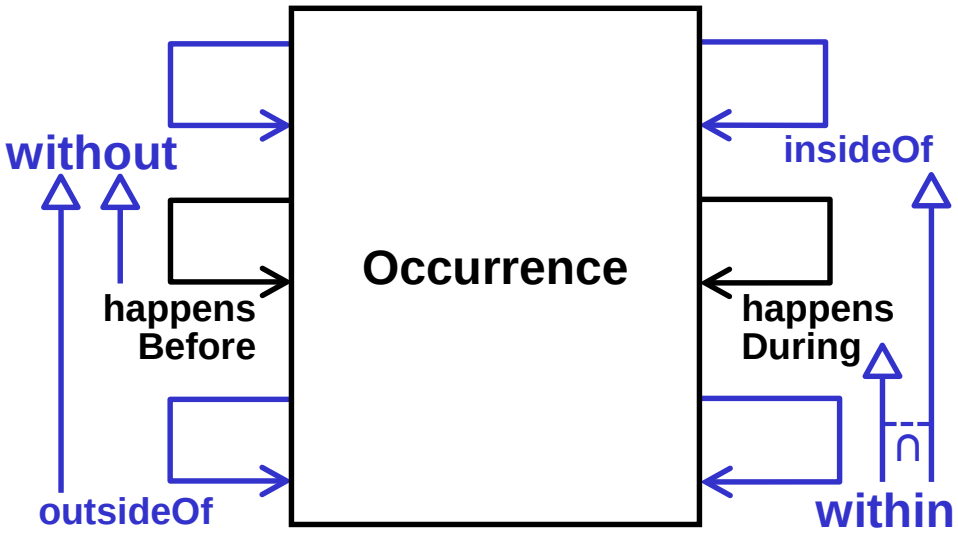
Without and Within



- **Completely separate or overlapping**
  - **Different dimensions (time, space) and terms.**
  - **Same thing (without, within).**

Without and Within (M1)

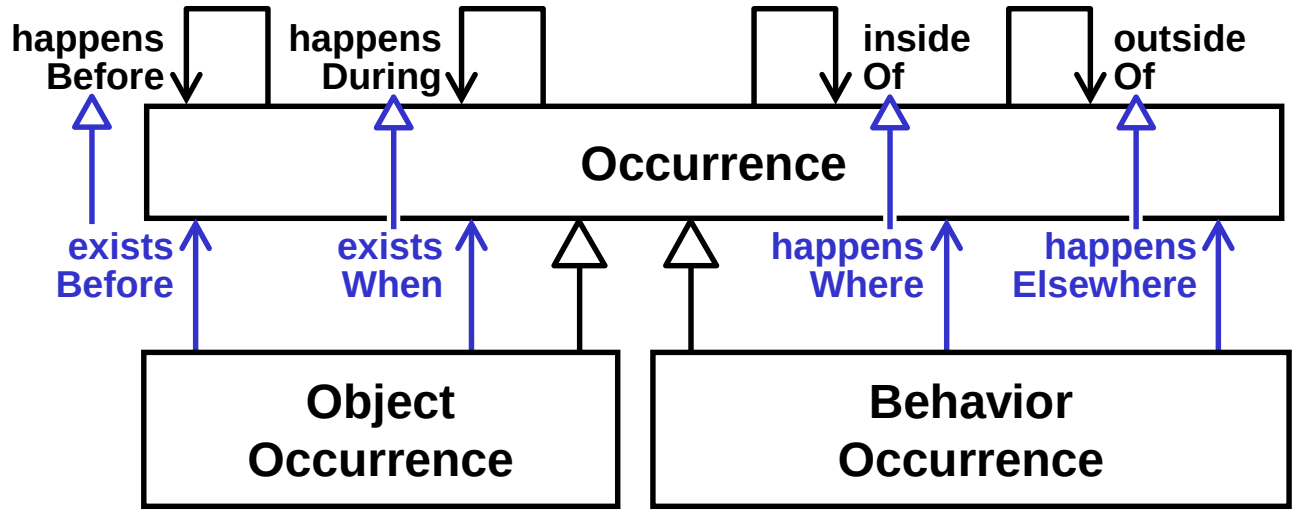
Standard Model Library (M1)



- **Without = happensBefore or outsideOf or both**
- **Within = Both happensDuring and insideOf**

Object & Behavior Terms

Standard Model Library (M1)



- **Objects and behaviors might have different names for 4D relations**
  - **But the meaning is the same.**

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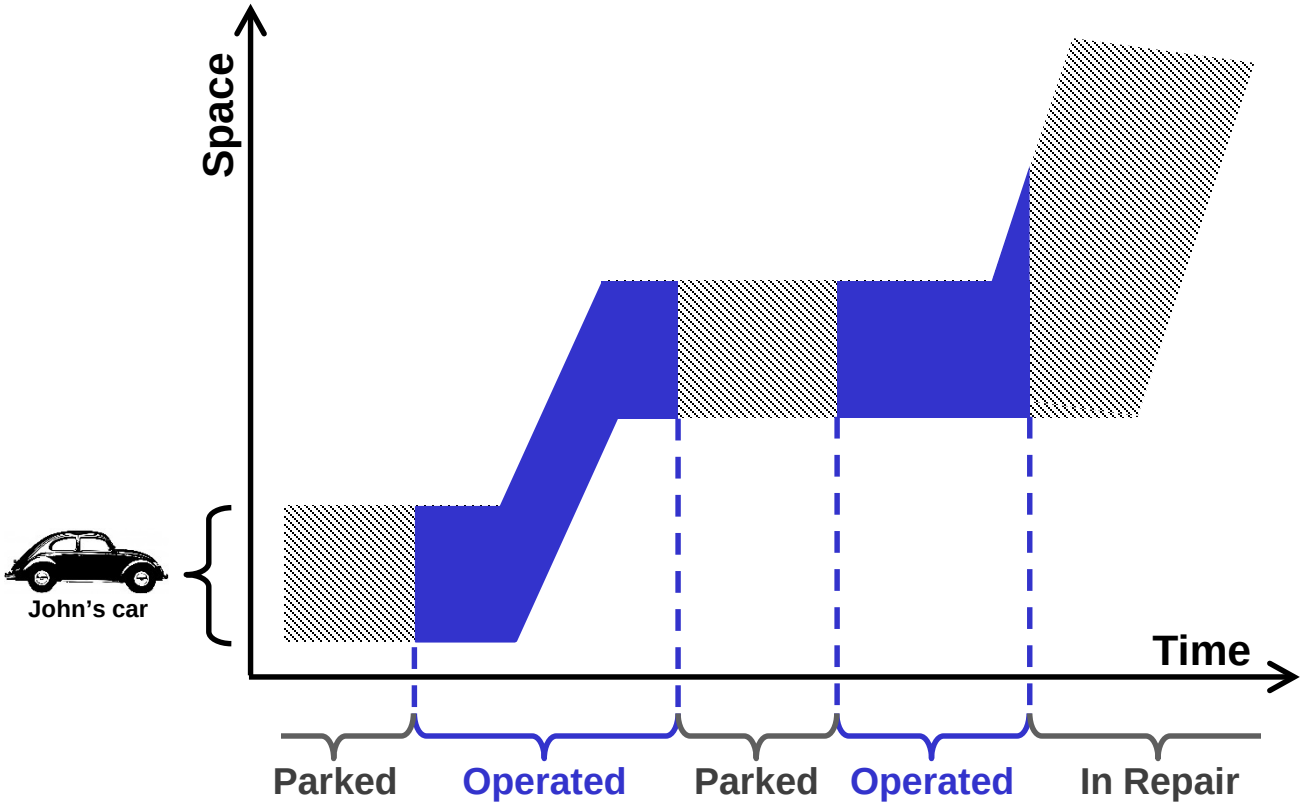
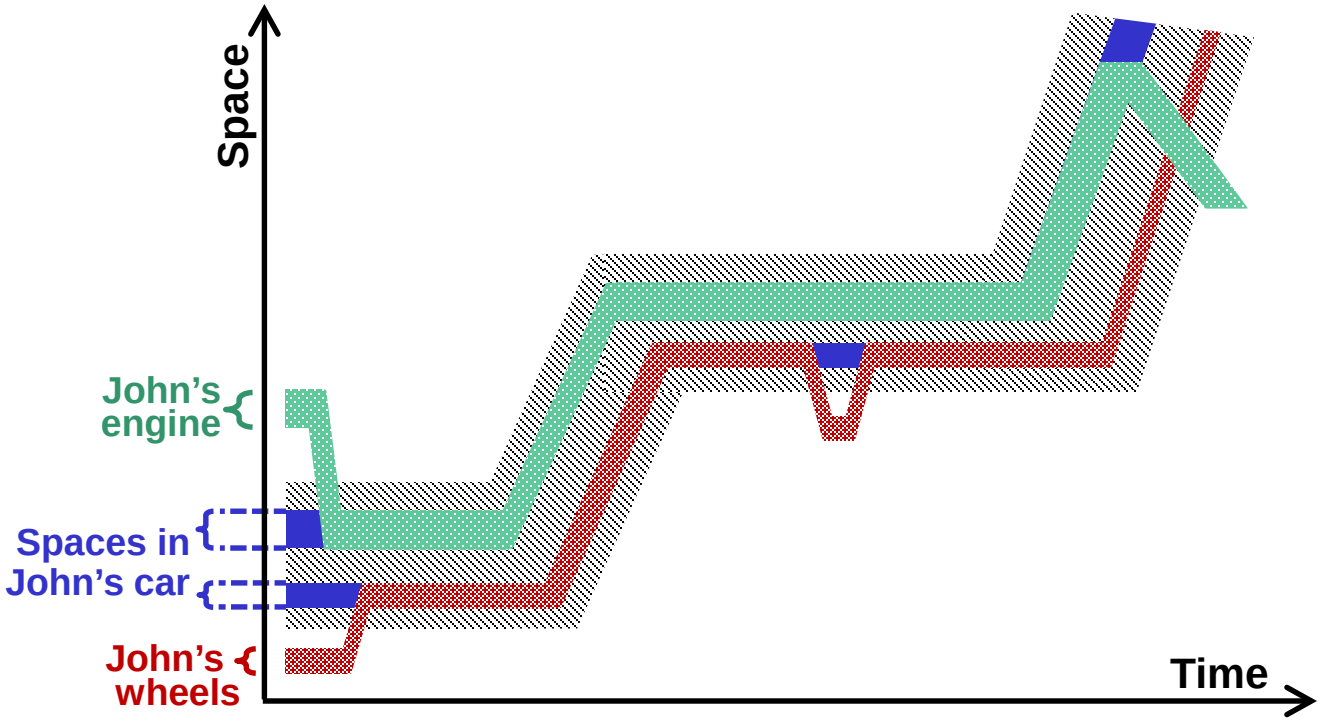
Time Slices



- **All space in 4D region during time intervals.**

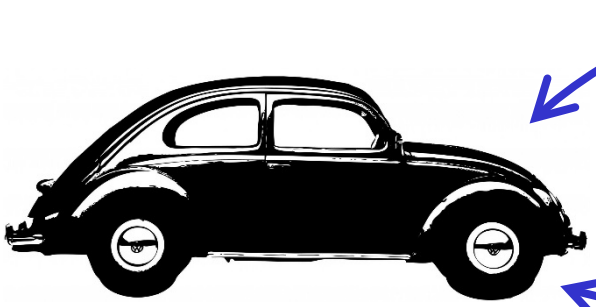
Adapted from Matthew West, Developing High Quality Data Models, Morgan Kaufmann, 2011.

