SST/SysML2 Semantic Assets and Debt : Onto (Time and) Space Modeling

Conrad Bock
U.S. National Institute of Standards and Technology

Hans Peter de Koning, DEKonsult
Ed Seidewitz, Model-driven Solutions

Overview

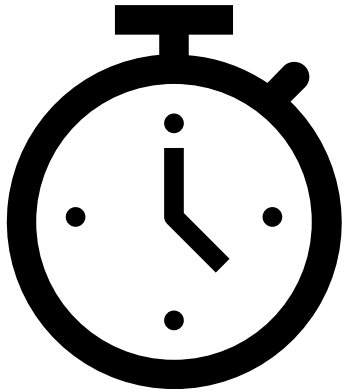
- Quantitative and Qualitative (Time)
- Space Modeling
  - Qualitative
  - Topology
    - Boundaries
    - Structure
  - SST Library
  - TBD
- Summary

Semantic credit card

Overview

- **Quantitative and Qualitative (Time)**
- **Space Modeling**
  - **Qualitative**
  - **Topology**
    - **Boundaries**
    - **Structure**
  - **SST Library**
  - **TBD**
- **Summary**

Qual- and Quant- itative Time

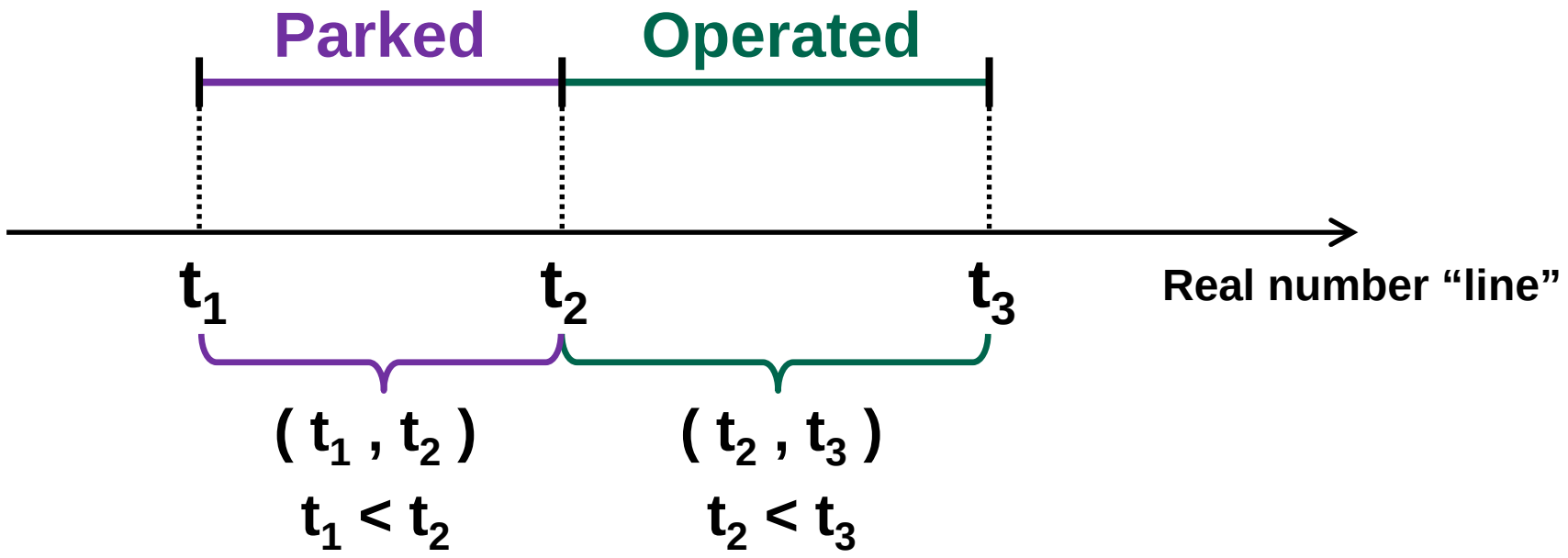


Qual- itative

Quant- itative

§ **Numbers not always necessary.**

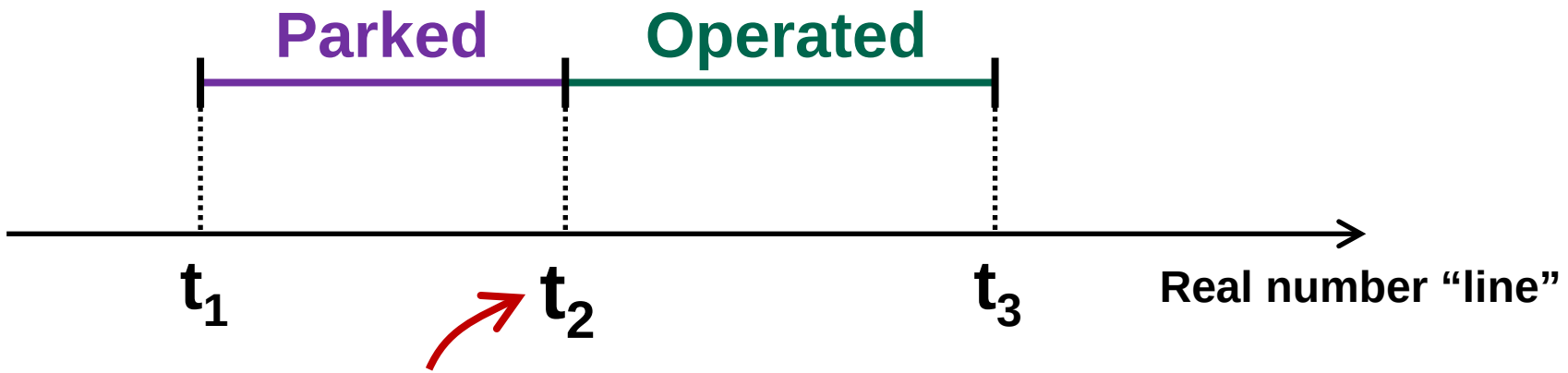
Quantitative Time Intervals



Time as Number

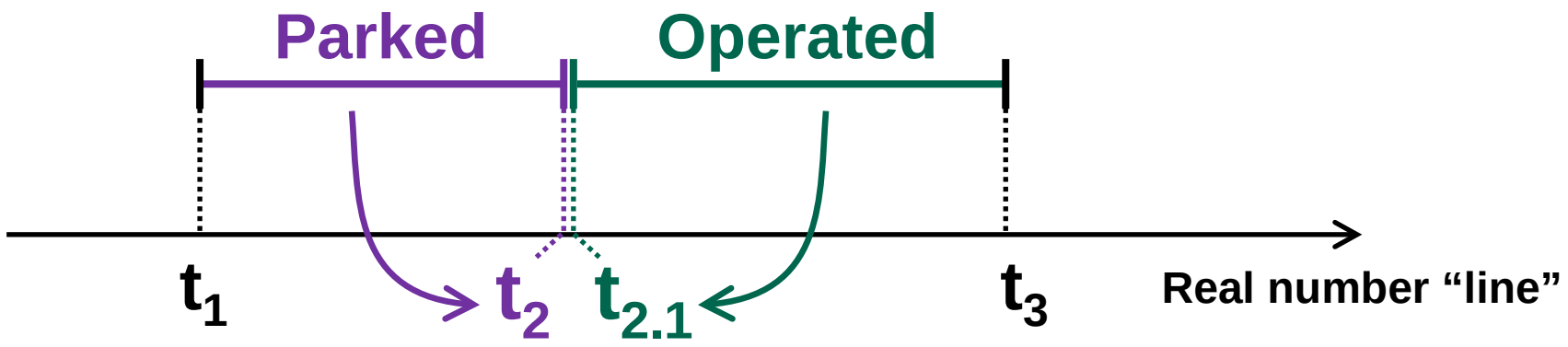
- Time interval = pair of real numbers.

Quantitative Time Intervals Problem



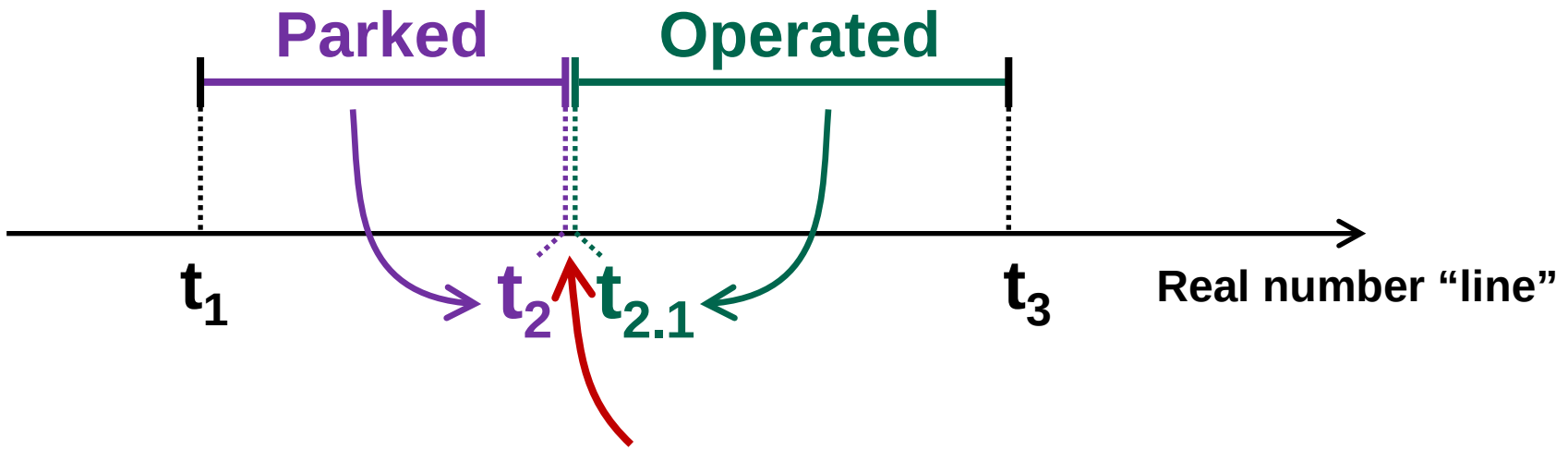
- Intervals share the same number?
- Contradict each other.

Quant Time Intervals Separate?



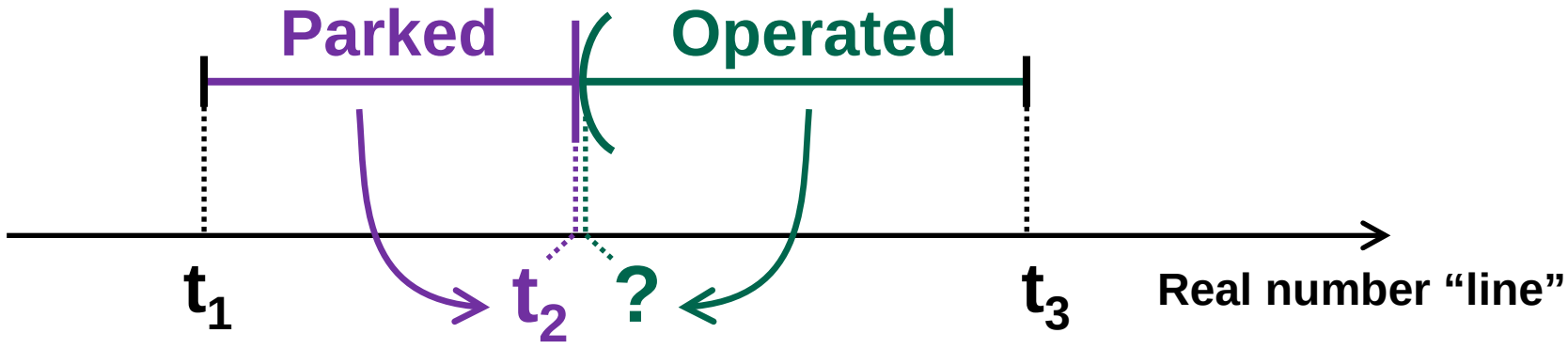
- t_2 $t_{2.1}$ “right next” to each other?
- Eliminates contradiction.

Quant Time Intervals Separate → Gap



- **Gap** without shared number.
  - Not parked or operated in gap.
- Filling gap with "middle" state leads to same problem.

Quant Time Intervals Closed/Open?

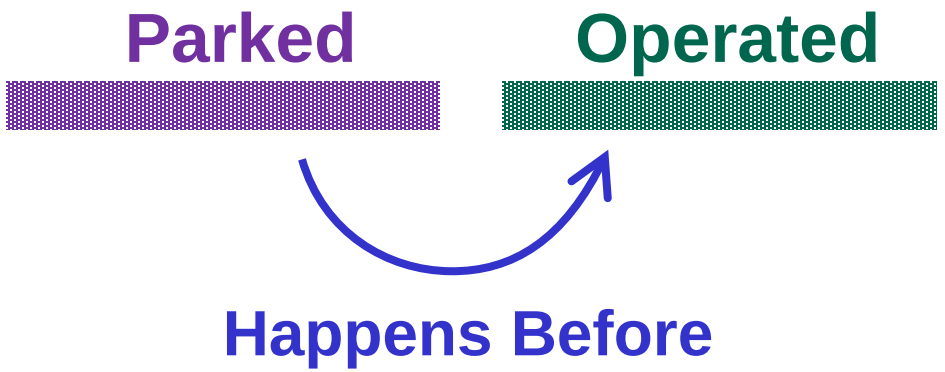


Closed set of numbers includes t_2

Open set of numbers includes all down to t_2 but not t_2

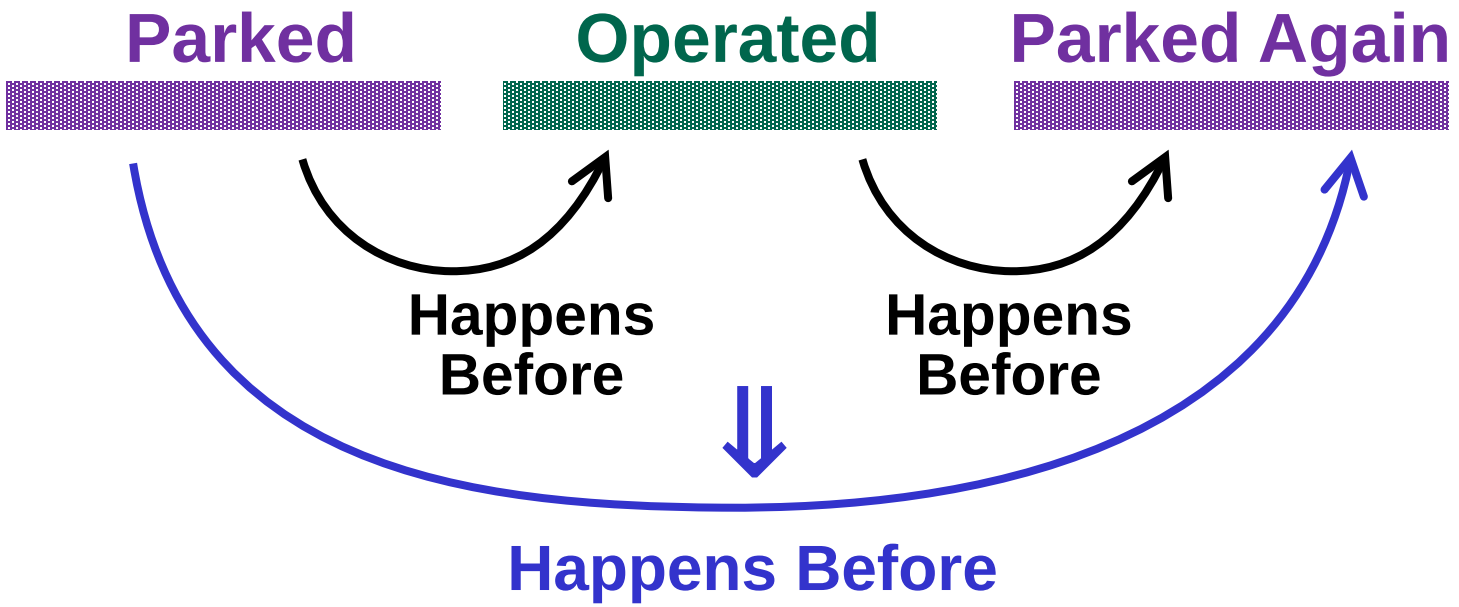
- **What time does the car start operating?**
  - **No number for it.**

Qual Time: Relations *Between* "Periods"



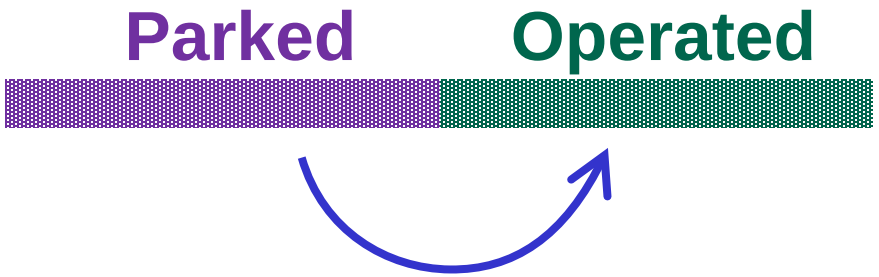
- Only relations between periods of time.
- No numbers
- Time "points" are periods of zero duration.