Space Slices



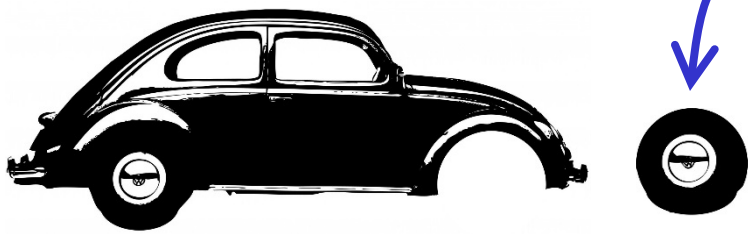
- **All time in 4D region during (relative) space intervals.**

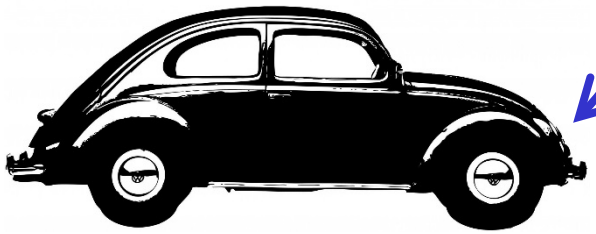
Composition (Integral)



Wholes and parts are *different kinds* of things (cars and wheels)

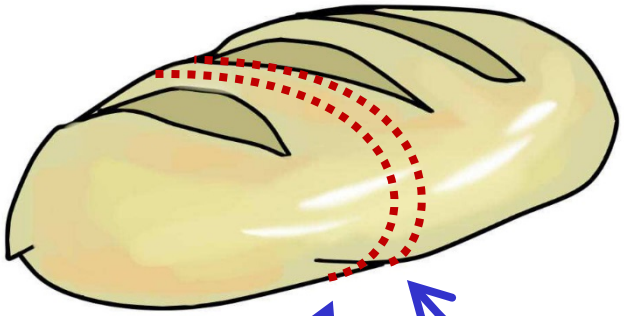
Can take parts out and put them back





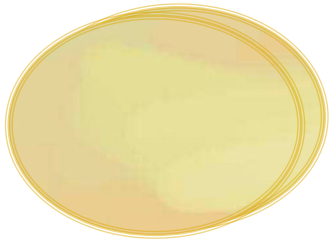
- **Composite aggregation (“black diamond”)**

Composition (Portional)



Wholes and portions are the *same kinds* of things (bread)

Can't **take parts out and put them back in**

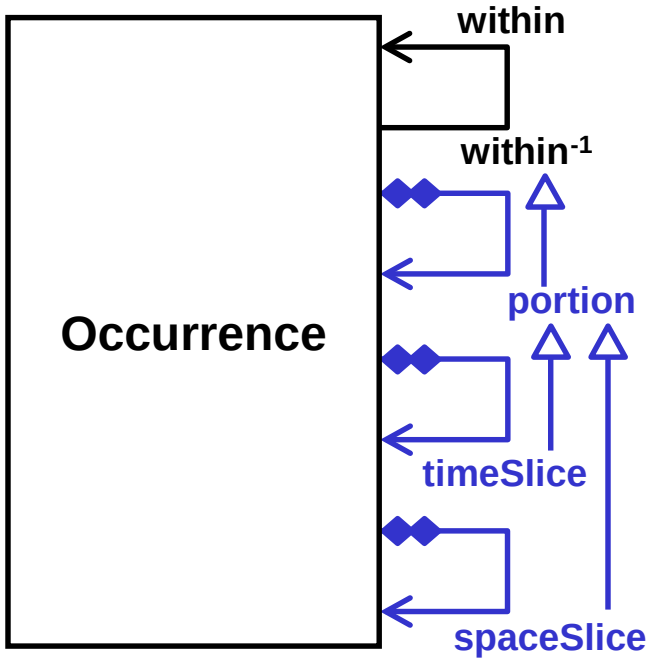


- **Same applies to slicing 4D things.**
- **New notation:** 

Winston, M., R. Chaffin, and D. Herrmann, "A Taxonomy of Part-Whole Relations," *Cognitive Science* 11: 417–444, 1987.
Odell, J. 1994. "Six Kinds of Composition." *Journal of Object-Oriented Programming* 5: 8, 1994.

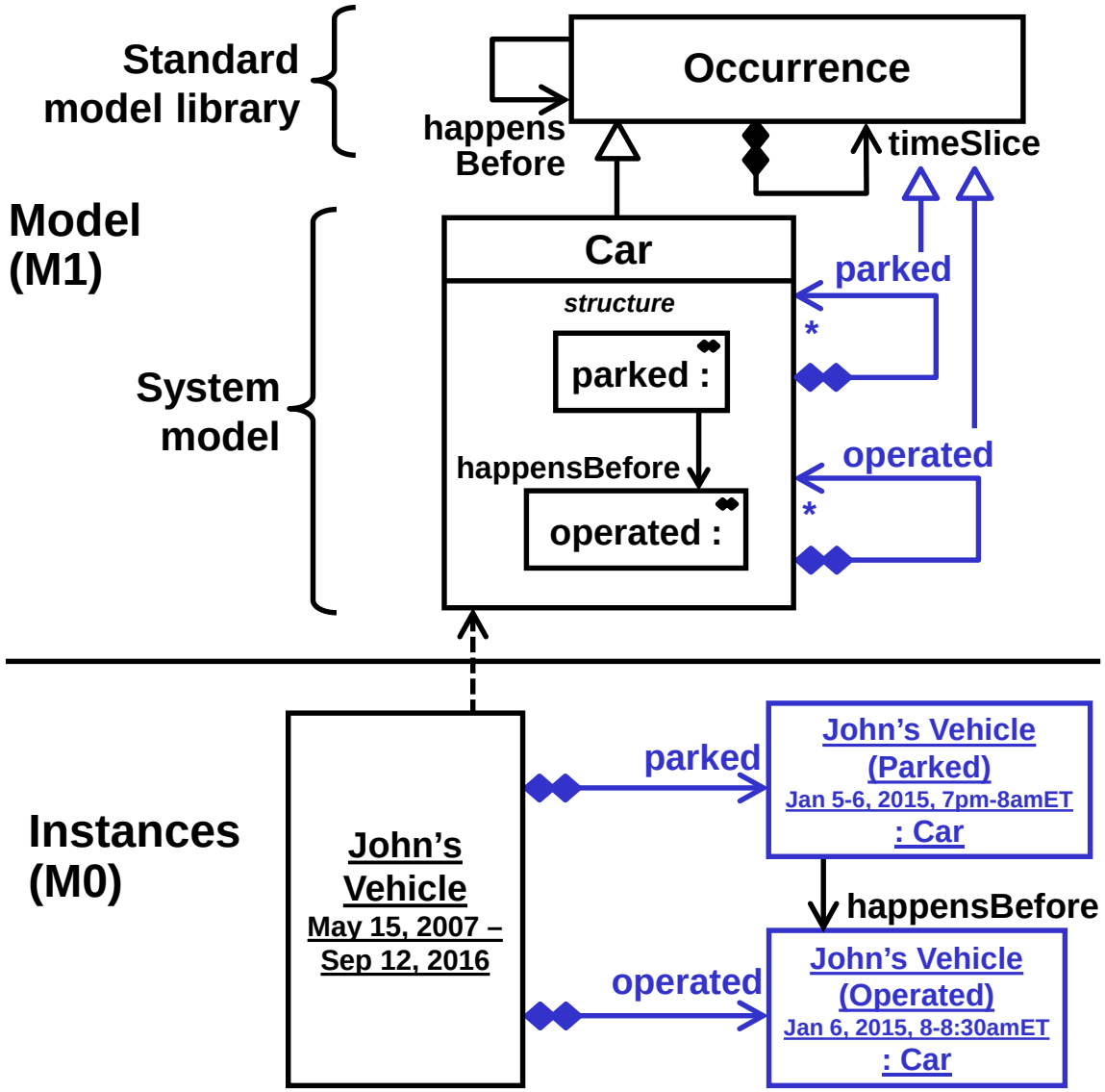
Portions (M1)

Standard Model Library (M1)



- **Portions are completely within their wholes.**
- **Time and space slices are portions**