Qual Time: Logical Relations



- **Transitive relation (logically-speaking, ie “onto”)**
- **Other logical characteristics, see onto time modeling**

Qual Time: Logical Solution



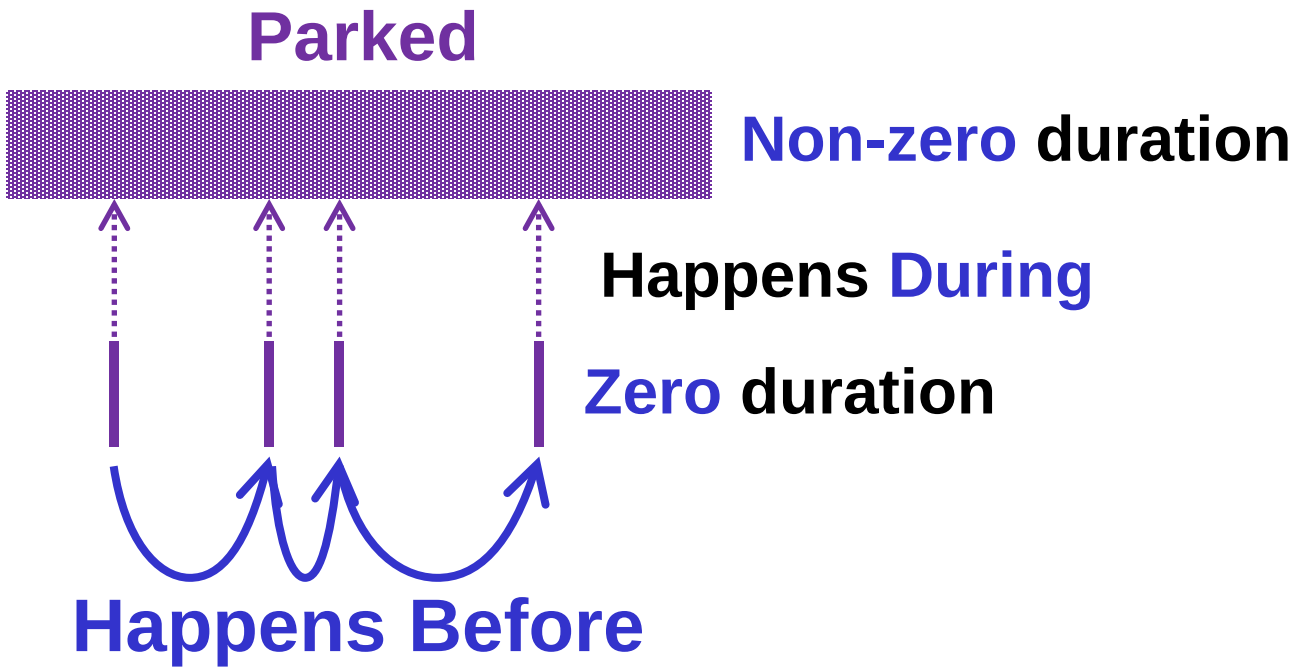
Happens Just Before

≡

No periods happen
after Parked and before Operated

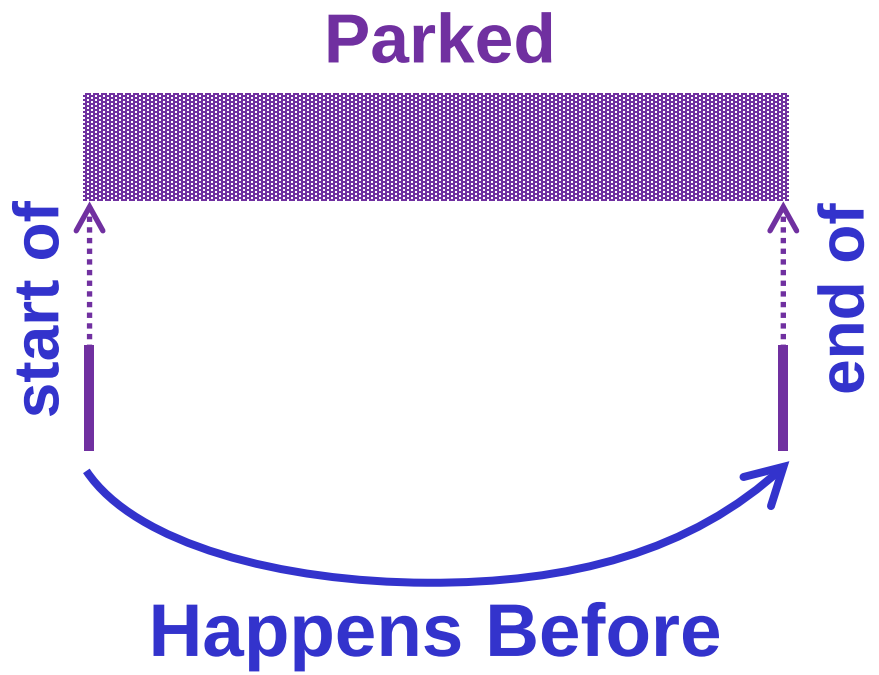
- A special kind of Happens Before
  - No time periods after the earlier one and before the later one.
- No contradiction
  - Parked and Operated apply to completely separate periods.

Qual Time: "Time Point" Periods



- Time "points" are periods of zero duration, which can
  - Happen during others of (same or) longer duration.
  - Happen before others (but not themselves).

Qual Time: Start/End "Time Points"



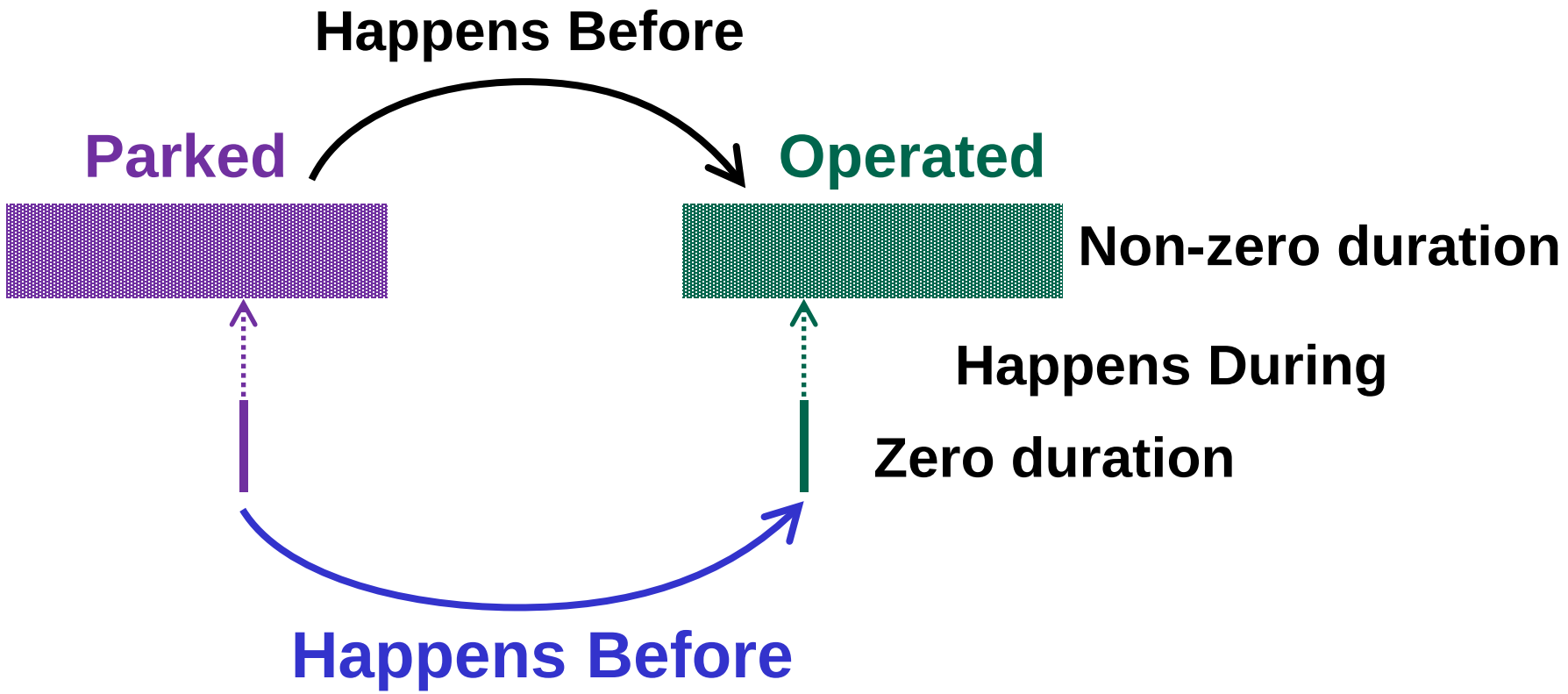
Non-zero duration

Happens During

Zero duration

- Can "start" a period, "end" a period.
  - Start happens before end (transitivity).
  - These are the same for zero duration periods.

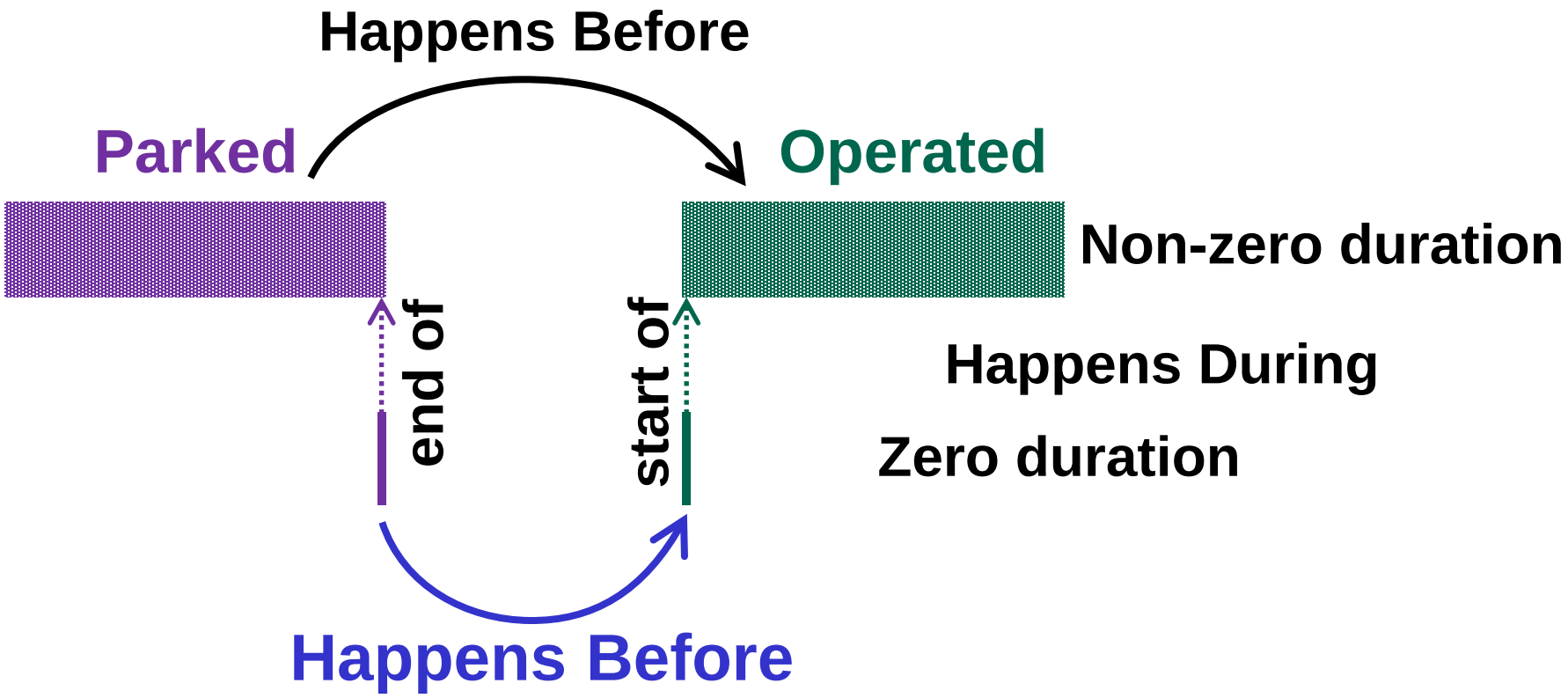
Qual Time: “Time Points” Between Periods



- All zero periods in earlier one …
- … happen before all in later one.

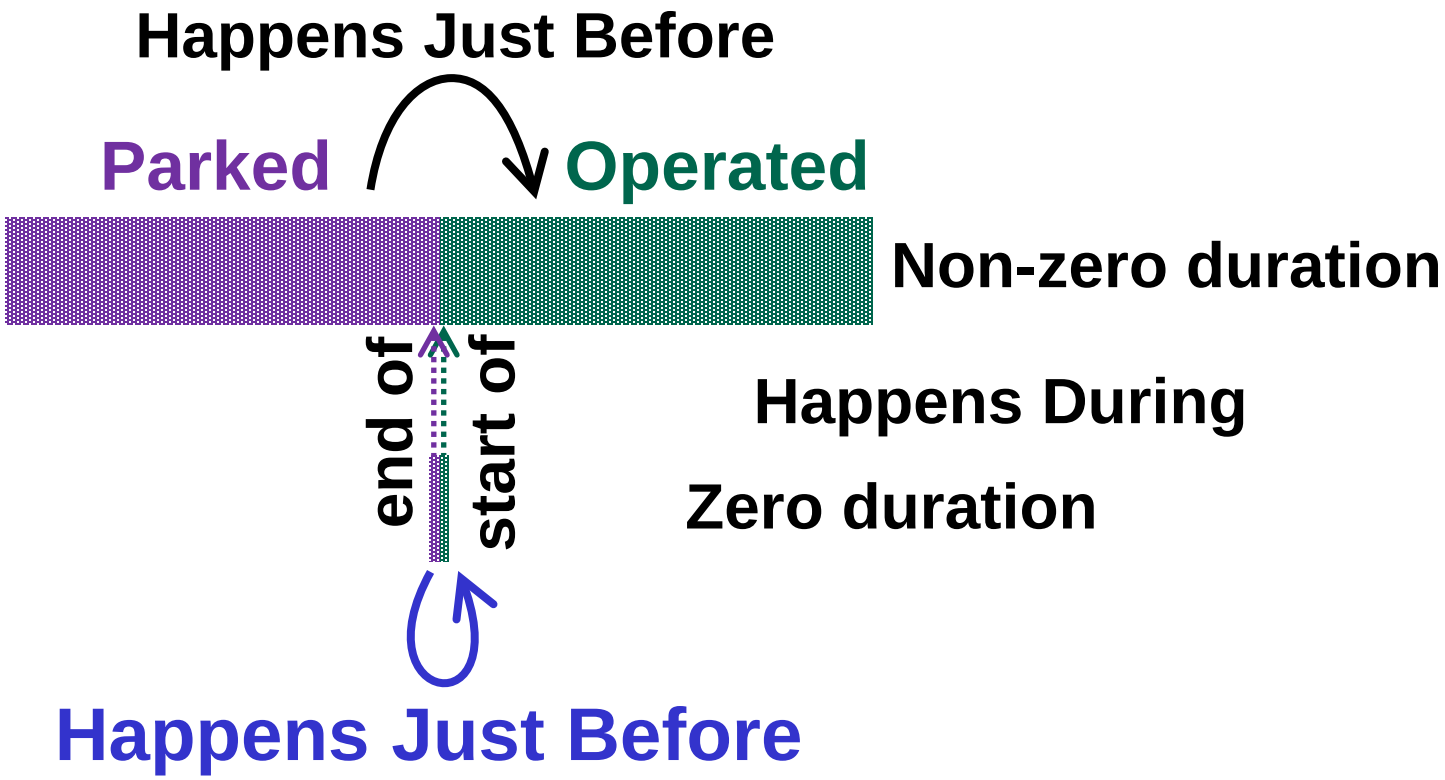
Qual Time: “Time Point” Relations

Between Start /End



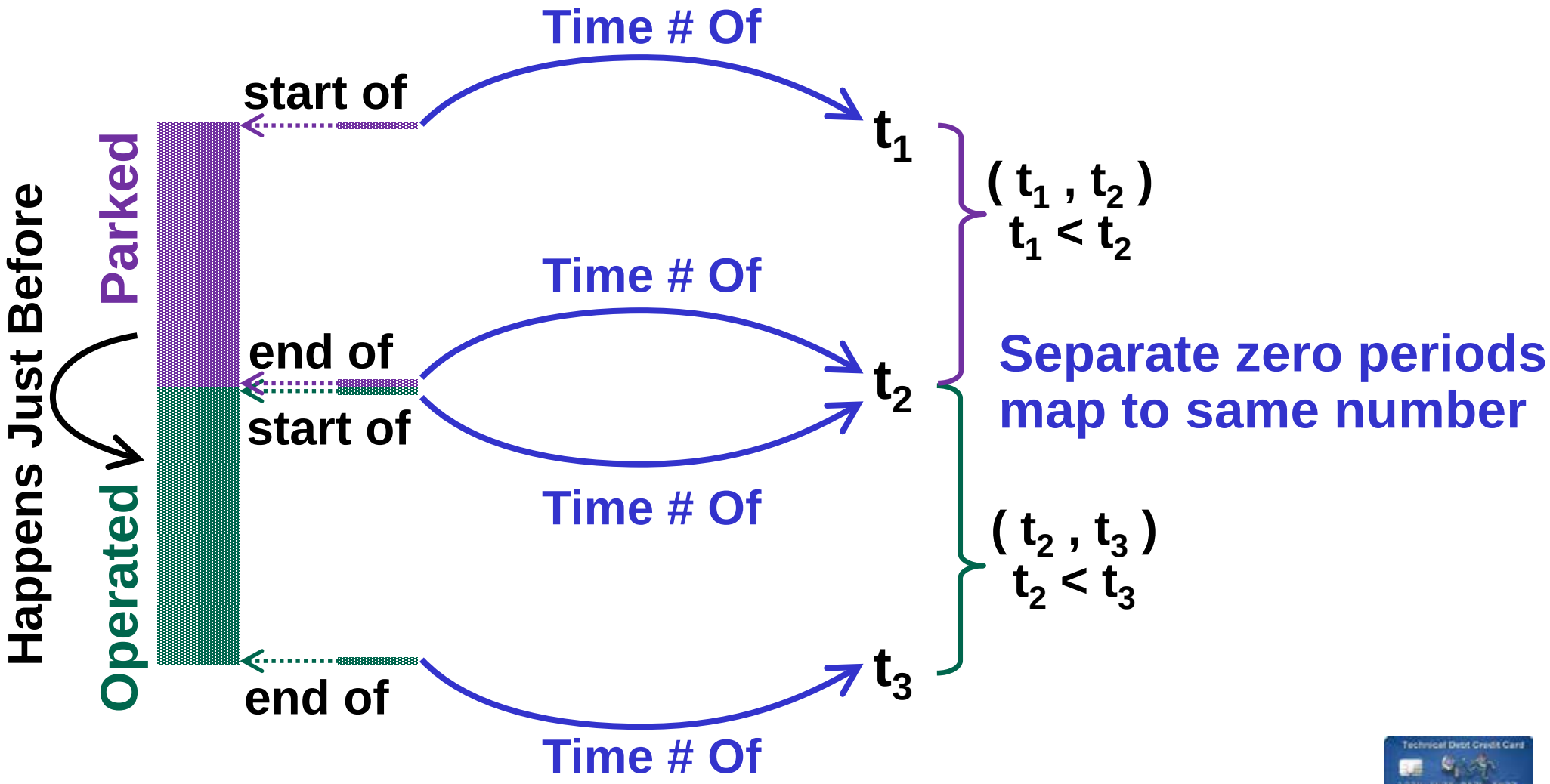
§ … including start/ends.