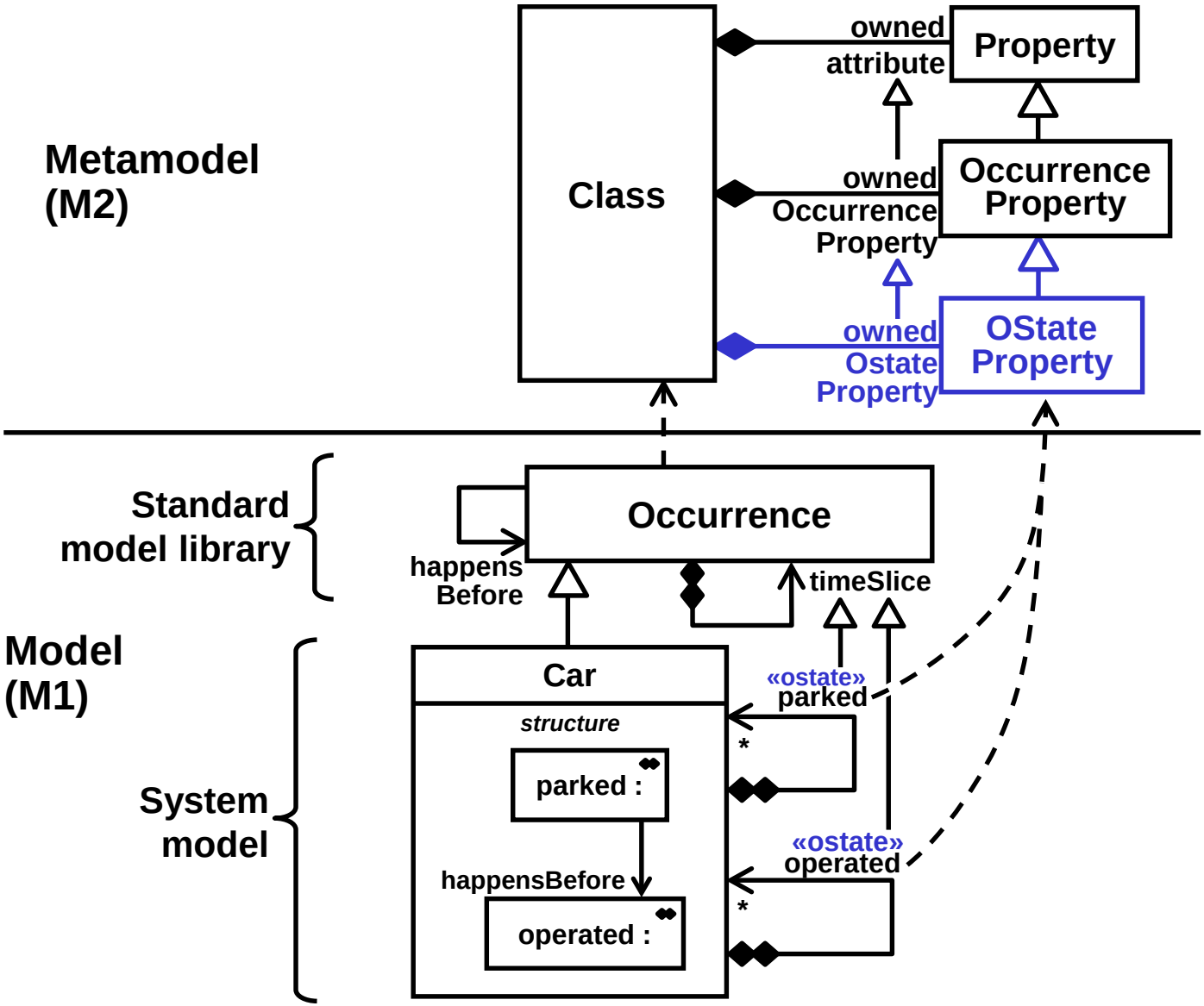
Time Slices (M1)



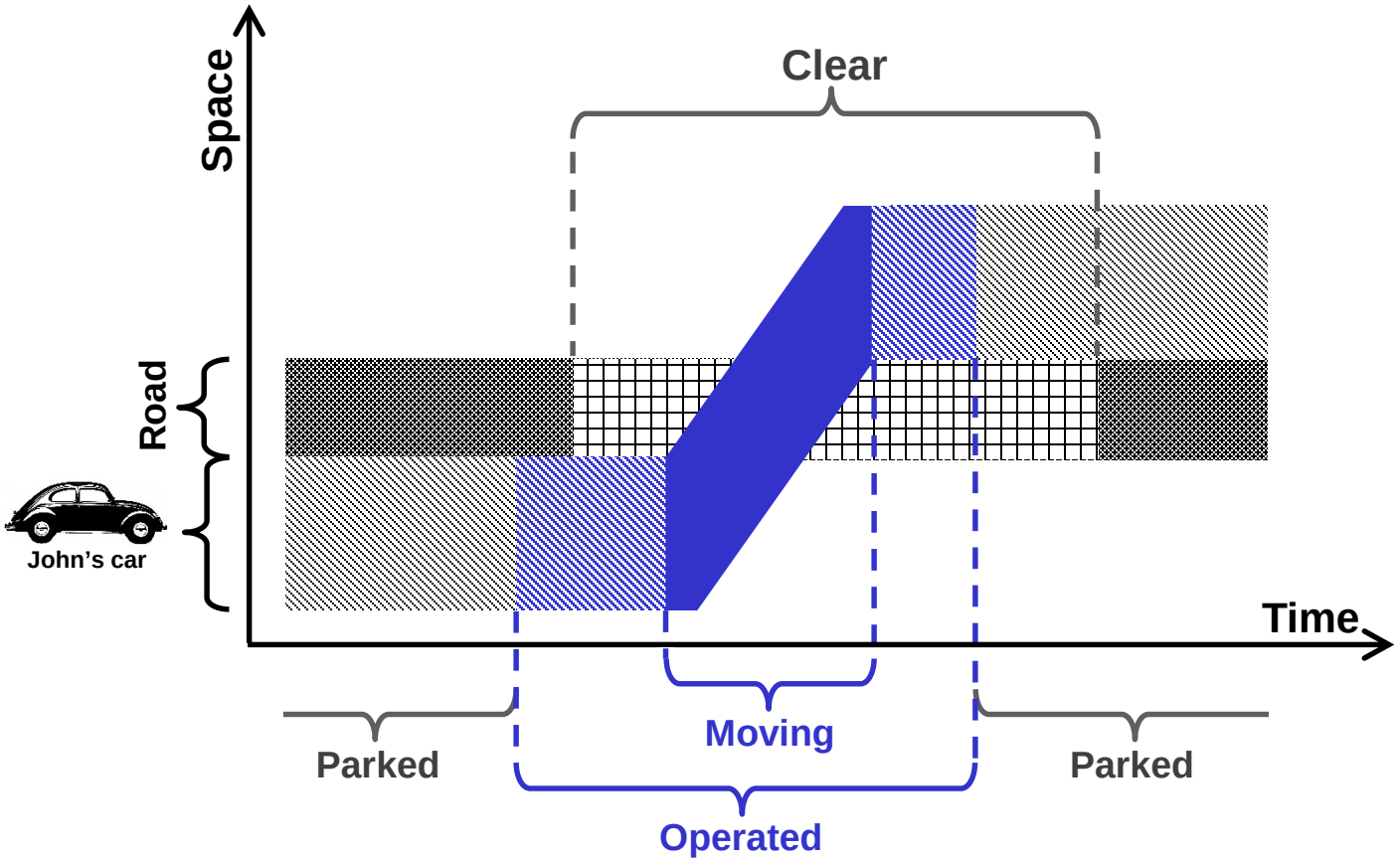
Time slices of cars are also cars

(could be subtypes)

Time Slices (M2)



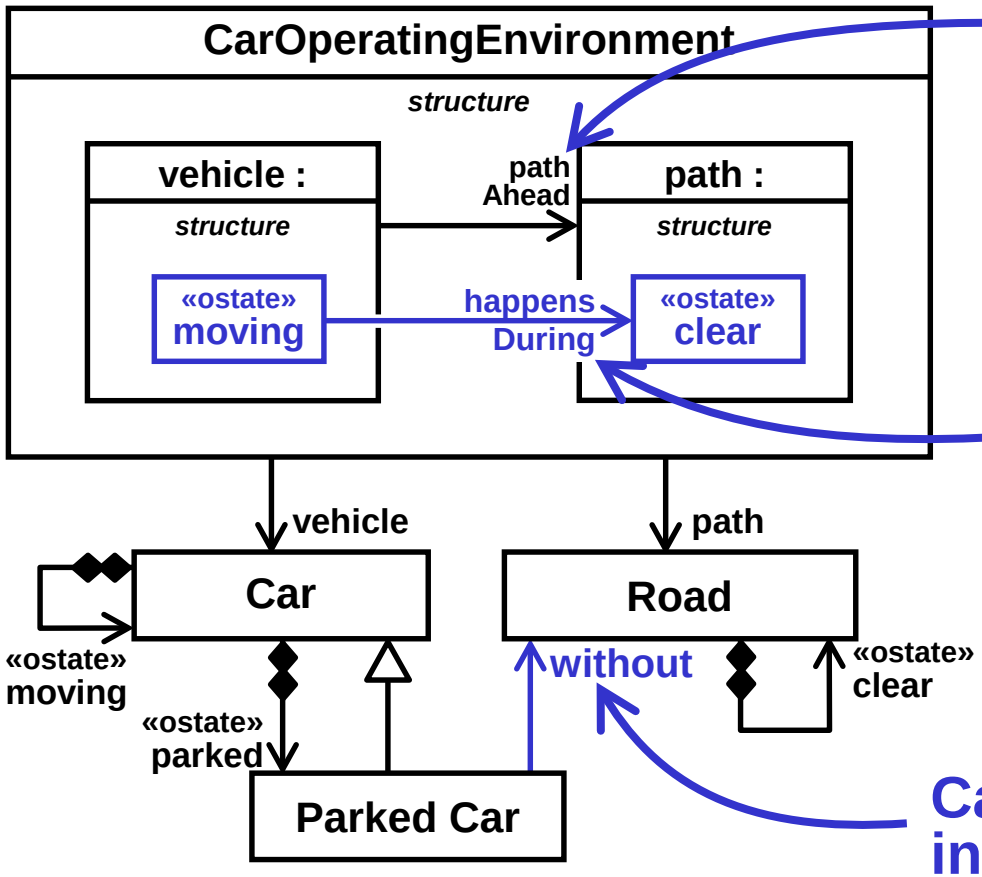
4D, Multi-object



- **Car should only be in road when it's clear.**

4D, Multi-object (M1)

Model (M1)