Qual Time: “Time Point” Relations Between Start /End, Just Before



- No periods, including zeroes, happen …
- … after the first and before the second.

Qual to Quant Time (SST)

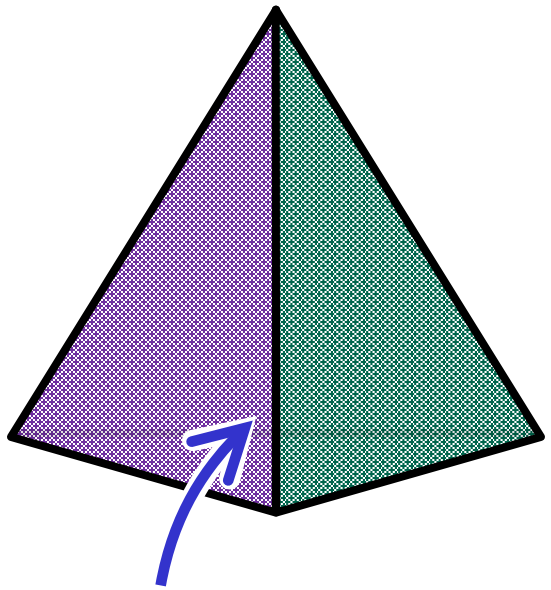


§ Happens just before ⟶ same real number

Overview

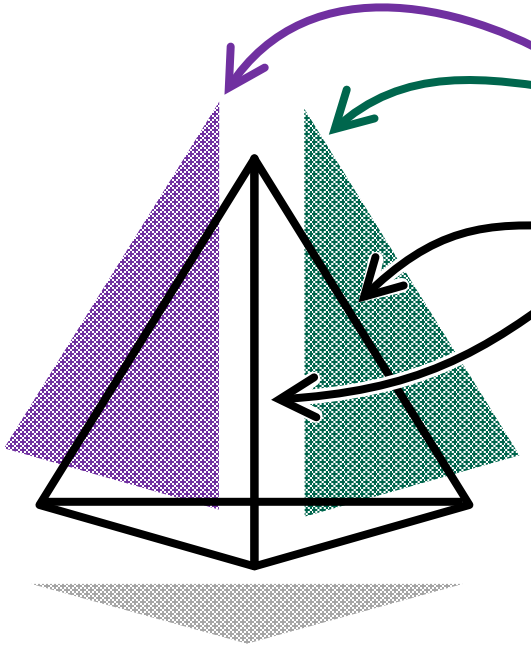
- Quantitative and Qualitative (Time)
- **Space Modeling**
  - **Qualitative**
  - Topology
    - Boundaries
    - Structure
  - SST Library
  - TBD
- Summary

Space Modeling



What color is this edge?

Quant

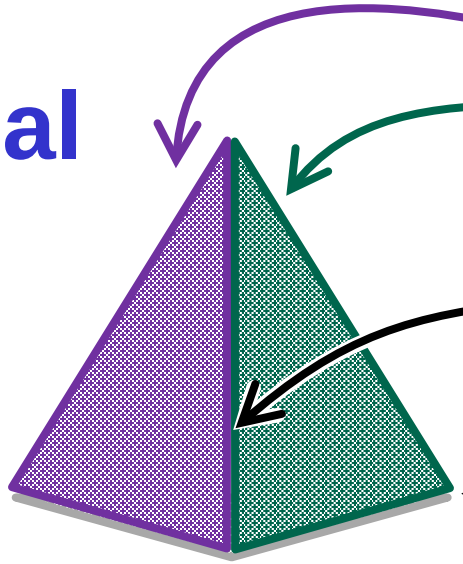


Open sets of surface points

bounded by the same lines with …

either no color or contradictory colors

Qual

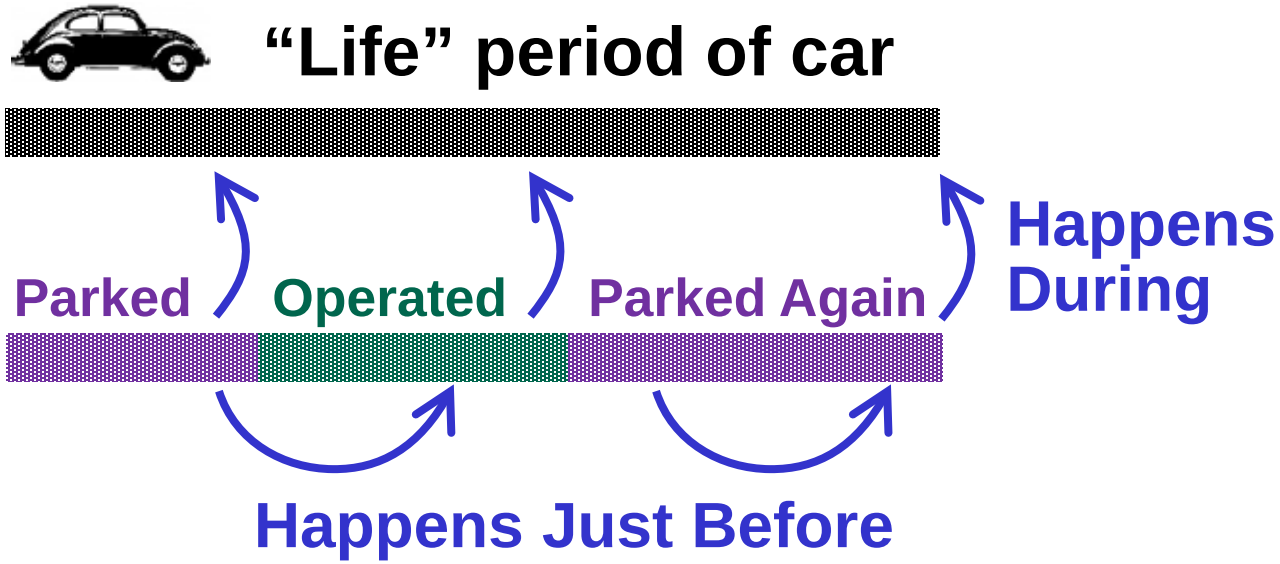


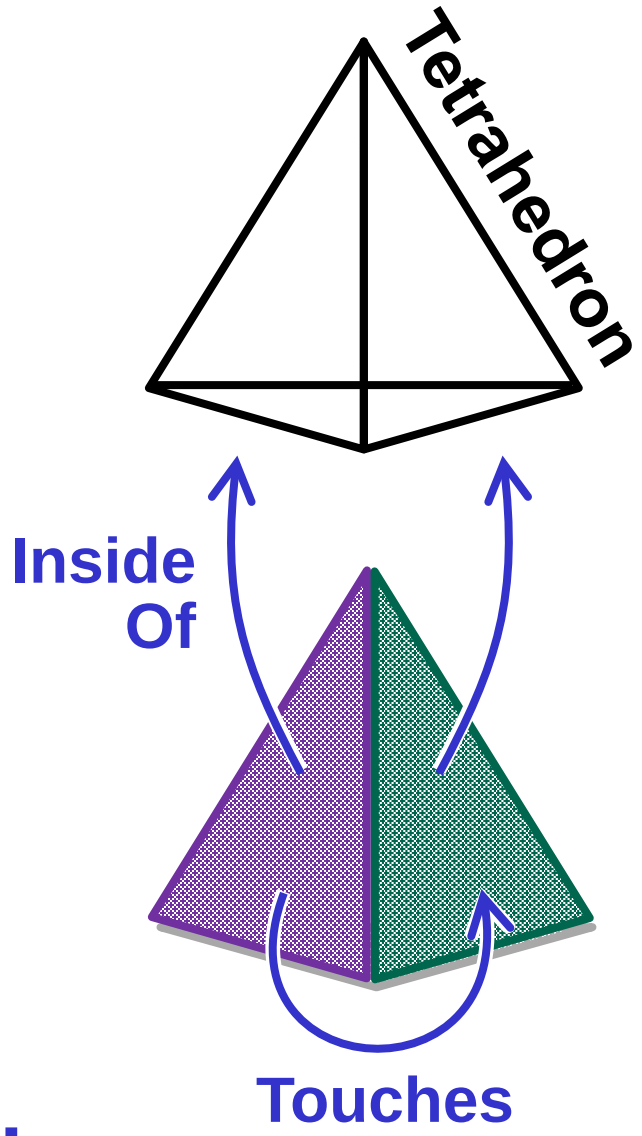
Spatial regions with their own boundary lines and colors

and no other regions in between

- Same problem …
- … same solution.

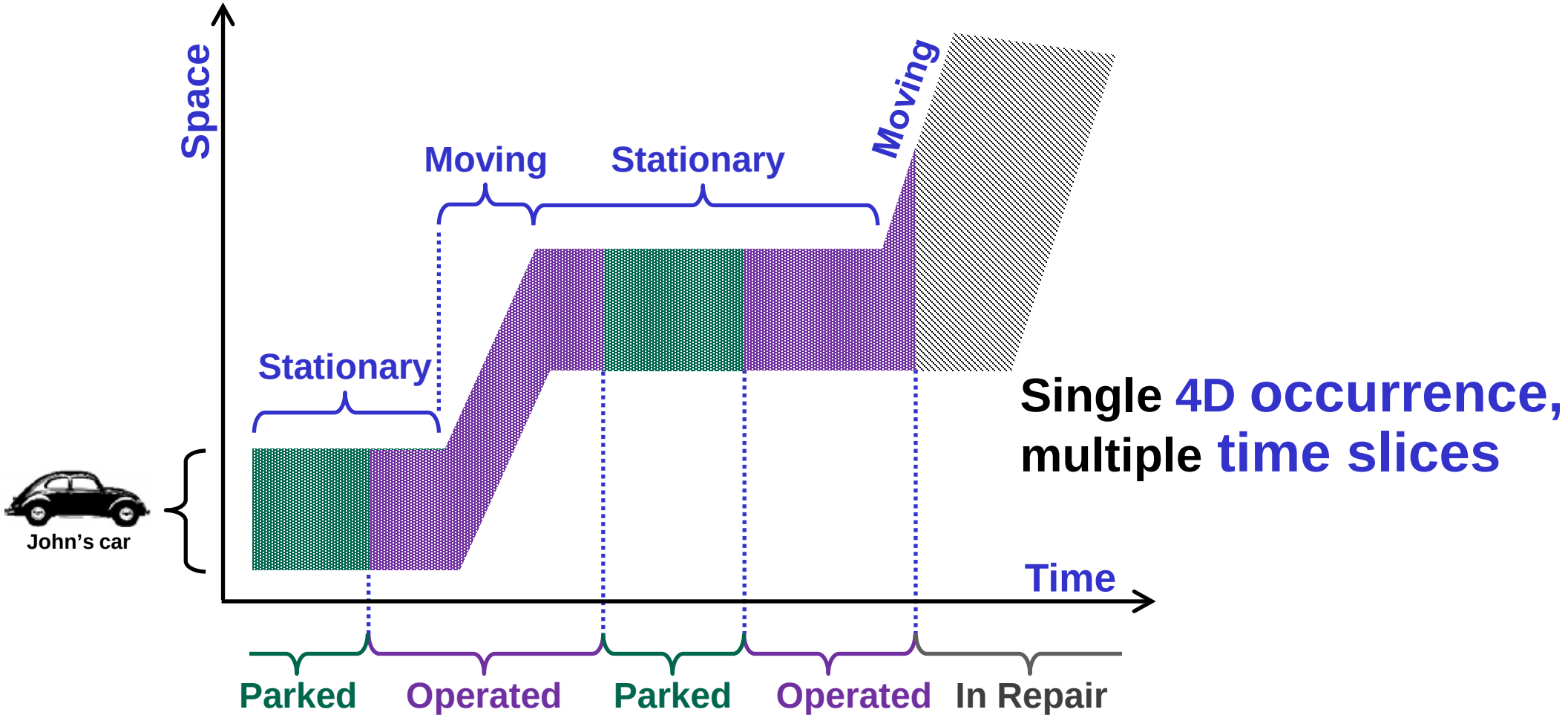
Qual Time and Space: Similarities





- Time period ~ space region
- Happens during ~ inside
- Happens before ~ outside
- Happens just before ~ touches
- Time period start/end ~ space boundary

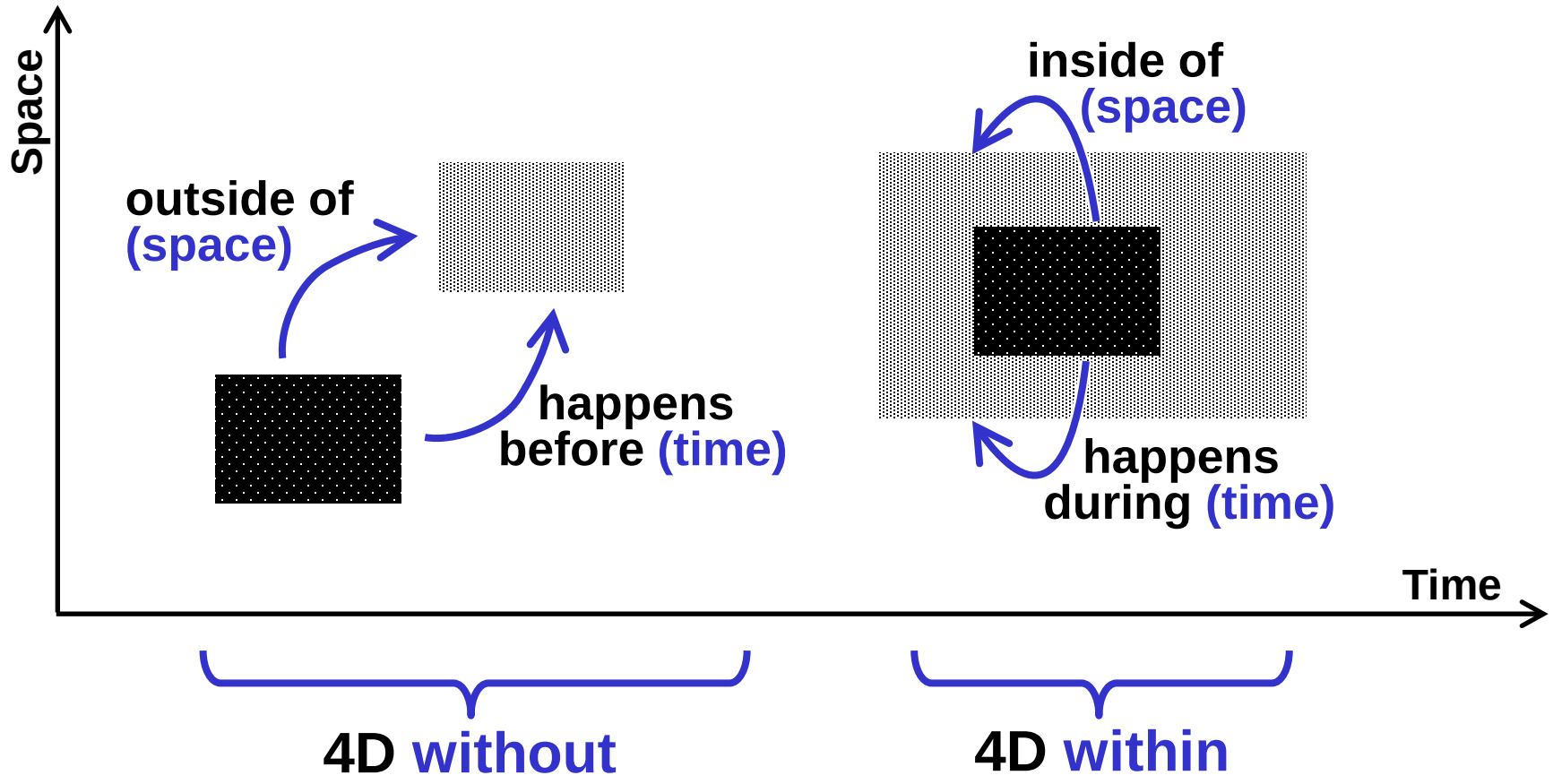
Qual Time & Space: 4D (SST Occurrences)



Single 4D occurrence, multiple time slices

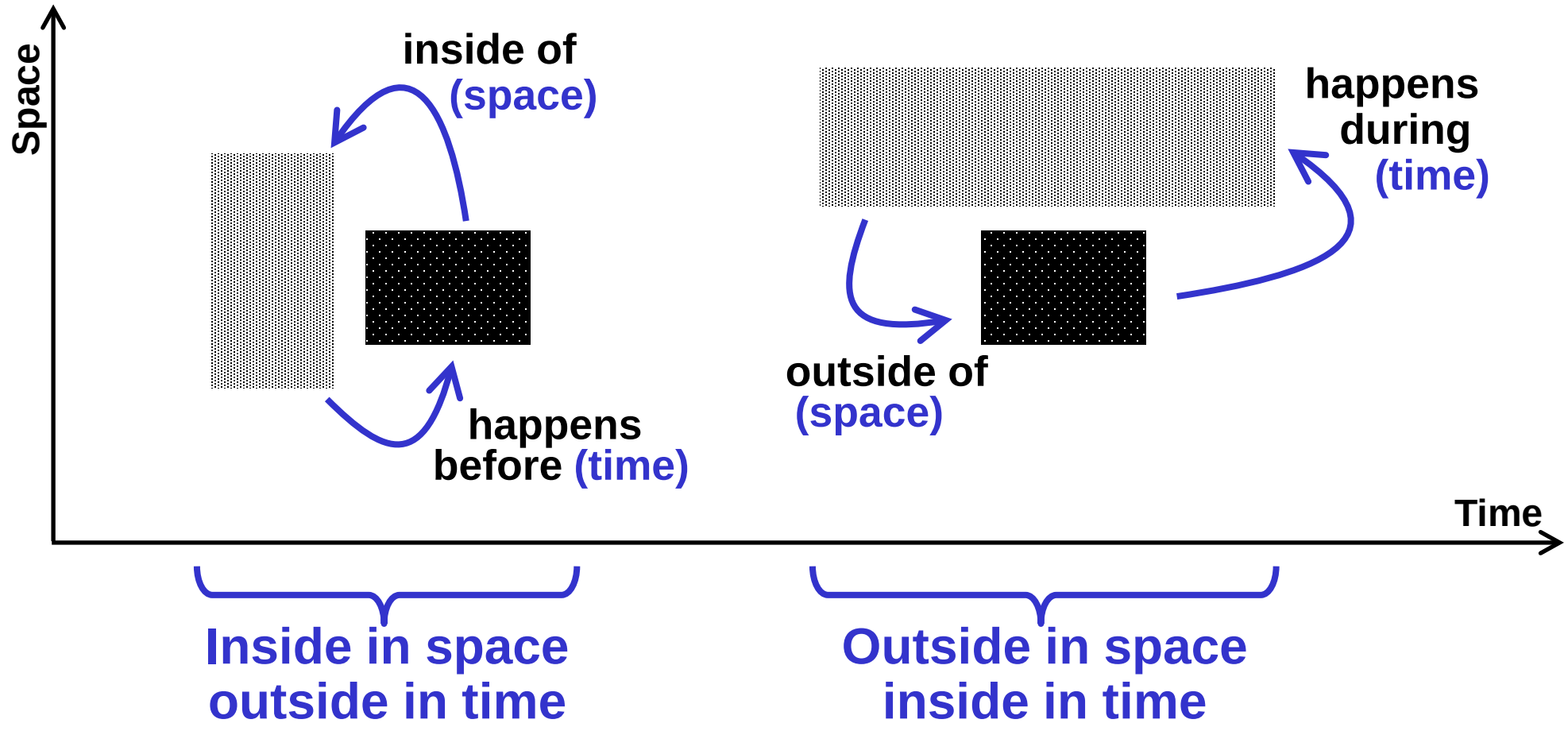
§ "Occupying" space, "taking up" time, all at once.

4D: “Exclusion” and “Inclusion”



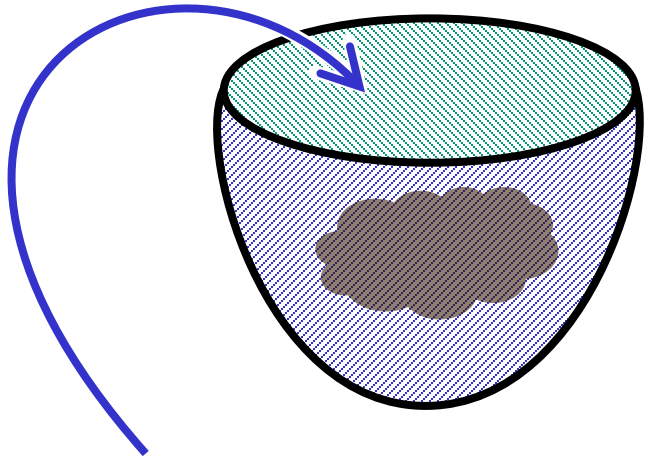
- Completely separate in 4D or completely included
  - Specialized to time and space separation/inclusion.

Inclusion: Time xor Space, Not Both

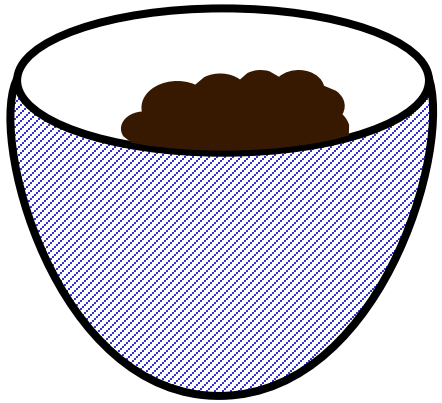


- Separate in time, not space, or vice-versa
  - Both imply 4D without

“In”-word



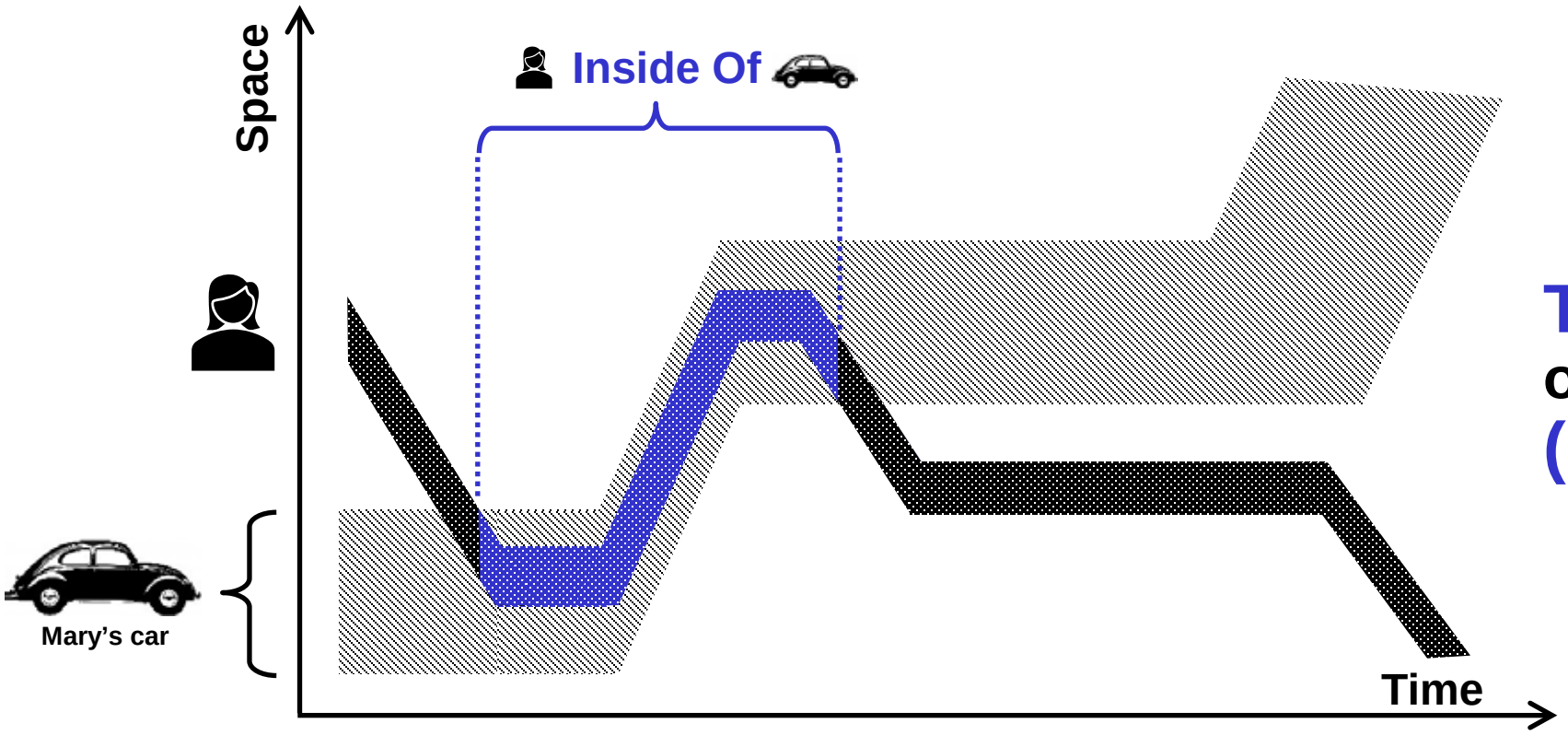
Opening of cup is
part of boundary
Coffee is 4D-insideOf cup



Opening of cup is
NOT part of boundary
Coffee is NOT 4D-insideOf cup

- English “inside” has multiple meanings
  - Distinguished by specifying what’s in included in the cup volume

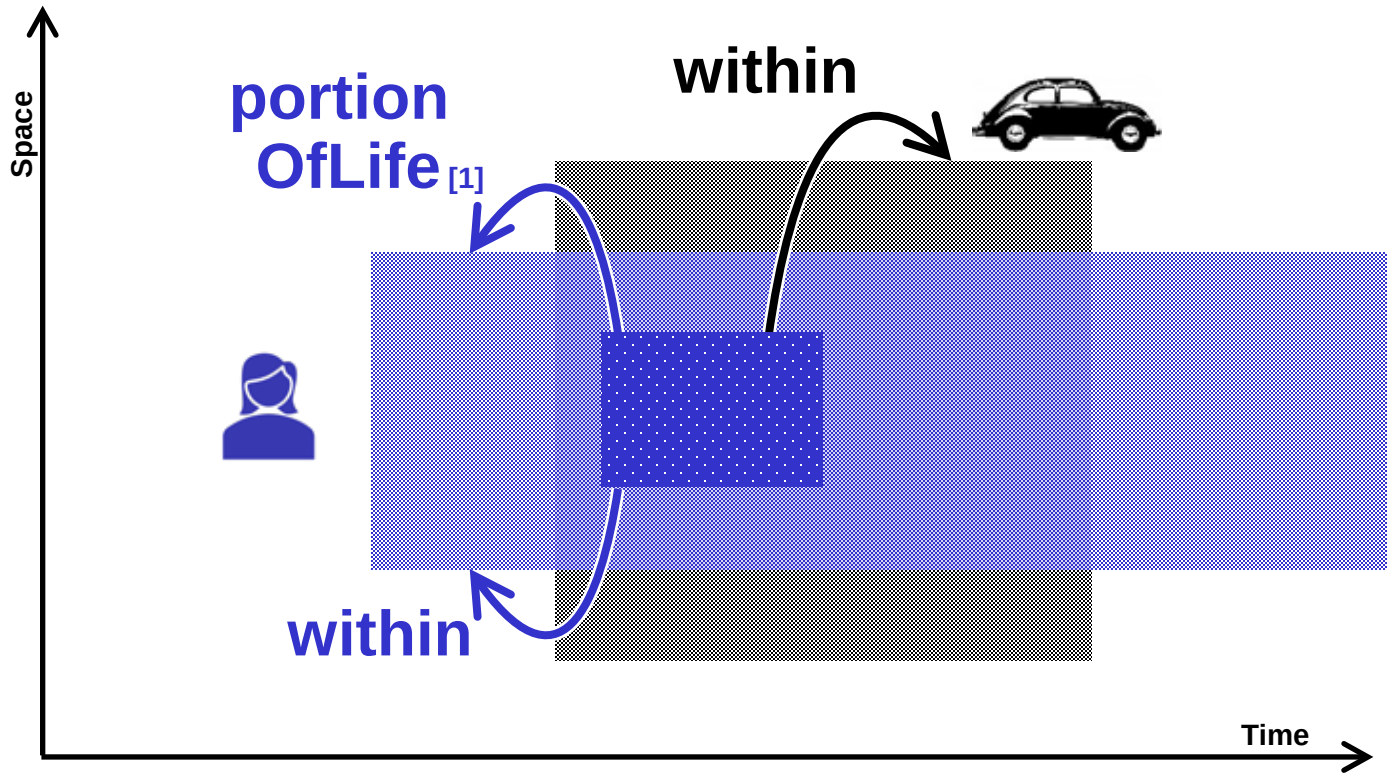
4D Inside Of ⇏ Part Of



Two 4D occurrences (SST Lifes)

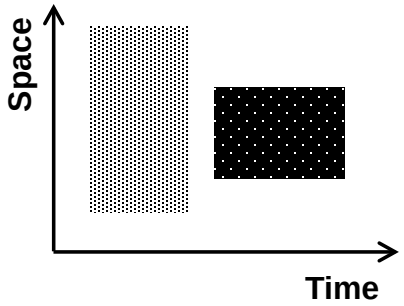
§ Driver is 4D-within car for some period
  – but not part of it.

4D Within ◁— Portion Of

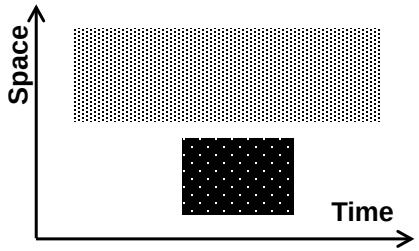


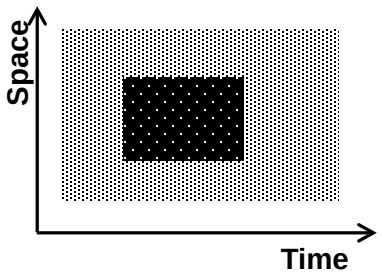
- Portion of one life, might be within multiple lives.
  - Multiple occurrences in the same time and space.
  - portionOf is a tree (one root, semi-lattice), within is a DAG.

Space Time Relation Terms

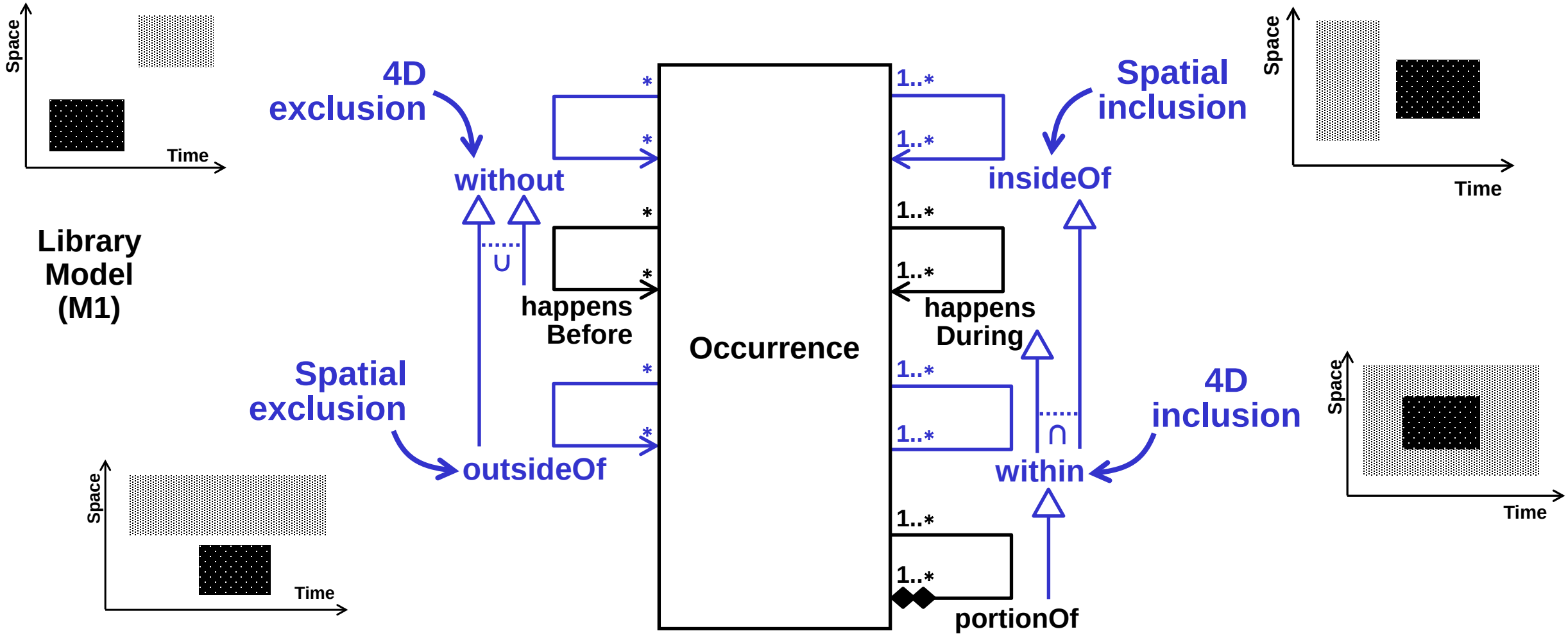


	Inclusion	Exclusion
Time	Happens During	Happens Before
Space	**Inside Of**	**Outside Of**
Both (4D)	**Within**	**Without**



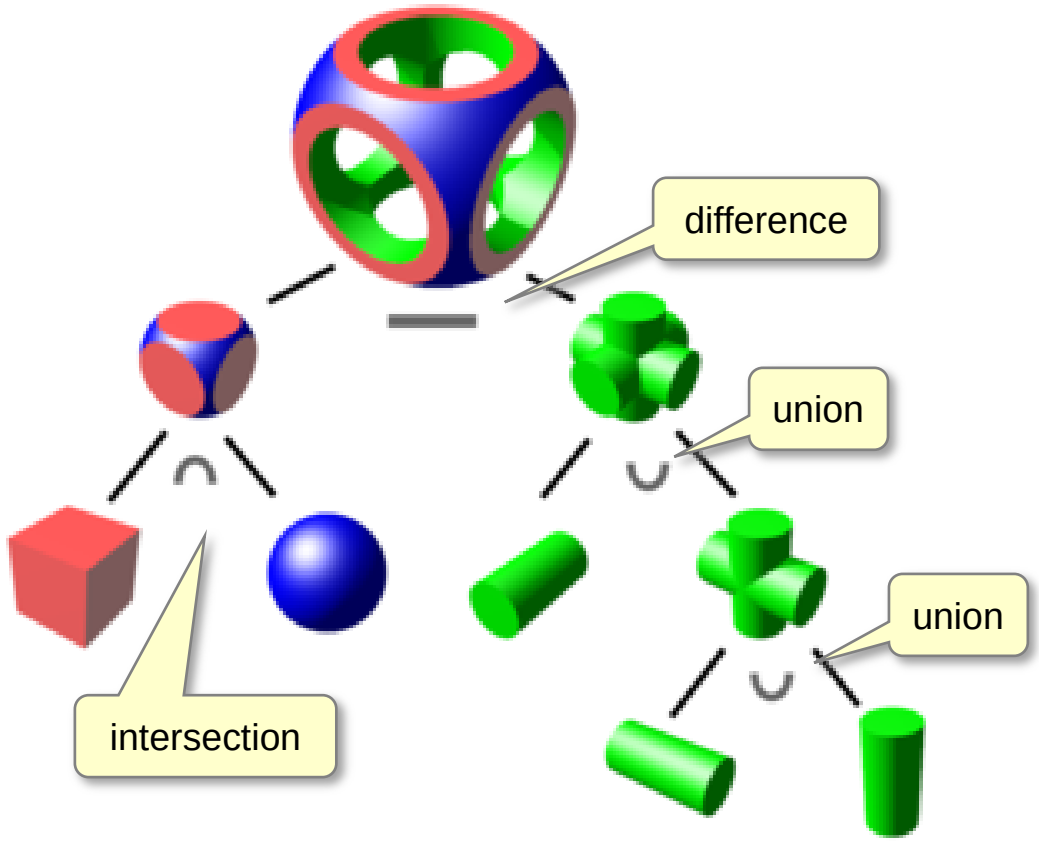


SST: 4D & Spatial relations



Bock, Galey, Onto 4D Requirements, https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=919164, 2019