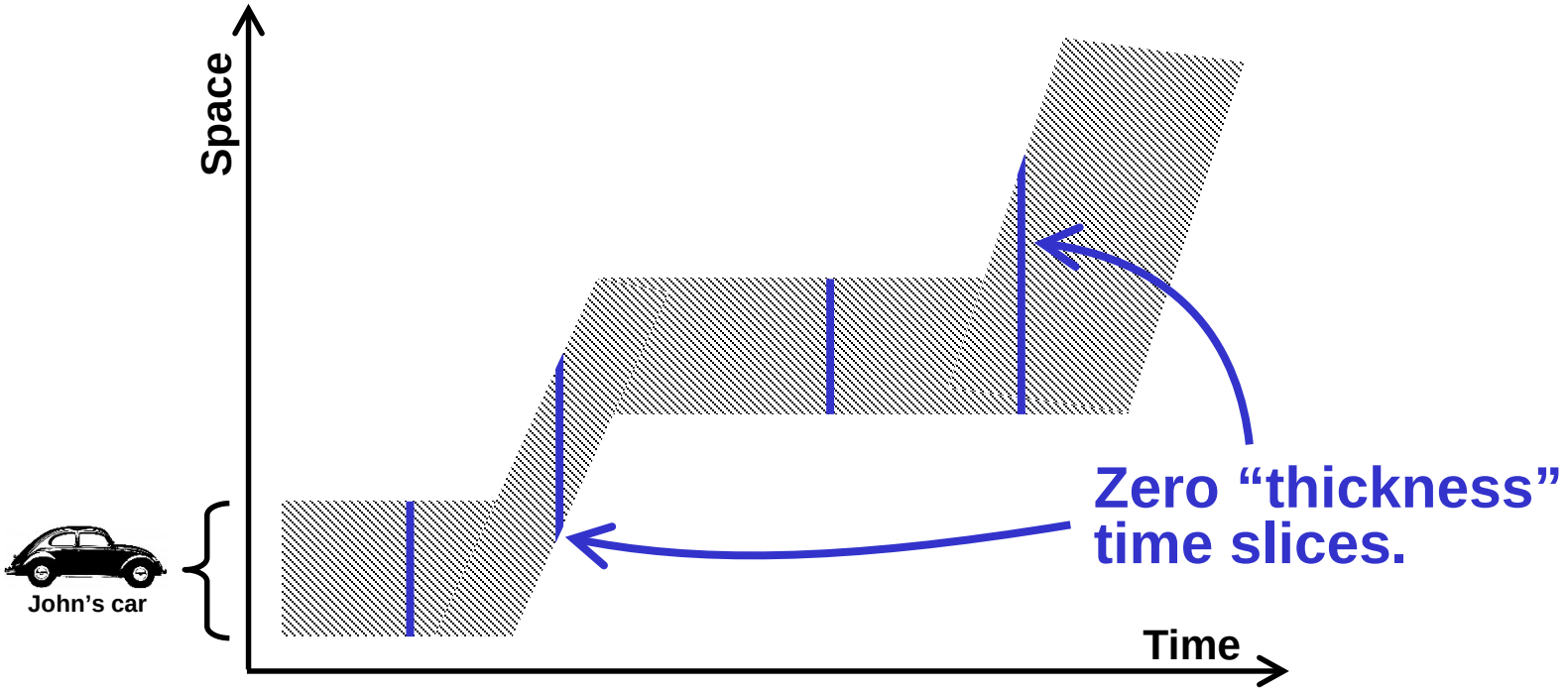


Portion of road where car is going.

Cars can move only when path ahead is clear.

Cars can't park in the road.

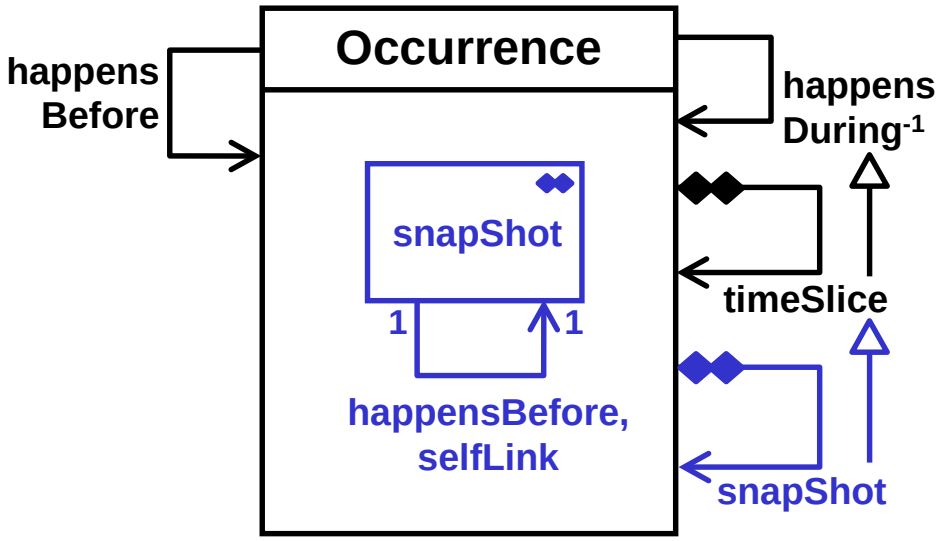
Snapshots



- **Times slices with zero duration.**

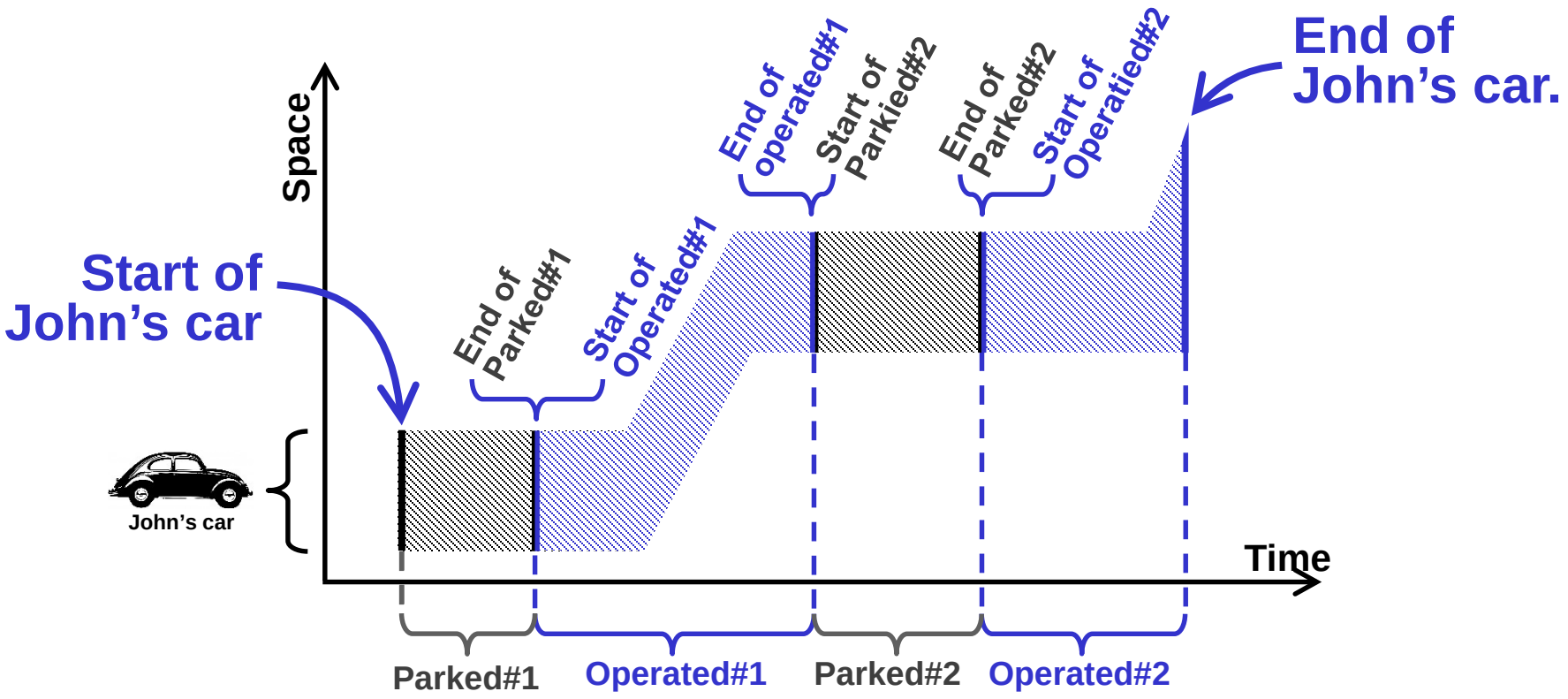
Snapshots (M1)

Standard Model Library (M1)



- **Snapshots happen before themselves.**
  - **They "meet" at beginning and end.**