Constructive Solid Geometry (CSG)

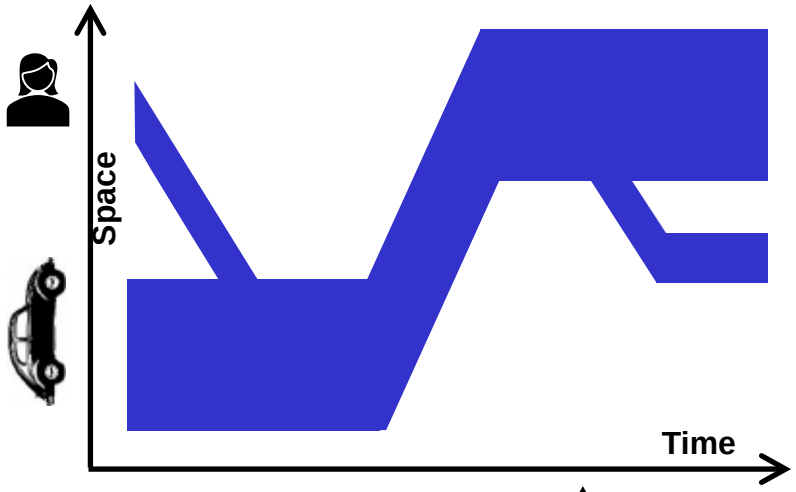


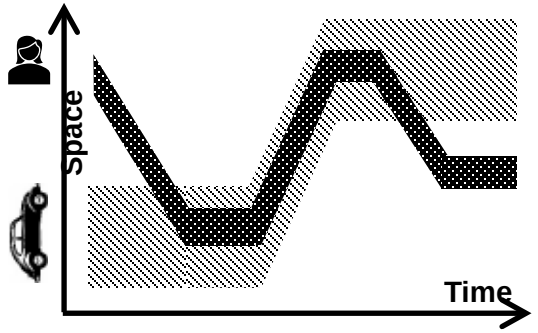
§ **Union, intersection, and subtraction of shapes**

– **Not assembly, shapes overlap.**

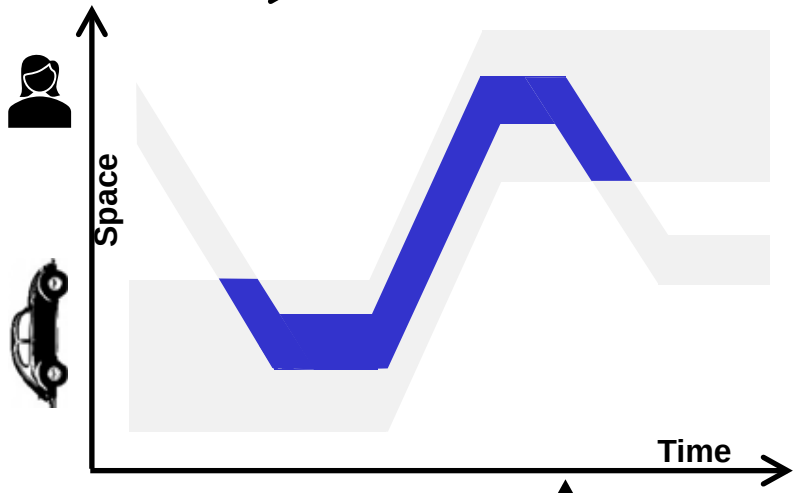
https://en.wikipedia.org/wiki/Constructive_solid_geometry

Mary and car





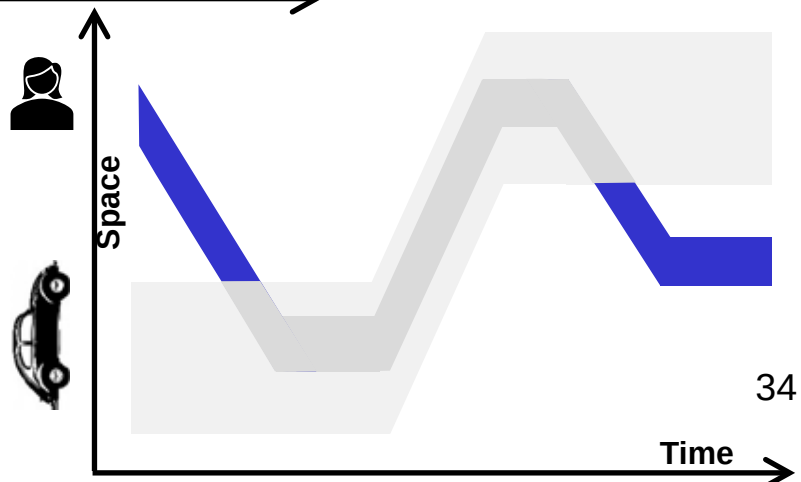
Mary “in” car



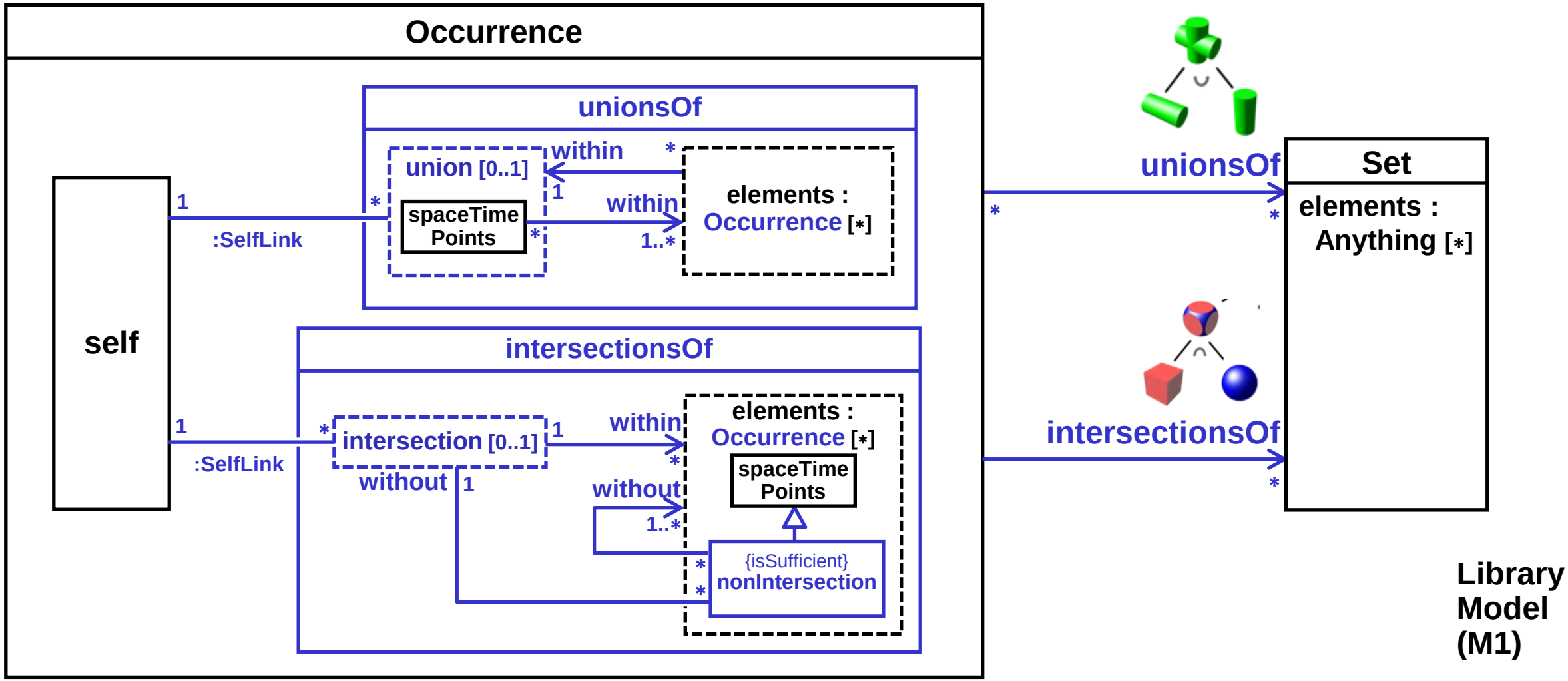
C “O”G

- Between 4D point sets.
- Applicable to assembly planning, traffic safety

Mary “out of” car



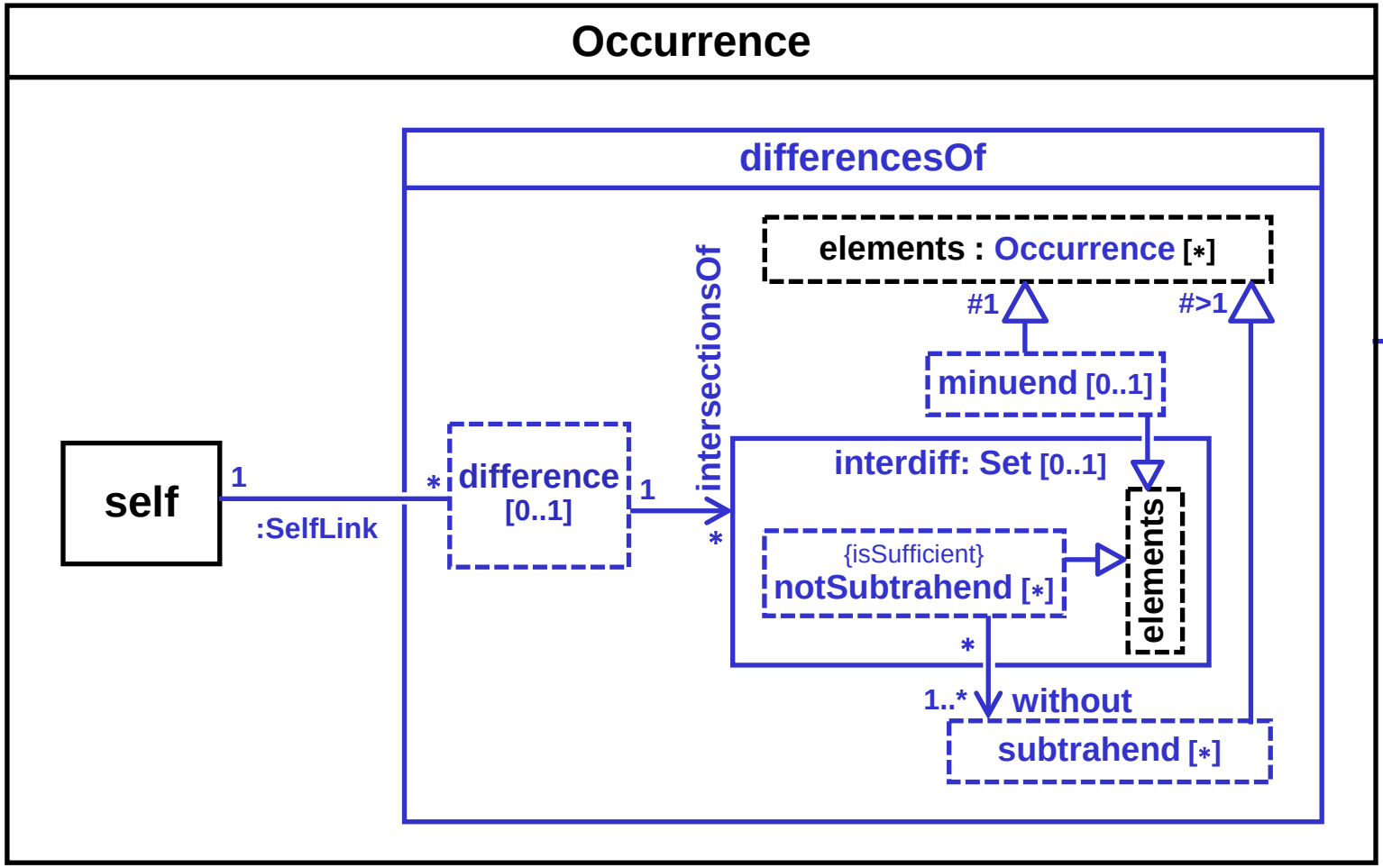
CSG Relations, Multiple, Union&Intersection



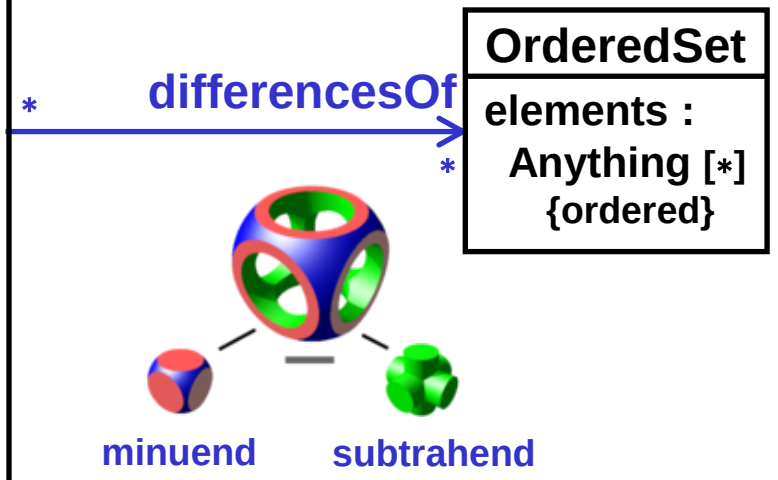
§ **Each union/intersection set result constrained separately.**

– **Connectors for necessary, sufficient conditions.**

CSG Relations, Multiple, Difference



interdiff element union
closure vs specialization?



https://en.wikipedia.org/wiki/Subtraction

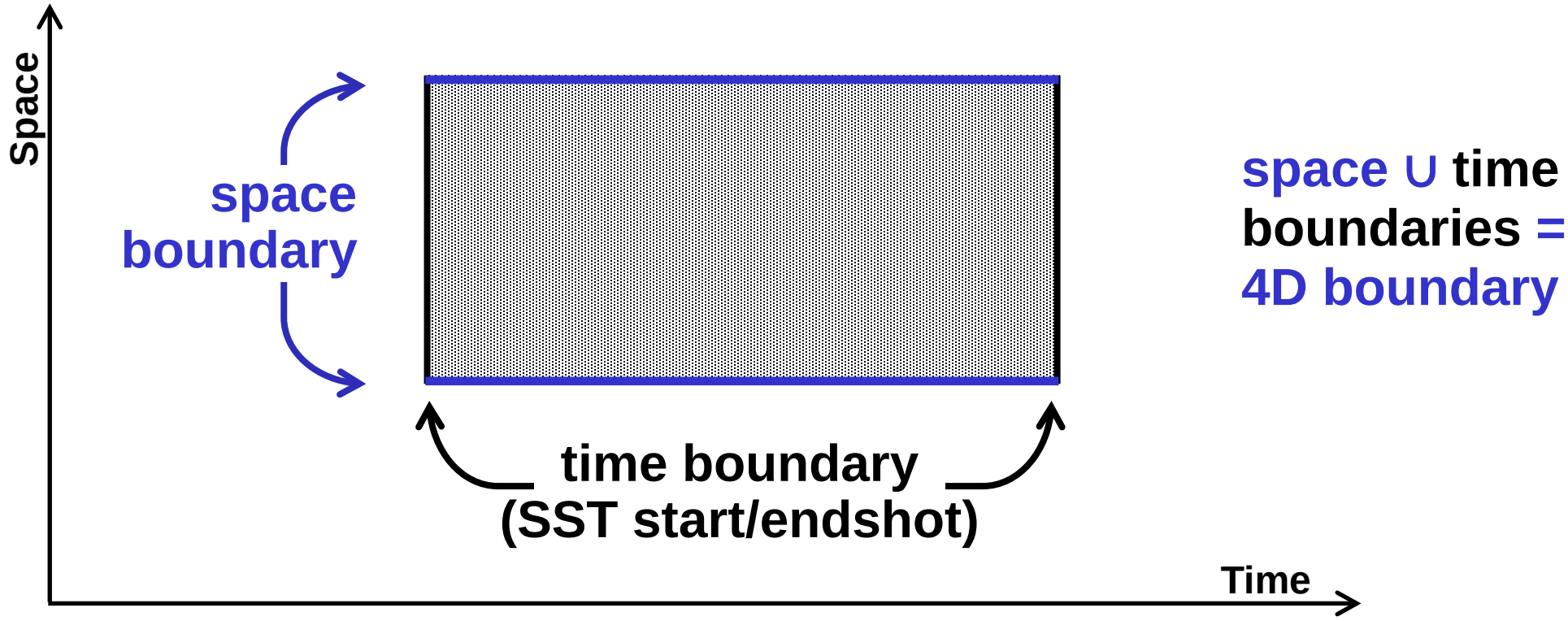
Library Model (M1)

§ **Constrains each difference set result separately.**
  – **As intersection of minuend and complement of subtrahend**