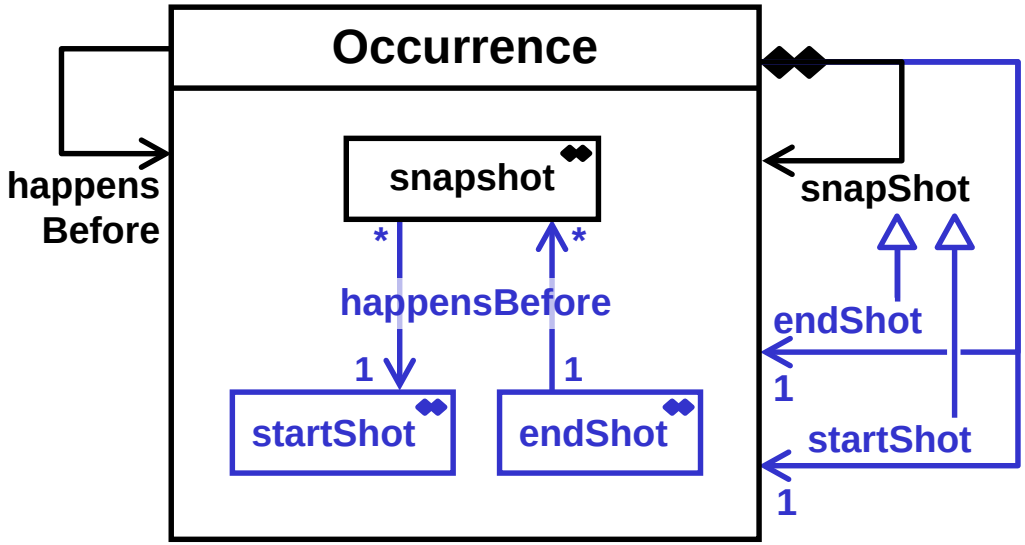
Start/Endshots



- **Snapshots at beginning and end of 4D occurrences (including slices).**

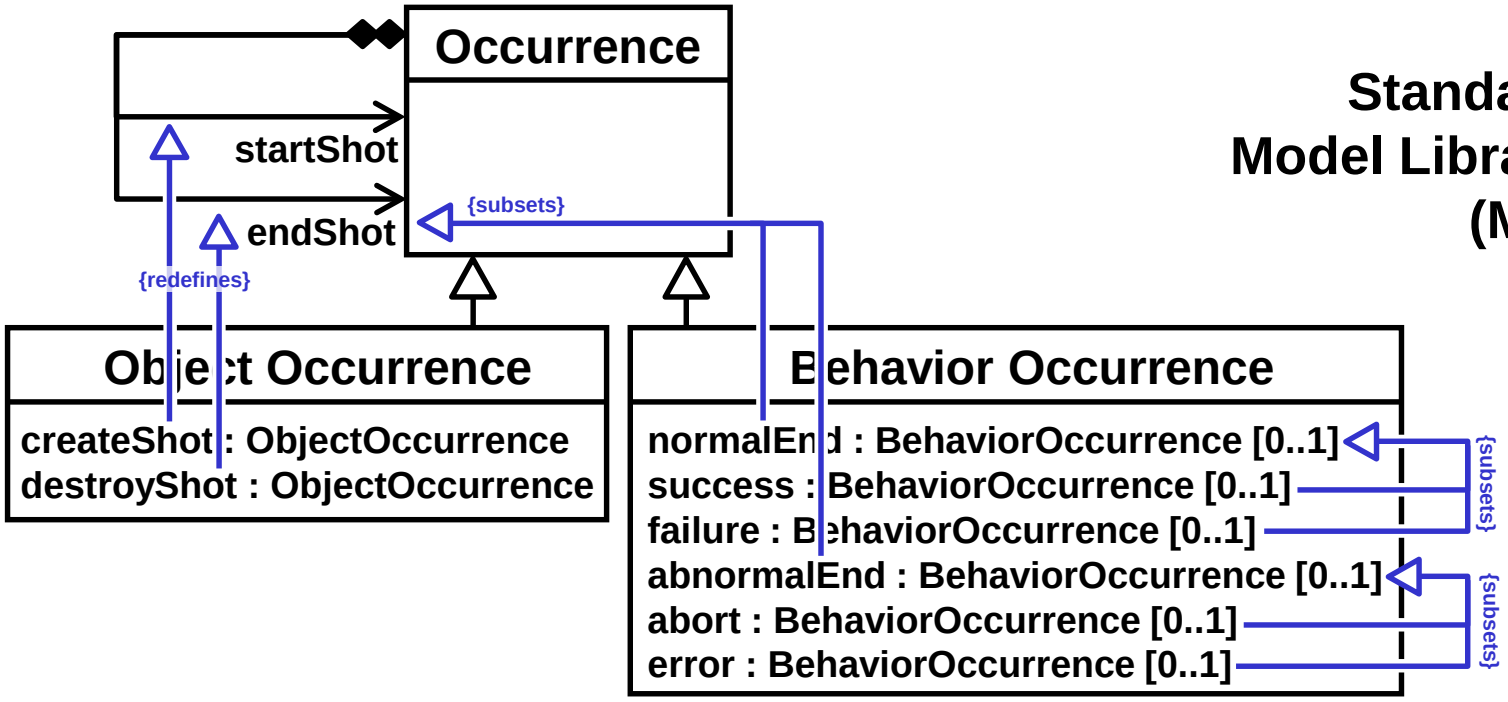
Start/Endshots (M1)

Standard Model Library (M1)



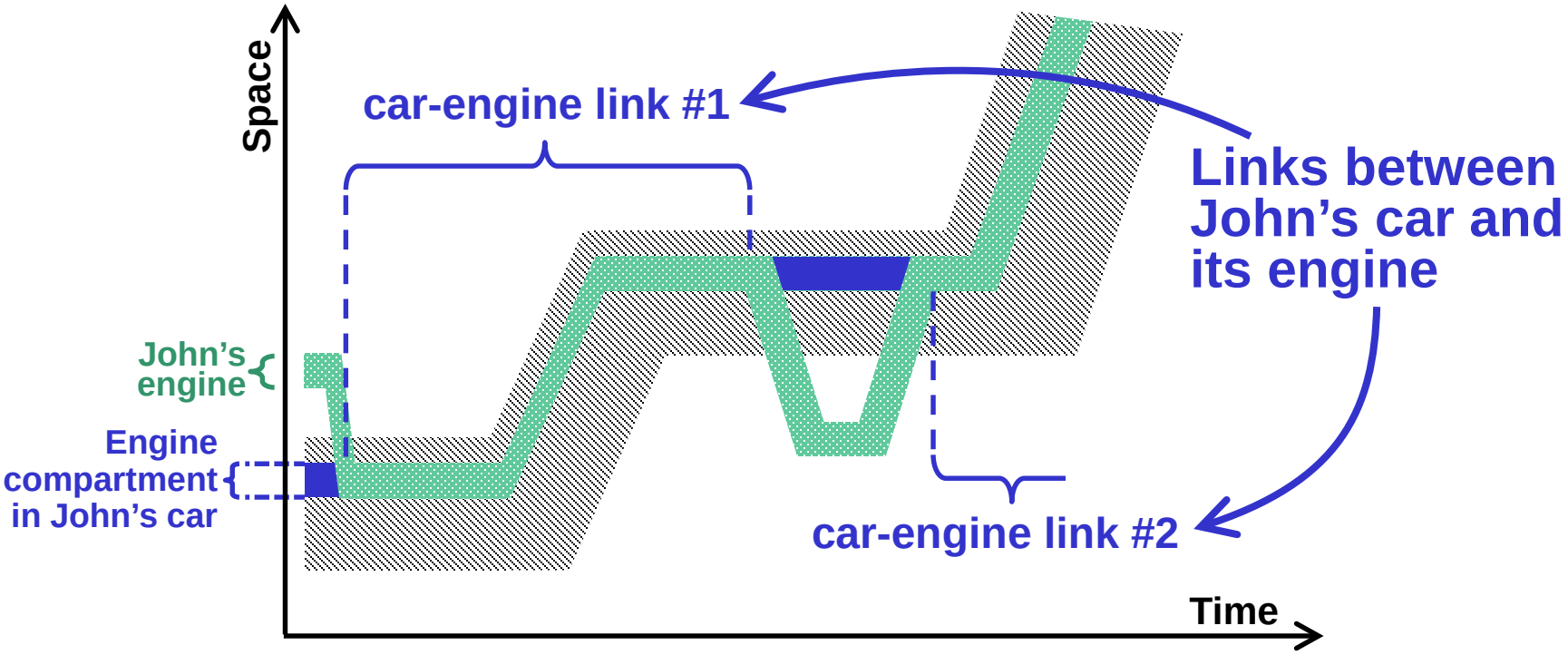
- **Start/Endshots happen before/after all snapshots.**

Object Terms, Behavior Specializations



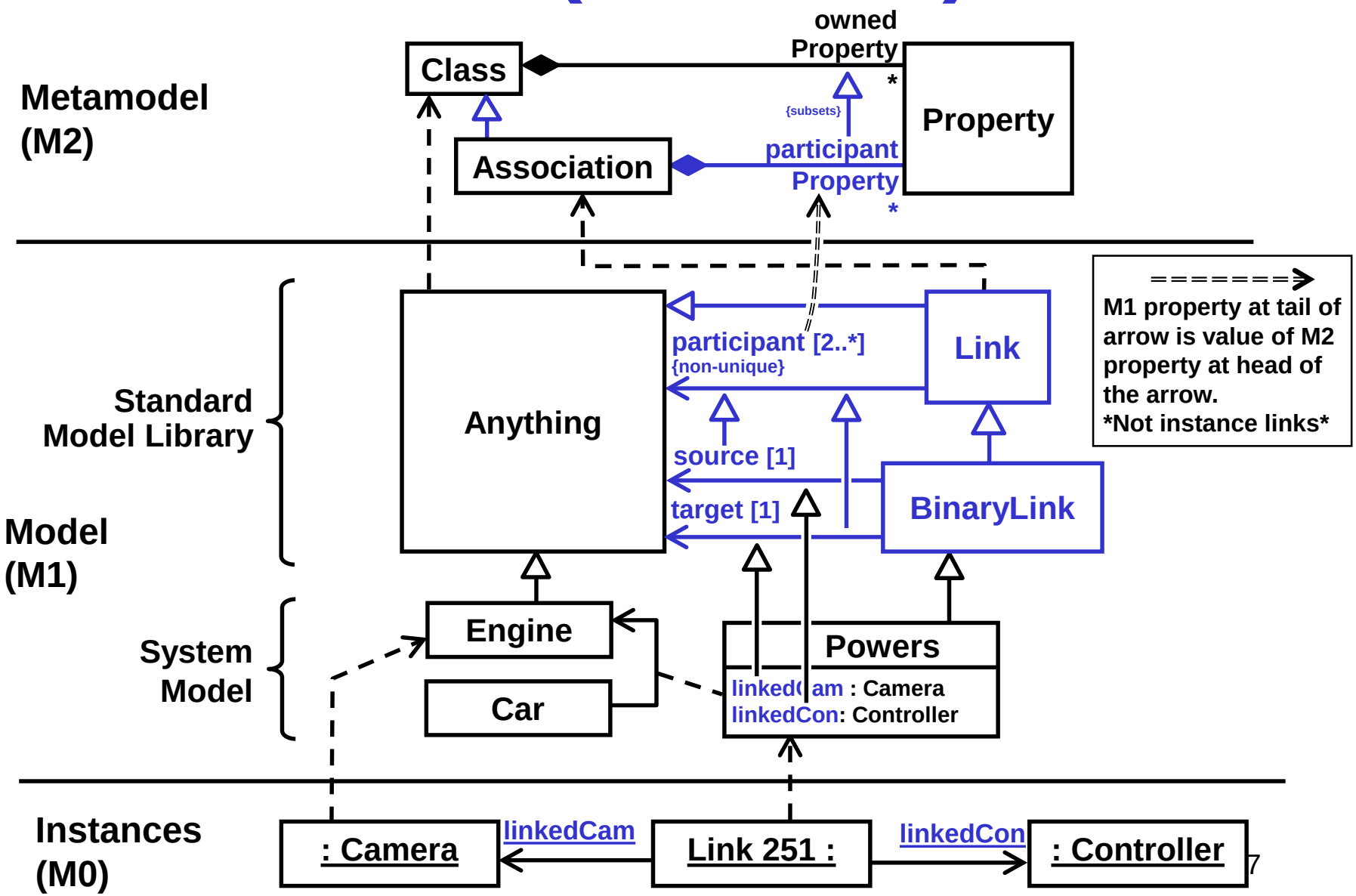
- Objects might have different names for start and end
  - But the meaning is the same.
- Behaviors might specialize for end status

Link Occurrences

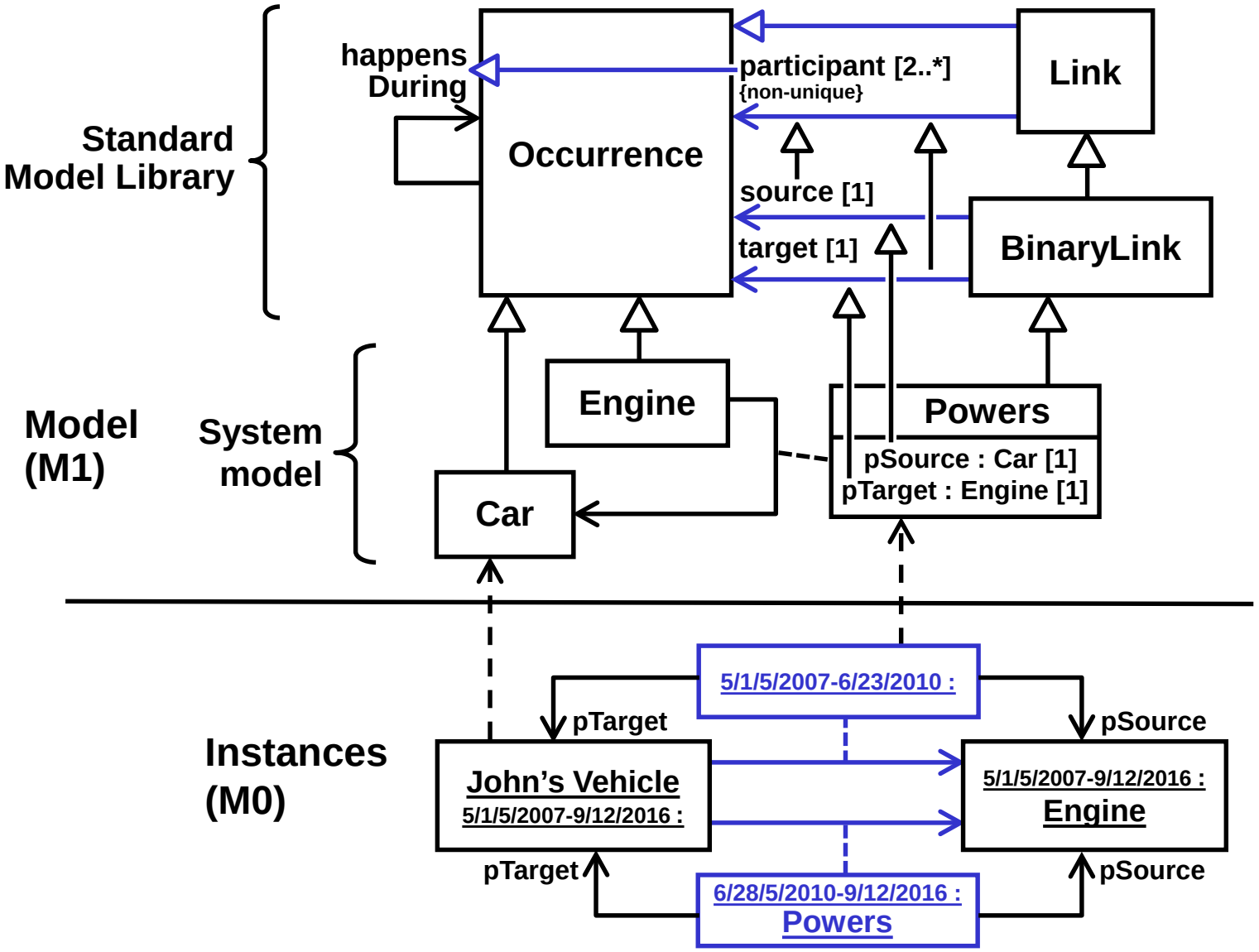


- **Two links between John's car**
  - **One before engine is removed and one after.**

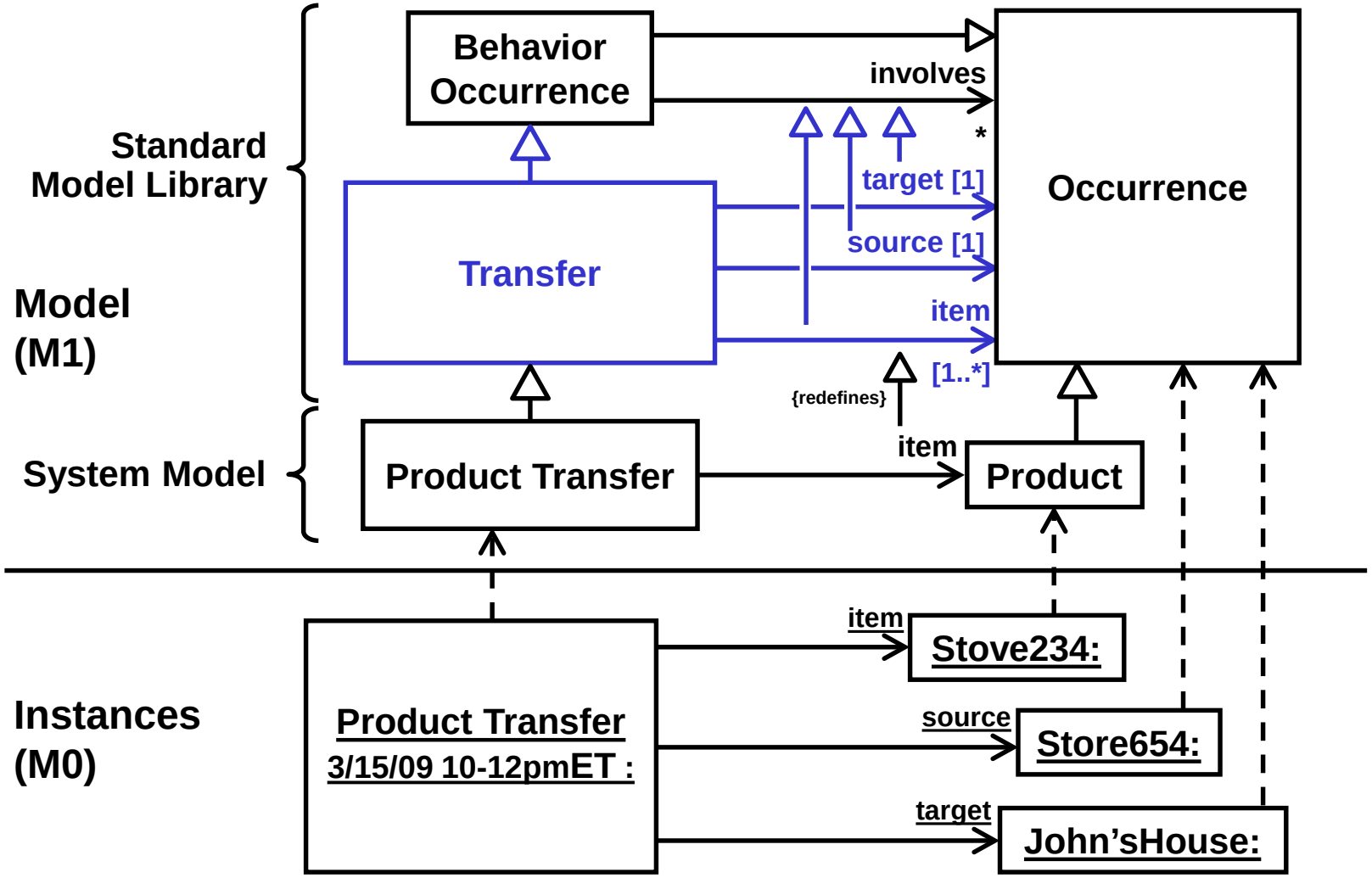
Links (M1 & M2)


Metamodel (M2)
Class
owned Property
*
Property
{subsets}
Association
participant Property
*
Standard Model Library
Model (M1)
Anything
participant [2..*]
{non-unique}
Link
source [1]
target [1]
BinaryLink
M1 property at tail of arrow is value of M2 property at head of the arrow.
Not instance links
System Model
Engine
Car
Powers
linkedCam : Camera
linkedCon: Controller
Instances (M0)
: Camera
linkedCam
Link 251 :
linkedCon
: Controller