Overview

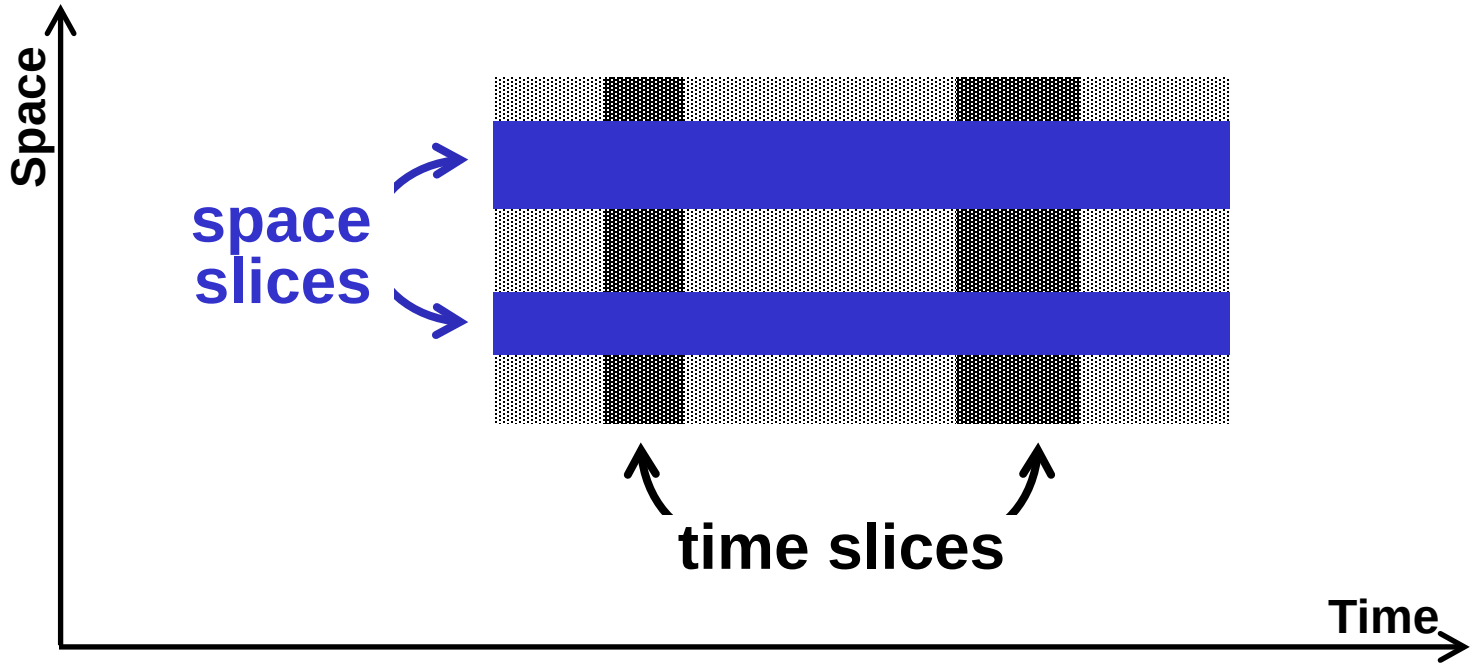
- Quantitative and Qualitative (Time)
- Space Modeling
  - Qualitative
  - **Topology**
    - **Boundaries**
    - Structure
  - SST Library
  - TBD
- Summary

“Shapes” ≡ Spatial Boundaries



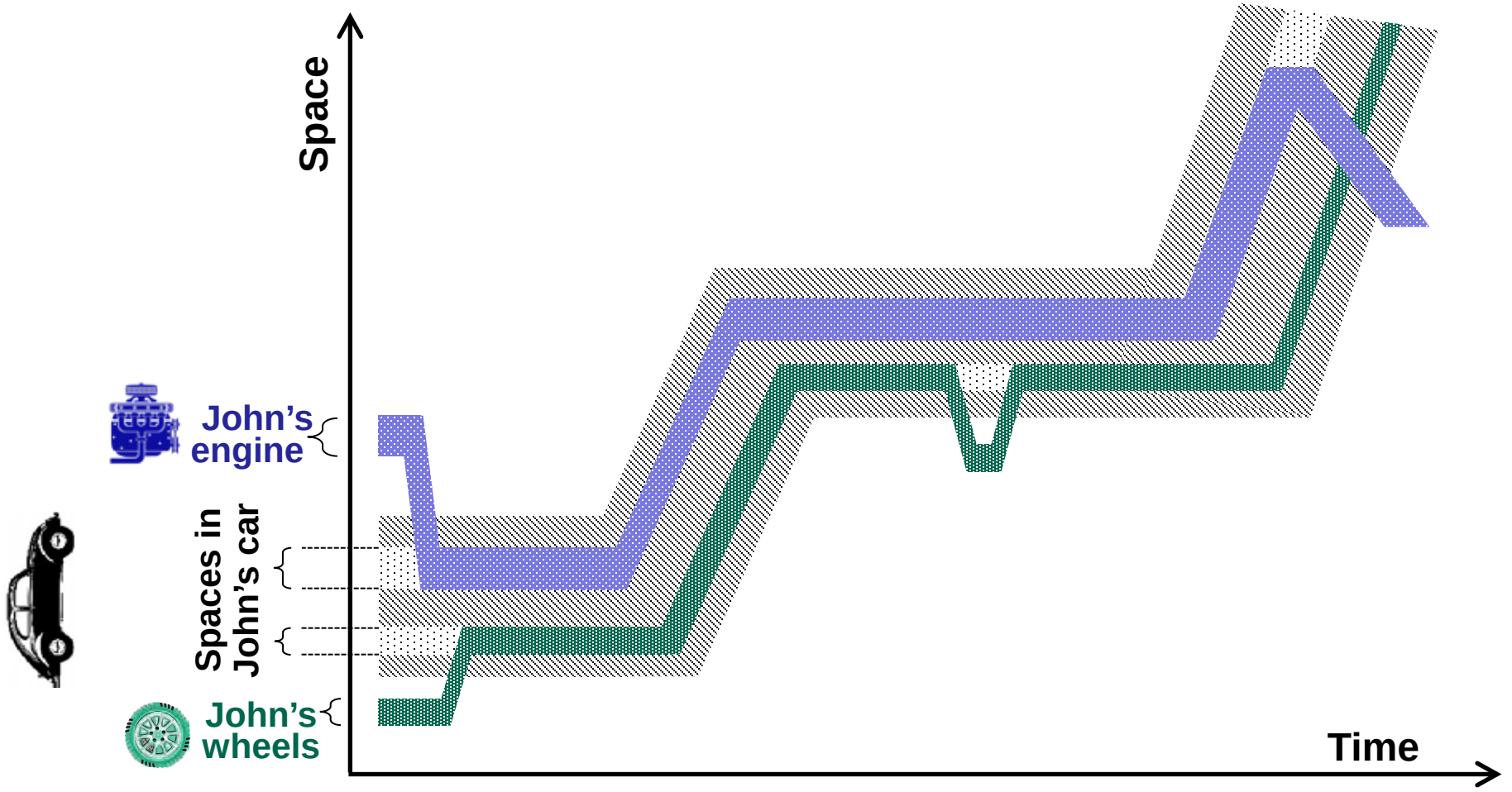
- Space boundary analogous to start/endShots ...
  - What’s the space version of time slices?

Space Slices (SST)



- Space slices are analogous to time slices.
  - Extend in time over entire life.

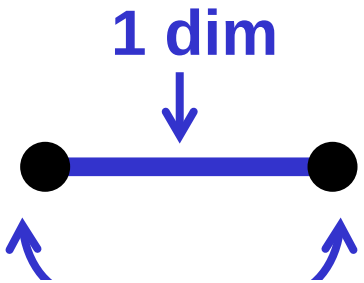
Space Slices & Shots, Relative

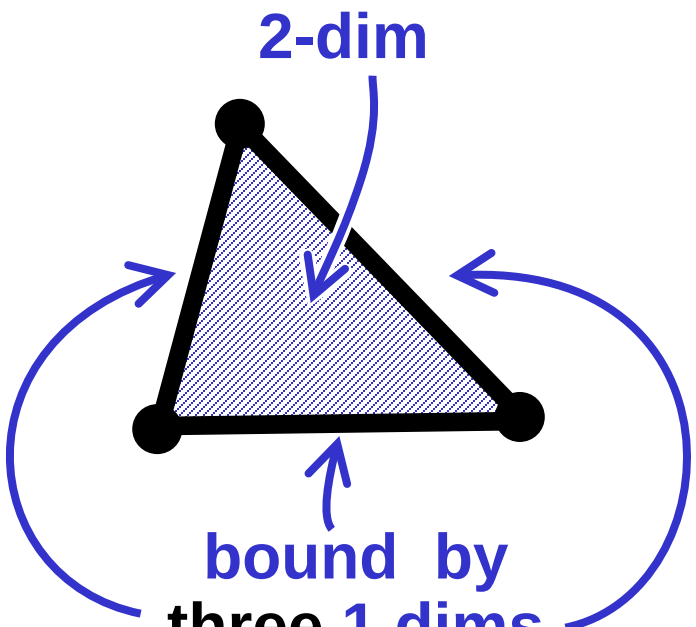


- Space slices = portions at the same place relative to what they're portions of.

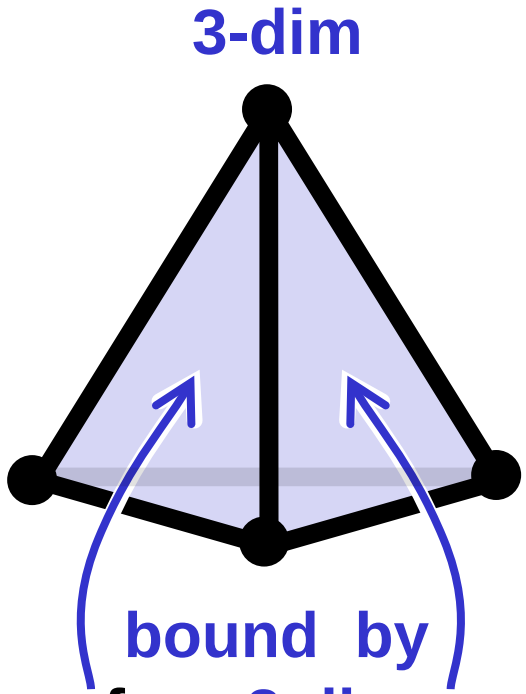
Boundaries are Lower Dimension

no boundaries





bound by
three (shared) 0 dims

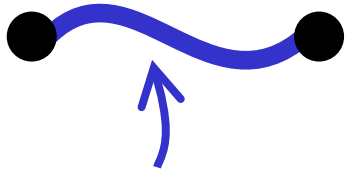


bound by
six (shared) 1 dims

bound by
4 (shared) 0 dims

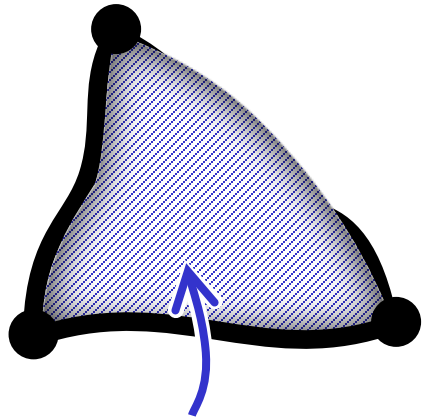
Boundaries ⇏ Flat/Straight

1 dim



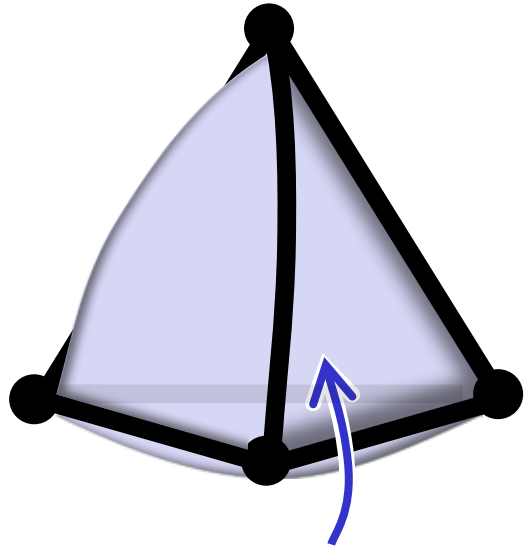
curved in two dimensions,
but still
a 1 dim bound by
two 0 dims

2-dim



extending in three dimensions
but still
a 2-dim bound by
three 1 dims bound by
three (shared) 0 dims

3-dim



faces not flat but still
a 3-dim bound by
four (shared) 2 dims bound by
six (shared) 1 dims

§ Dimensions are from the element's viewpoint.

Boundaries have no Boundaries

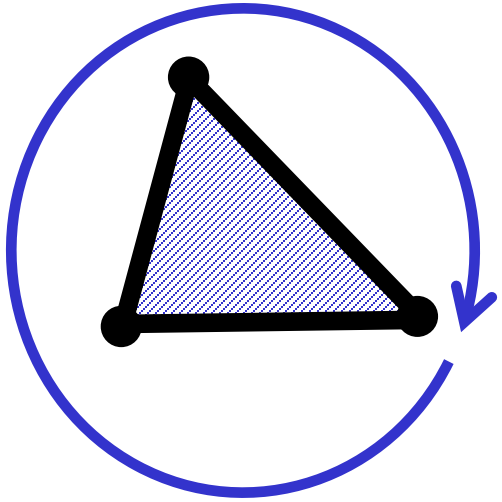
0 dim

no boundaries

1 dim

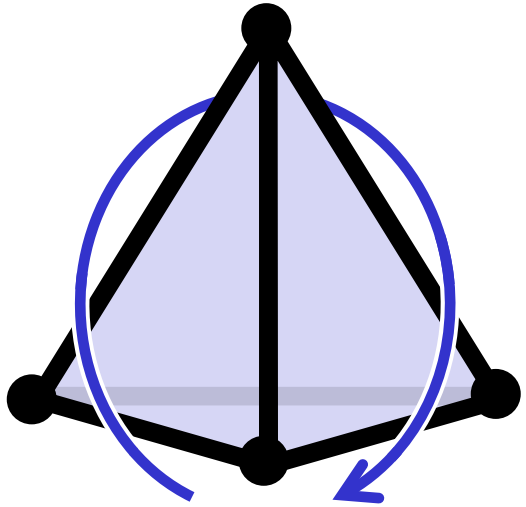
boundary
is 0 dims

2-dim



folds back on itself

3-dim

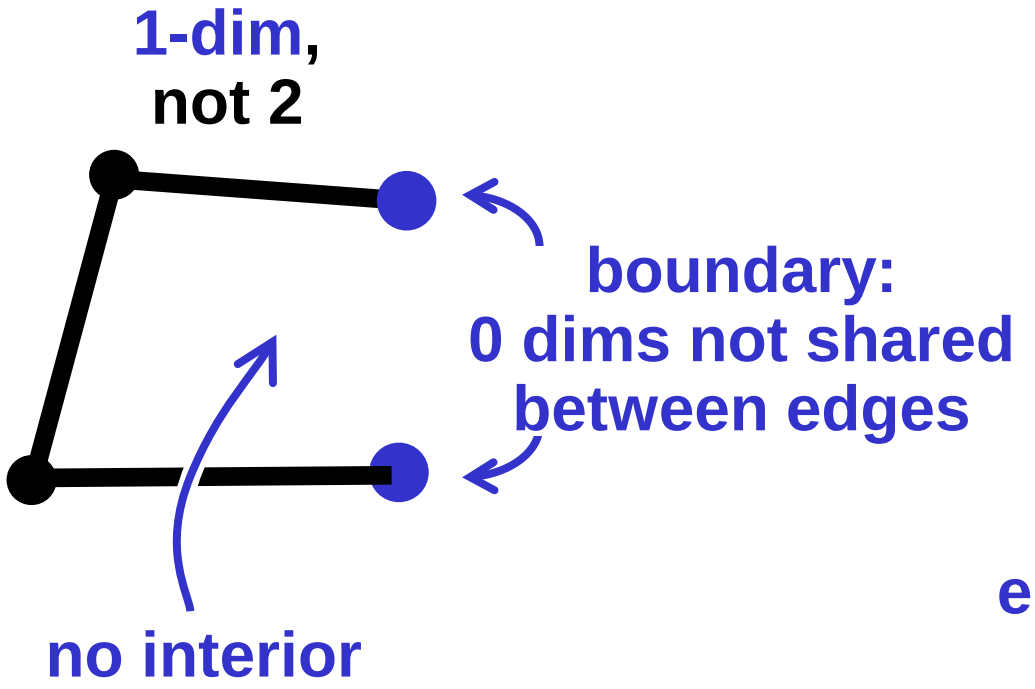


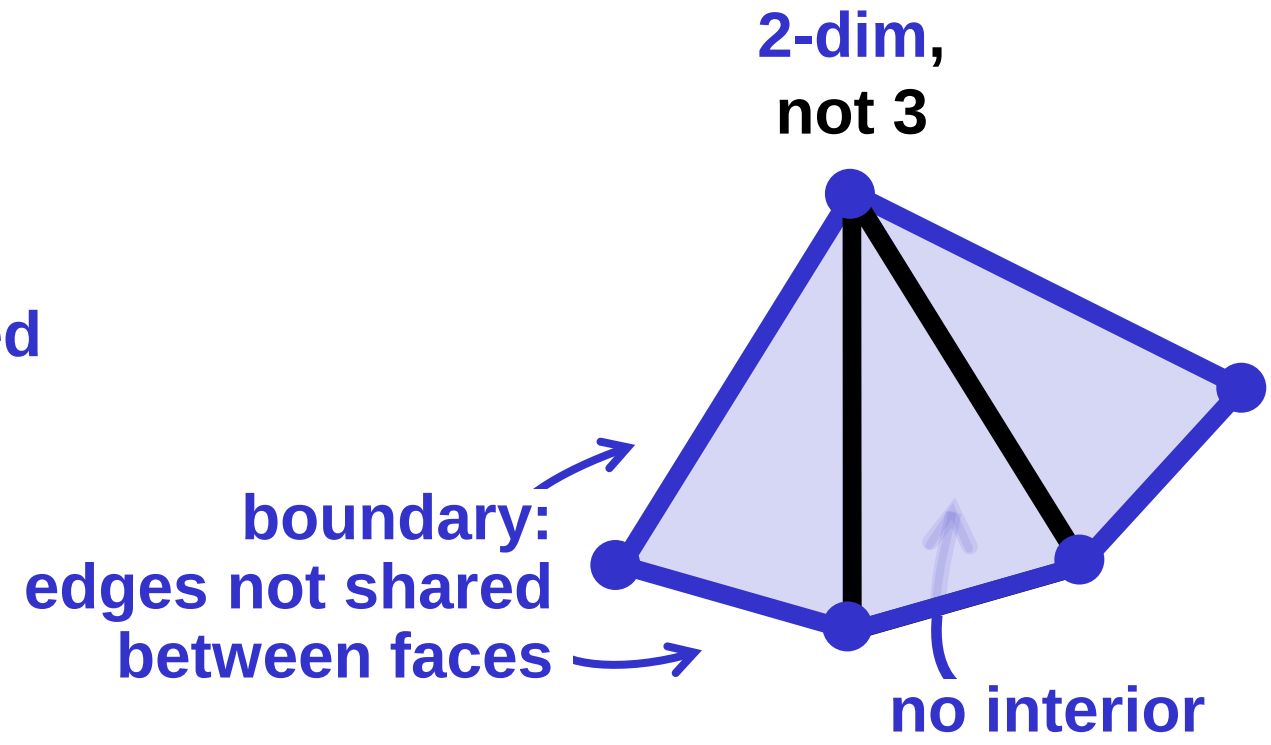
folds back on itself
in 3D

HpDK: Each edge must be visited twice in each direction walk through, determines whether the shape is closed, see orientation.