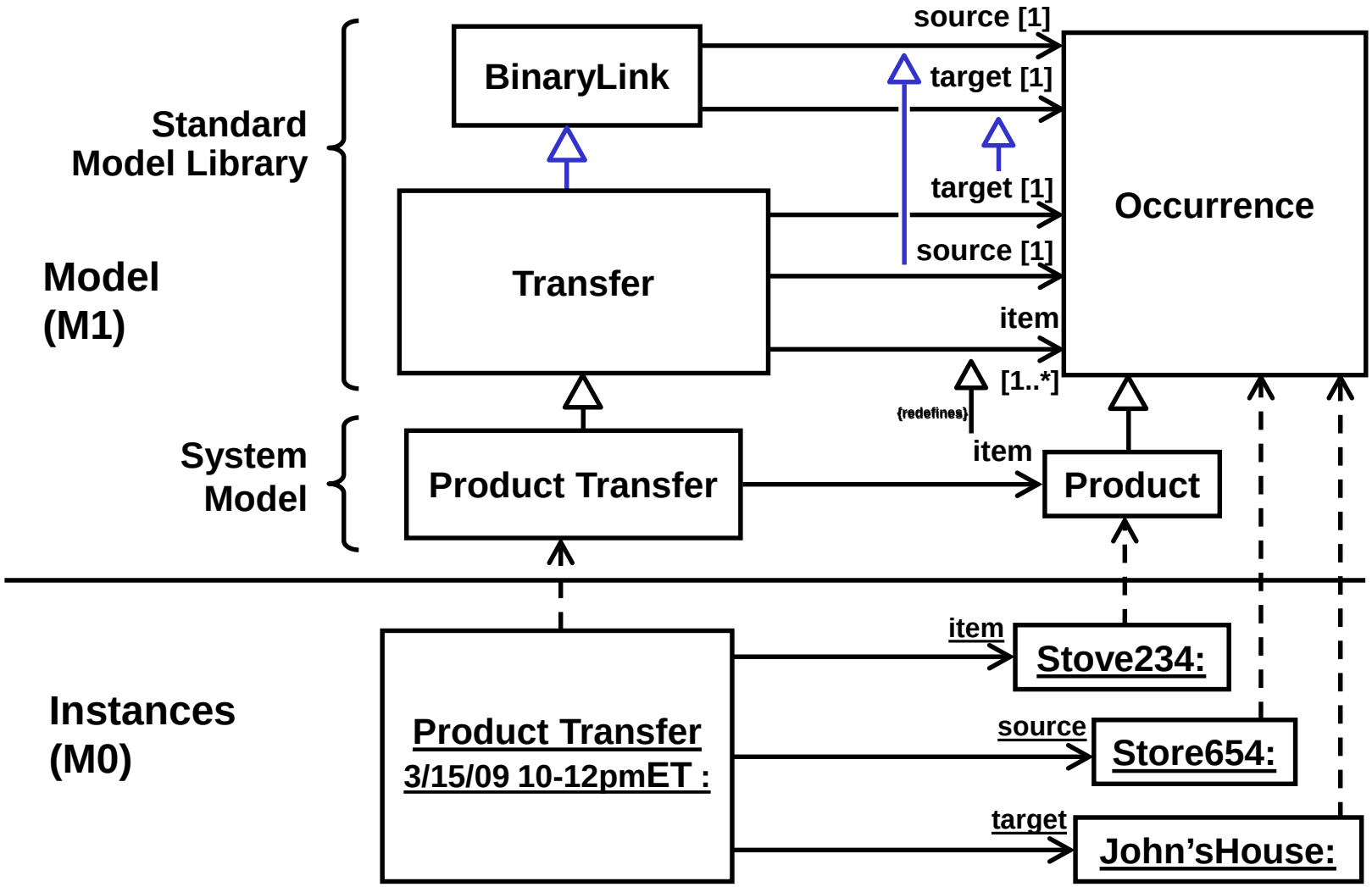
Link Occurrences (M1)



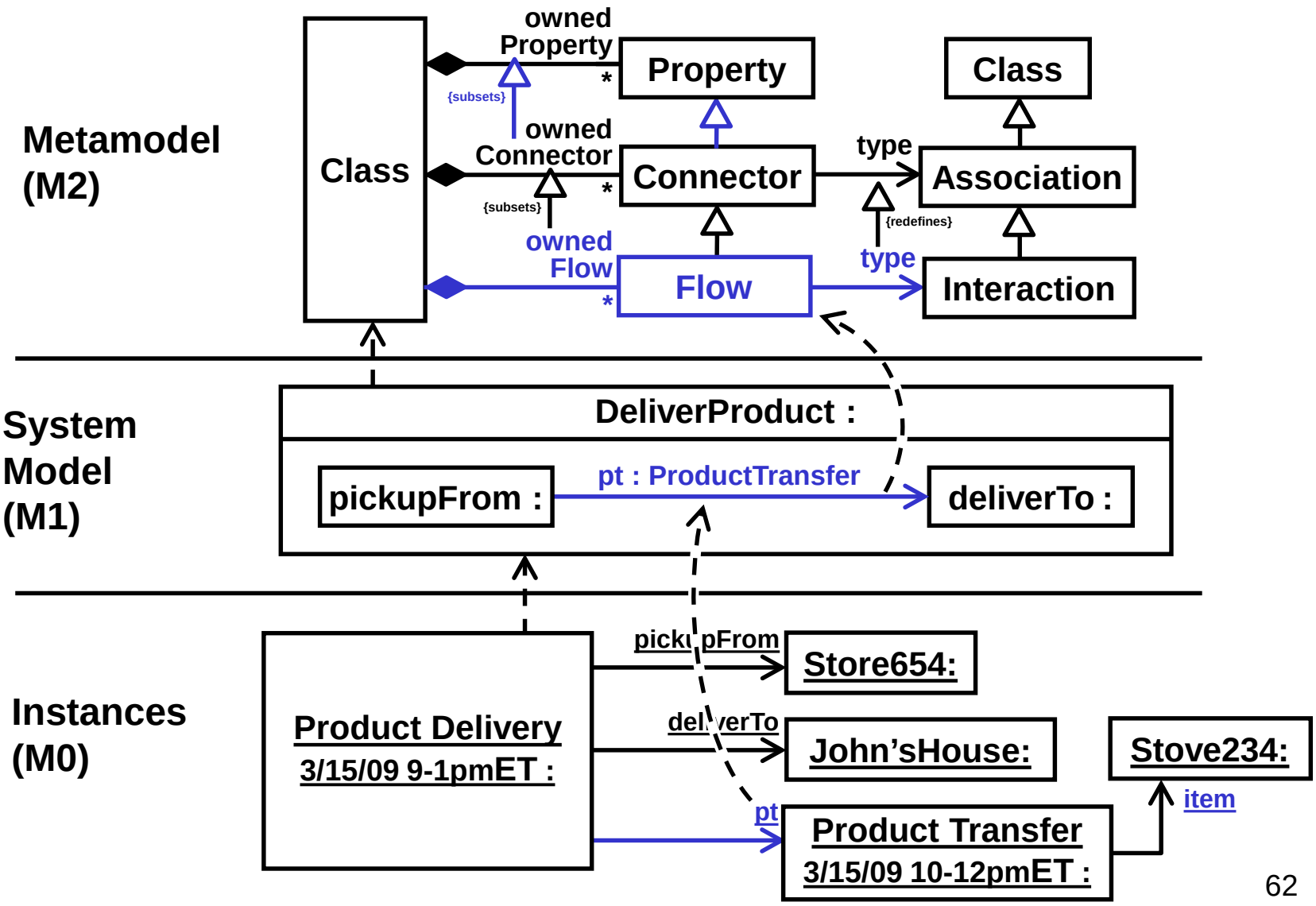
Transfers (M1)



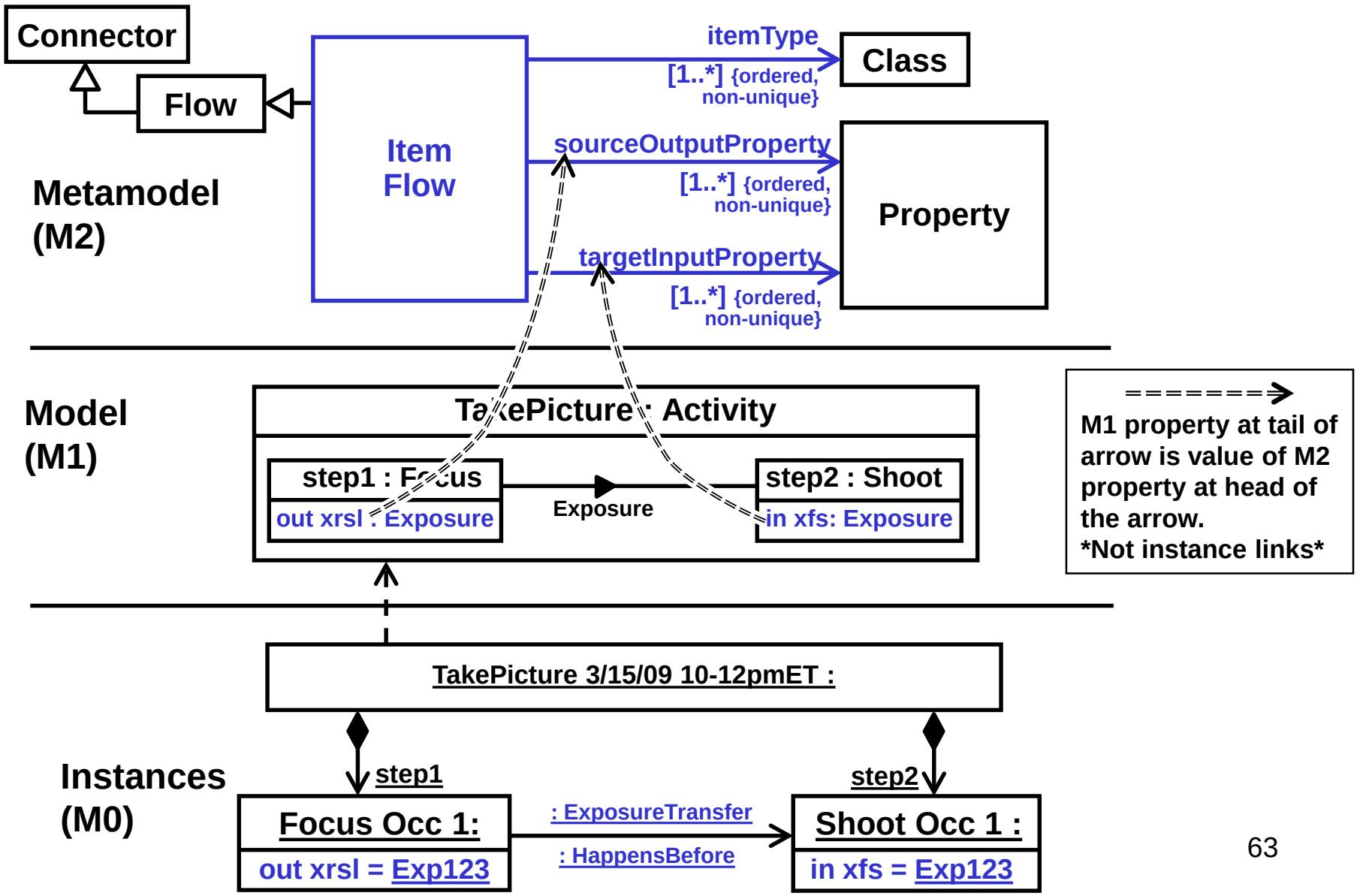
Transfers as Links (M1)