- They're "closed", have "interiors".
- For > 1 dim, all -2 dim elements are shared.

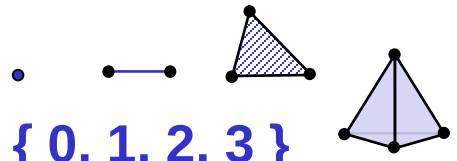
Have Boundaries ⇒ Not Boundaries





- These are “open”, no “interiors”.
- Some lower dim element is not shared (boundary).

Space Slices/Shots + Boundary/Interior



{ 0, 1, 2, 3 }

inner dim = outer
⇒ flat/straight

closed ⇒ no spaceBoundary

Library Model (M1)

not closed ⇒ 4D union of

Occurrence

innerSpaceDimension : Natural [1]

outerSpaceDimension : Natural [0..1]

/isClosed : Boolean [1]

space Boundary

1

outsideOf

0..1

space Interior

self

1..*

1..*

portion

1..*

1..*

spaceSlice

*

1..*

spaceshot

*

mult?

0..1

space Boundary

{isClosed}

0..1

0..1

spaceInterior

Same or lower inner dim than sliced occurrence

Lower inner dim than shotted occurrence

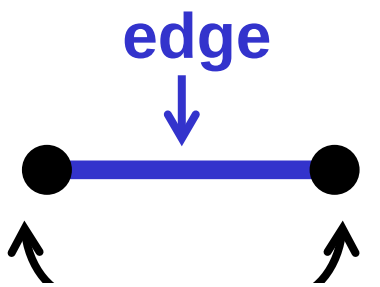
Boundaries have no boundaries (closed)

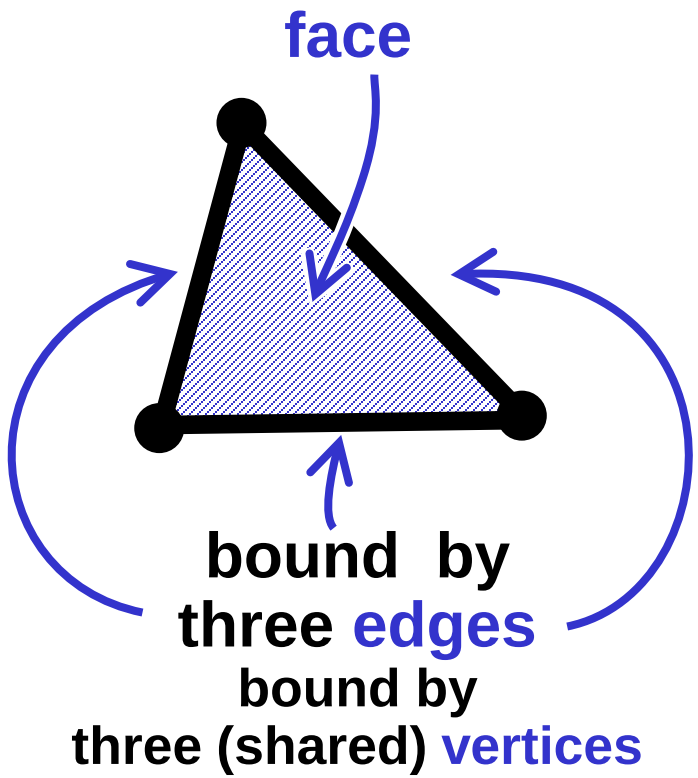
Same inner dim as occurrence its interior of.

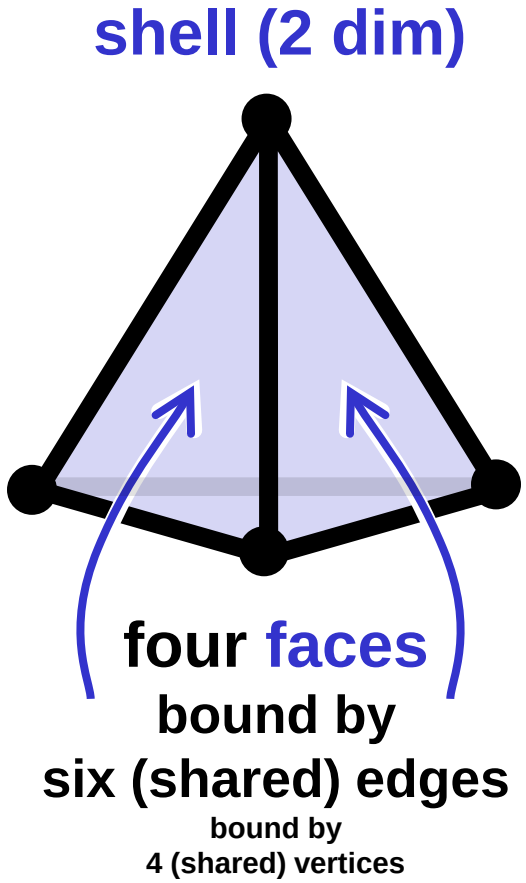
Overview

- Quantitative and Qualitative (Time)
- Space Modeling
  - Qualitative
  - Topology
    - Boundaries
    - **Structure**
  - SST Library
  - TBD
- Summary

Topological “Structure” (2D)

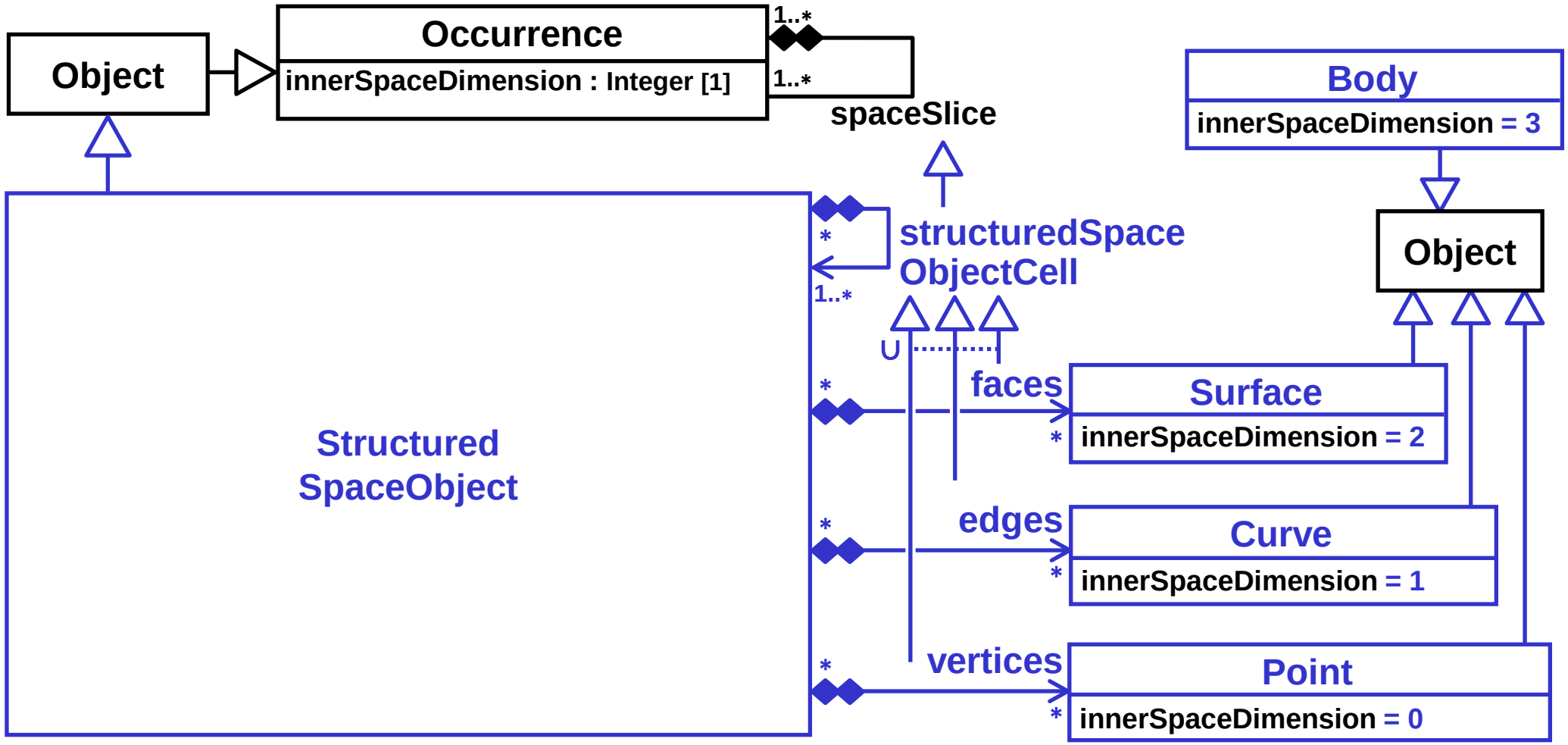






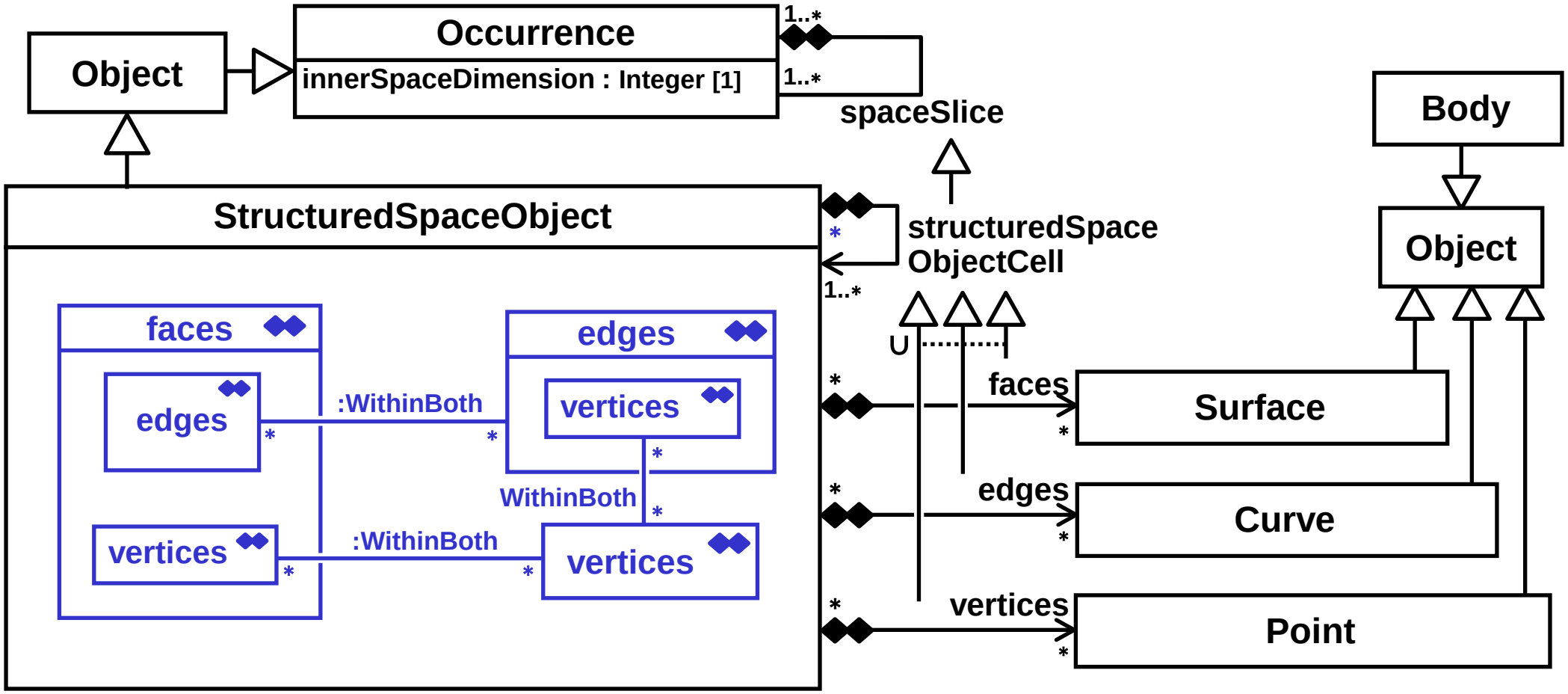
- Vertices, faces, and edges are roles played by
  - points, curves, and surfaces.