Transfers (M2)



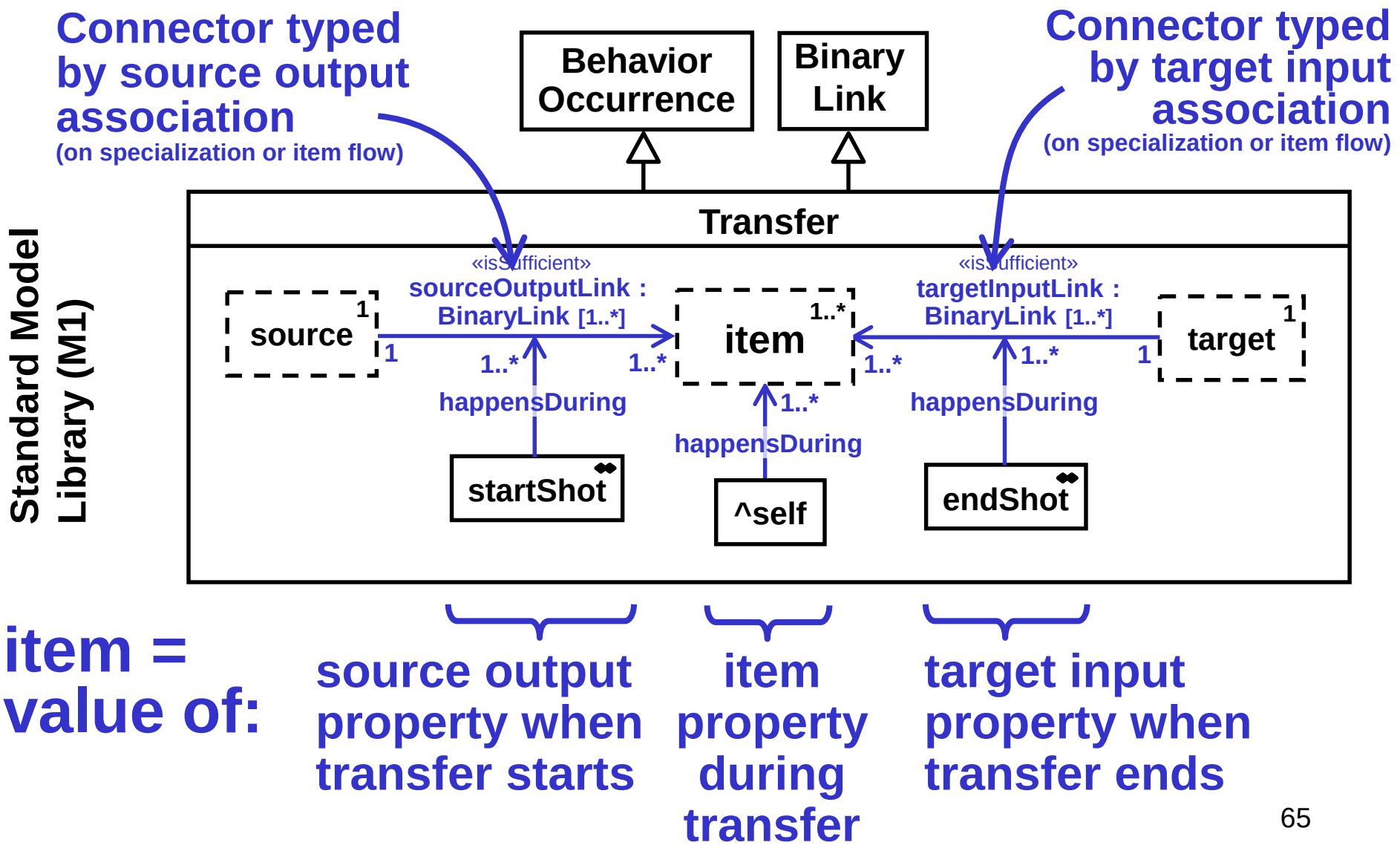
Transfers & I/O (M2)



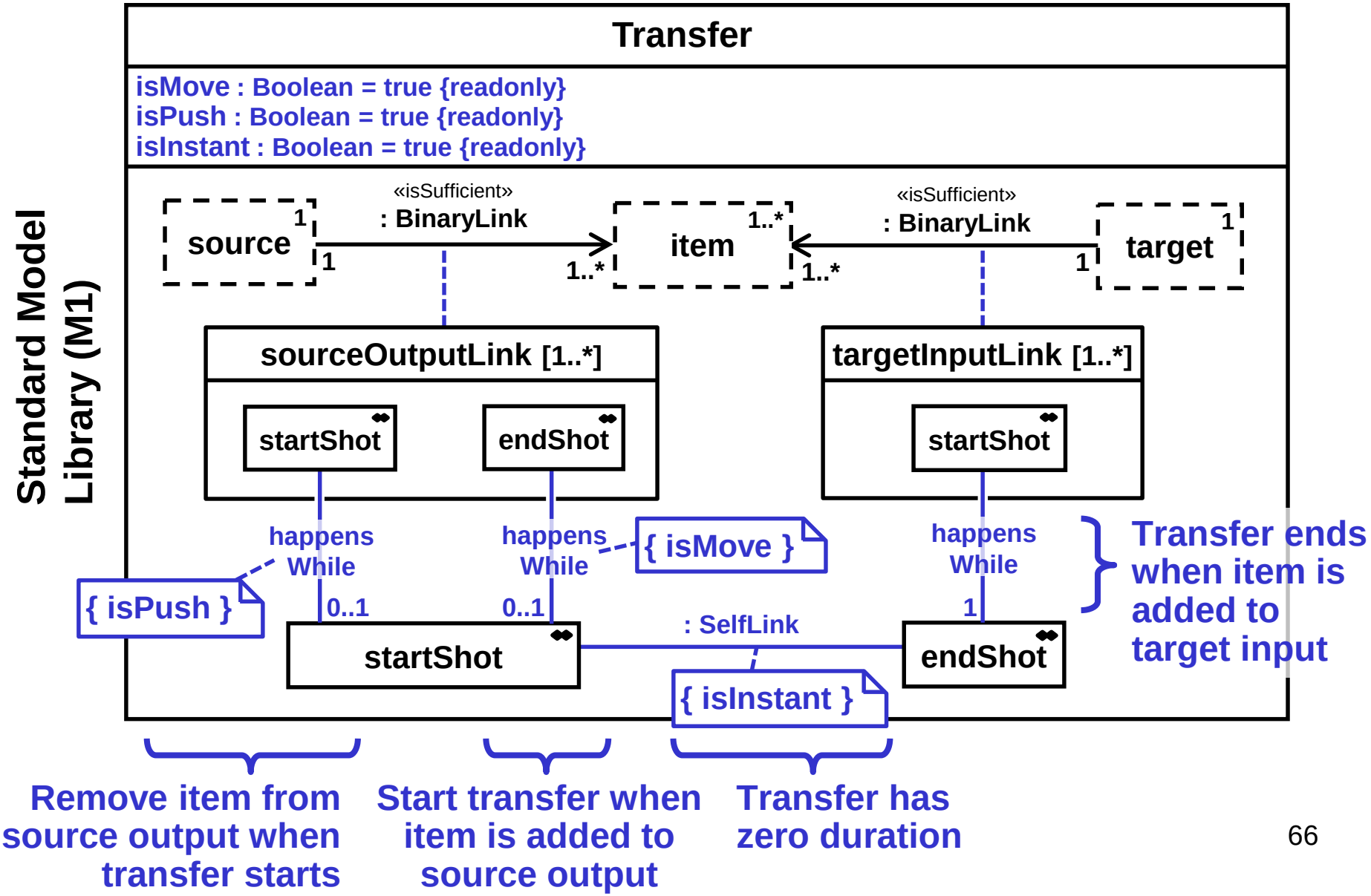
Transfer & I/O Semantics

1. **Transferred item = value of**
   - **source output property when transfer starts.**
   - **transfer item property during transfer.**
   - **target input property when transfer ends.**
2. **Transfer might:**
   - **remove item from source output property when it starts (isMove).**
   - **start when item is added to source output property (isPush)**
   - **have zero duration (isInstant)**

Transfer & I/O Semantics (#1)



Transfer & I/O Semantics (#2)



4D TBD

- More about space
- Formalize slicing
- Quantification
  - Units

Overview

- RoadMap
- Motivation
  - Behavior, review
  - 4D, requirements
- 4D Solution

  Objects and behaviors

  1. in space-time
  2. within time intervals, space regions
- **Summary**

Summary

- **Unify objects and behaviors as occurrences**
  - **occupying regions of space-time.**
- **Unify spatial and temporal relations as**
  - **relations between regions of space-time.**
- **Introduce portion composition**
  - **Specialize for slices of time and space**
  - **Specialize time slices for snapshots.**
  - **Specialized snapshots for start and end shots.**
- **Treat links as occurrences**
  - **Apply to model item flow semantics.**

Past ADTF Intro Slides

- **Intro to Behavior as Composite Structure**
  - **http://doc.omg.org/ad/2018-03-02**
- **Interactions: http://doc.omg.org/ad/18-06-11**
- **Object-orientation: http://doc.omg.org/ad/18-09-07**
- **State Machines, parts 1&2:**
  - **http://doc.omg.org/ad/18-12-09**
  - **http://doc.omg.org/ad/19-03-02**
- **Activities, part 2: http://doc.omg.org/ad/19-06-02**

More Information

- **Earlier slides (more onto)**
  - http://conradbock.org/bock-ontological-behavior-modeling-jpl-slides.pdf
- **Papers:**
  - **Ontological Behavior Modeling:** http://dx.doi.org/10.5381/jot.2011.10.1.a3
  - **Ontological Product Modeling:** https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=822748
  - **4D Requirements Modeling:** https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=919164
- **Application to BPMN:** http://conradbock.org/#BPDM
- **SysML2: Contact Bjorn Cole** bjorn.f.cole@lmco.com