Topological Roles



§ **Objects with topological roles (cells).**

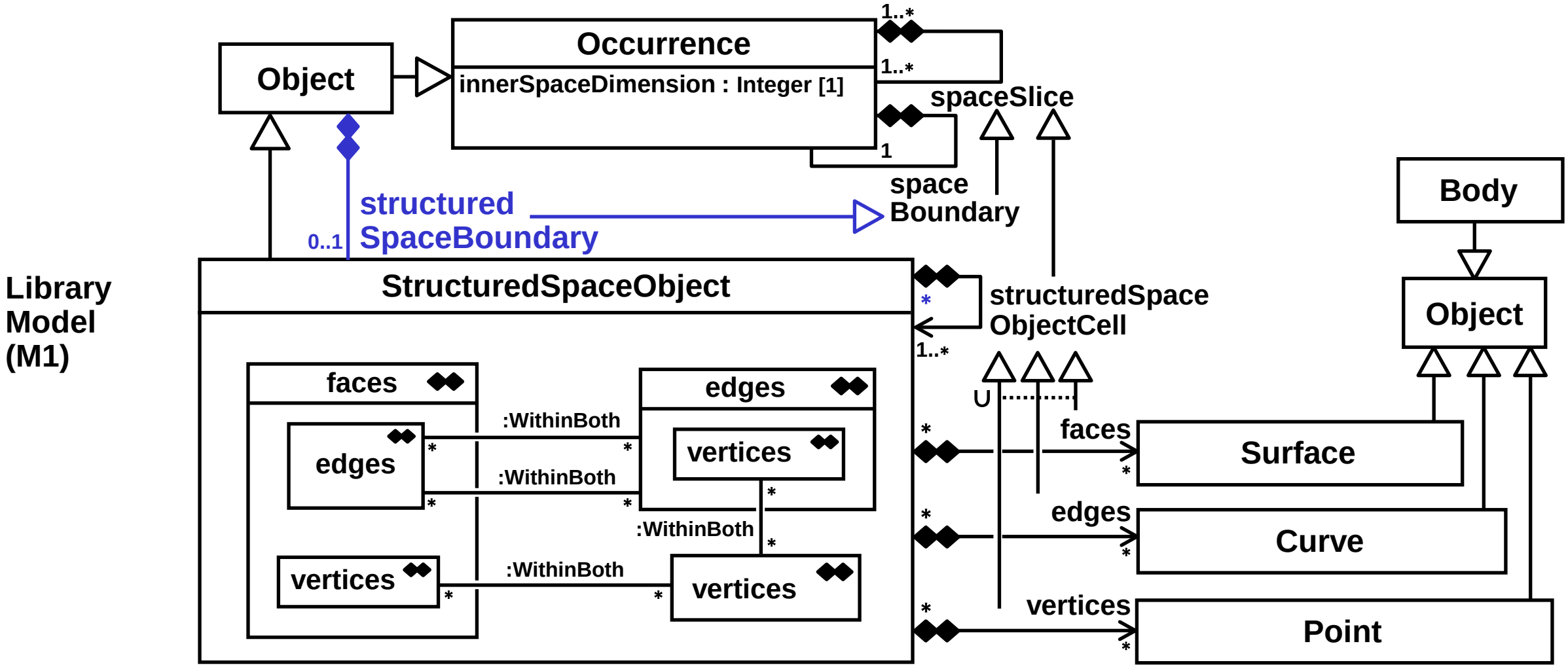
Topological Structure



§ **Adding topological structure**

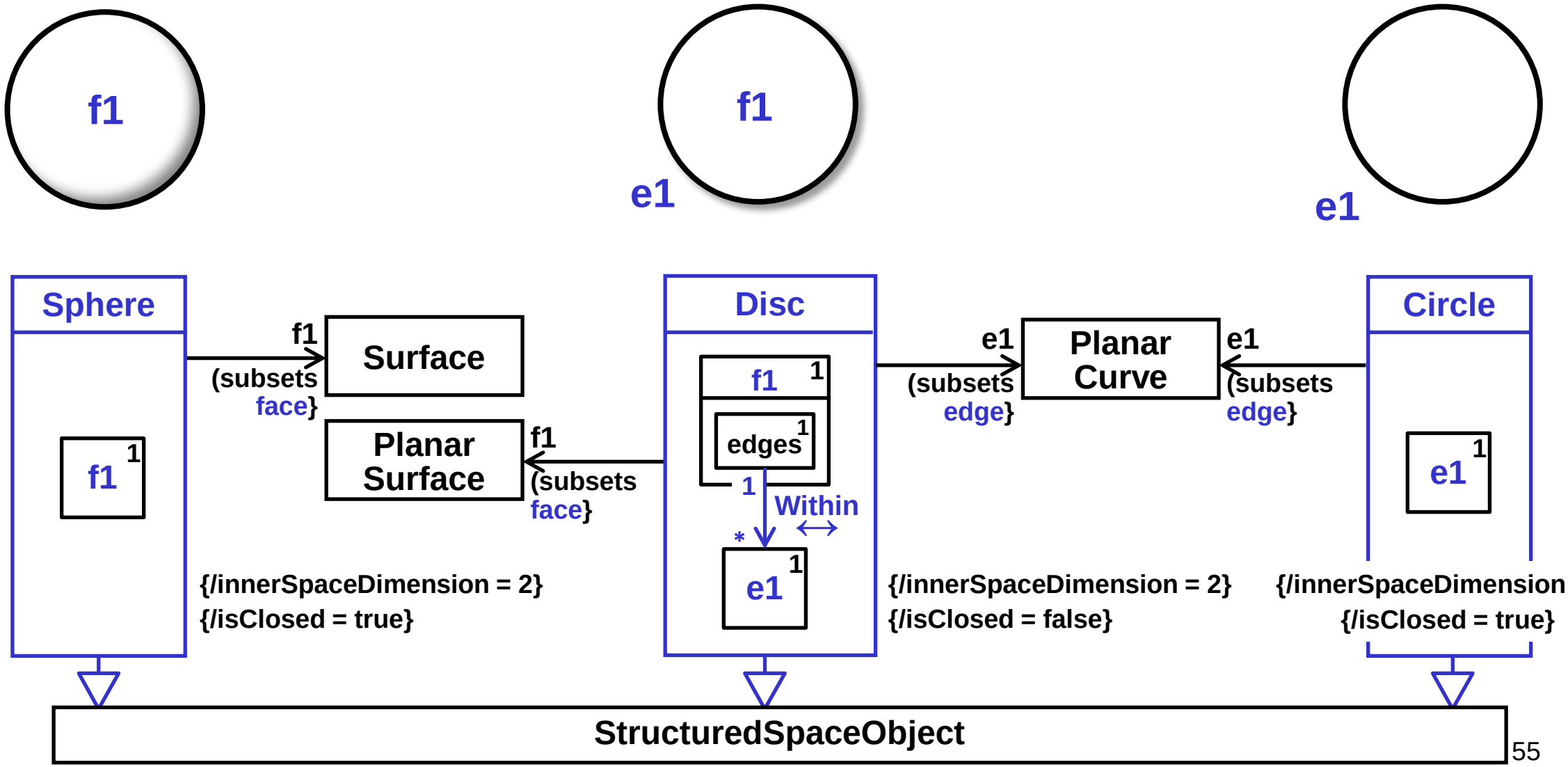
– **Connectors between topo roles**

Topological Structured Boundaries

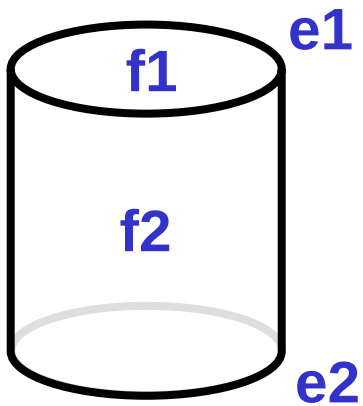


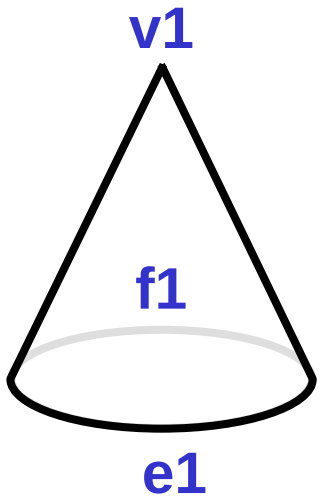
§ **Topo-structured object as space boundary**

“Shapes” = Specific Boundary Structures



More Boundary Structures





StructuredSpaceObject

Cylinder

f1 1 edges 1

f2 1 edges 2

f3 1 edges 1

1 Within * e1 2 2 2

1 Within * e2 2 2 2

{/innerSpaceDimension = 2}

{/isClosed = true}

f1,f3 {subsets face}

f2 {subsets face}

e1,e2 {subsets edge}

Planar Surface

Surface

Closed Conic

Planar Curve

Point

f2 {subsets face}

f1 {subsets face}

e1 {subsets face}

v1 {subsets face}

Cone

f1 1 vertices 1 edges 1

f2 1 edges 1

1 Within * v1 1

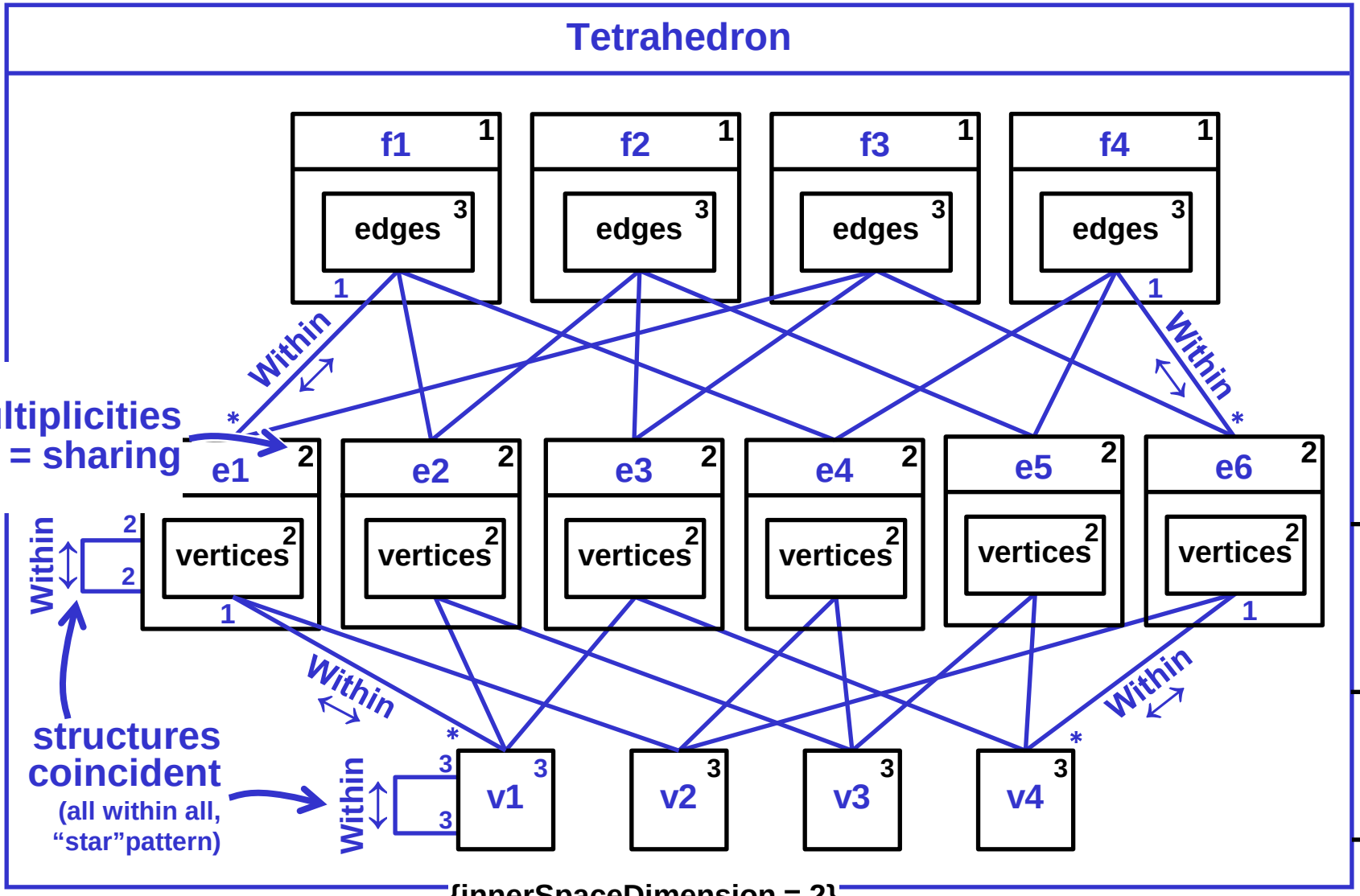
1 Within * e1 2 2 2

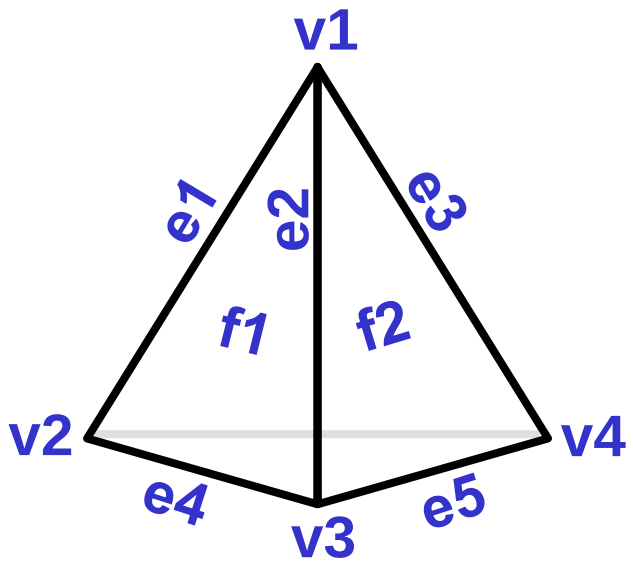
{/innerSpaceDimension = 2}

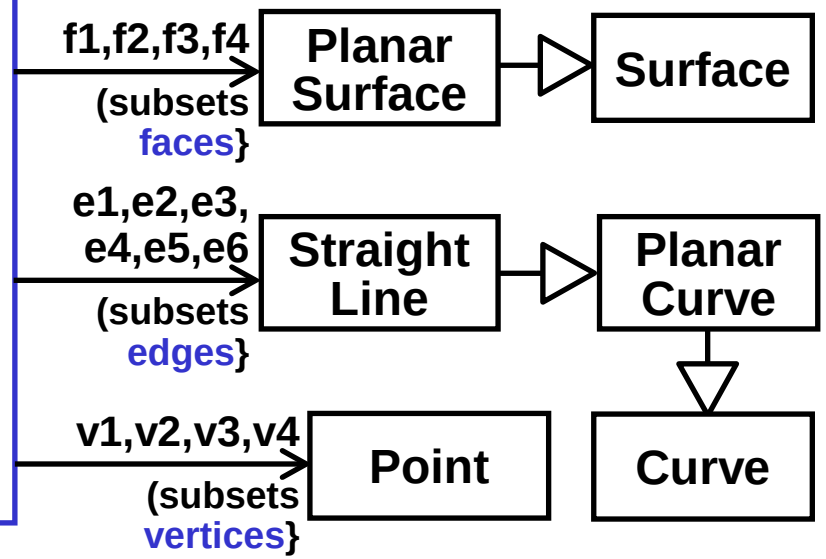
{/isClosed = true}

StructuredSpaceObject

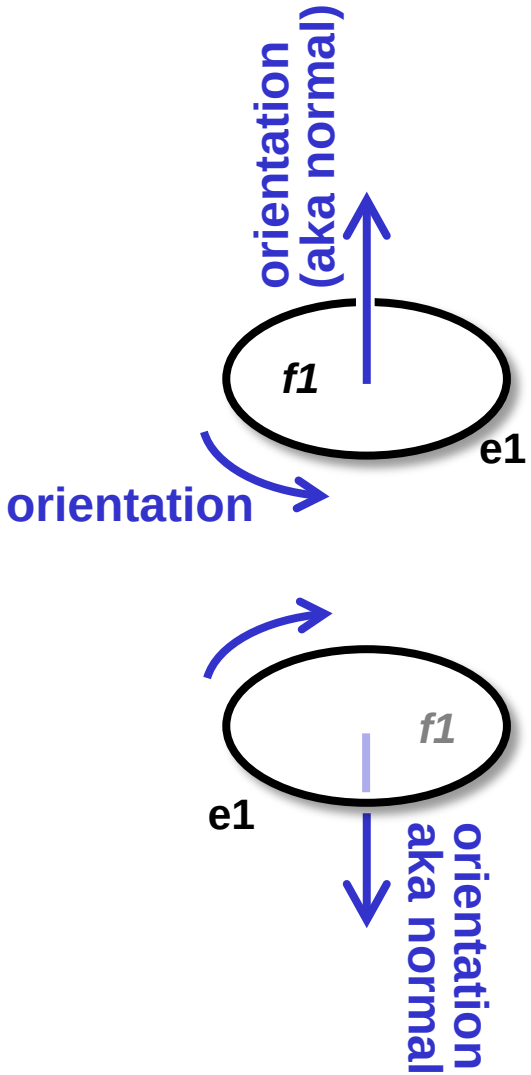
Yet Another Boundary Structures

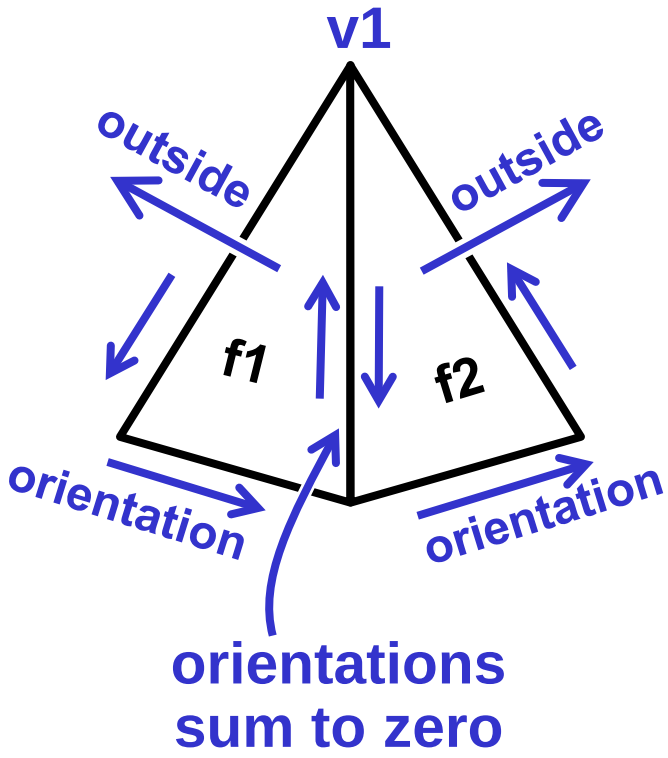


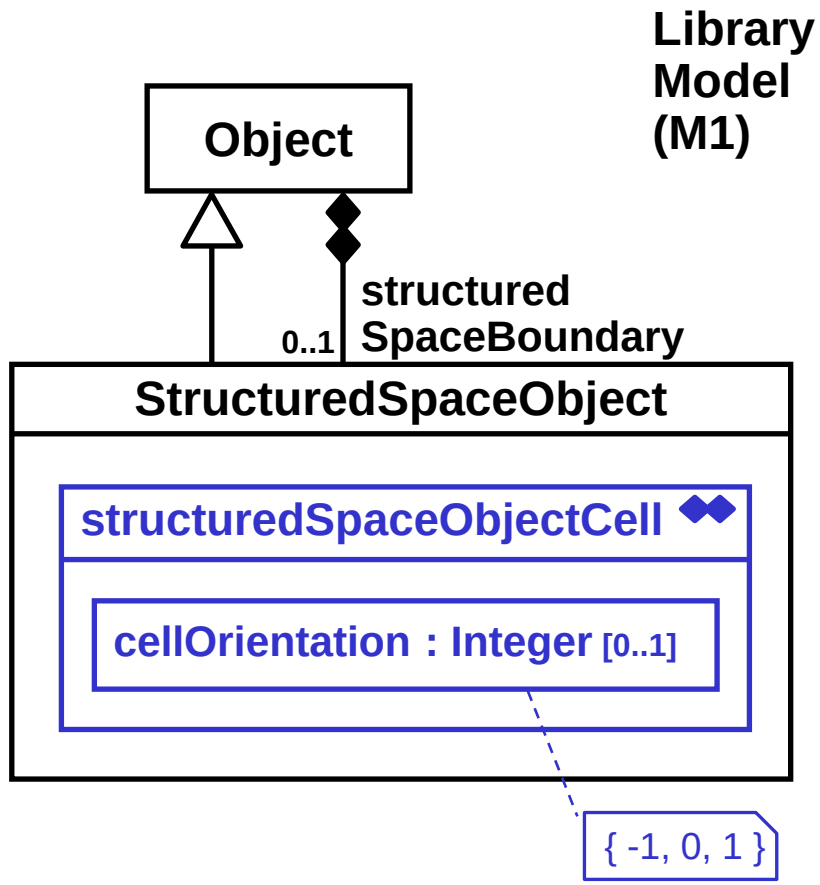




Orientation



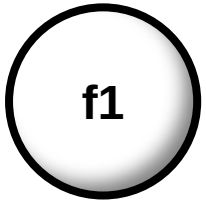




- For closed structures, orientations of the (completely) overlapping cells sum to zero.

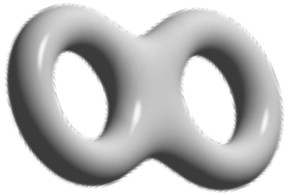
Surface Genus (# of “Holes”)

Space genus 0

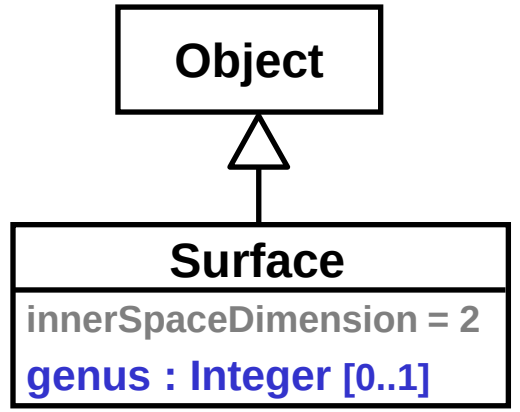


Space genus 1

Space genus 2



Space genus 3



Library Model (M1)

- **Boundaries of the same genus are topo equivalent.**
- **Closed surfaces only.**

https://en.wikipedia.org/wiki/Genus_g_surface

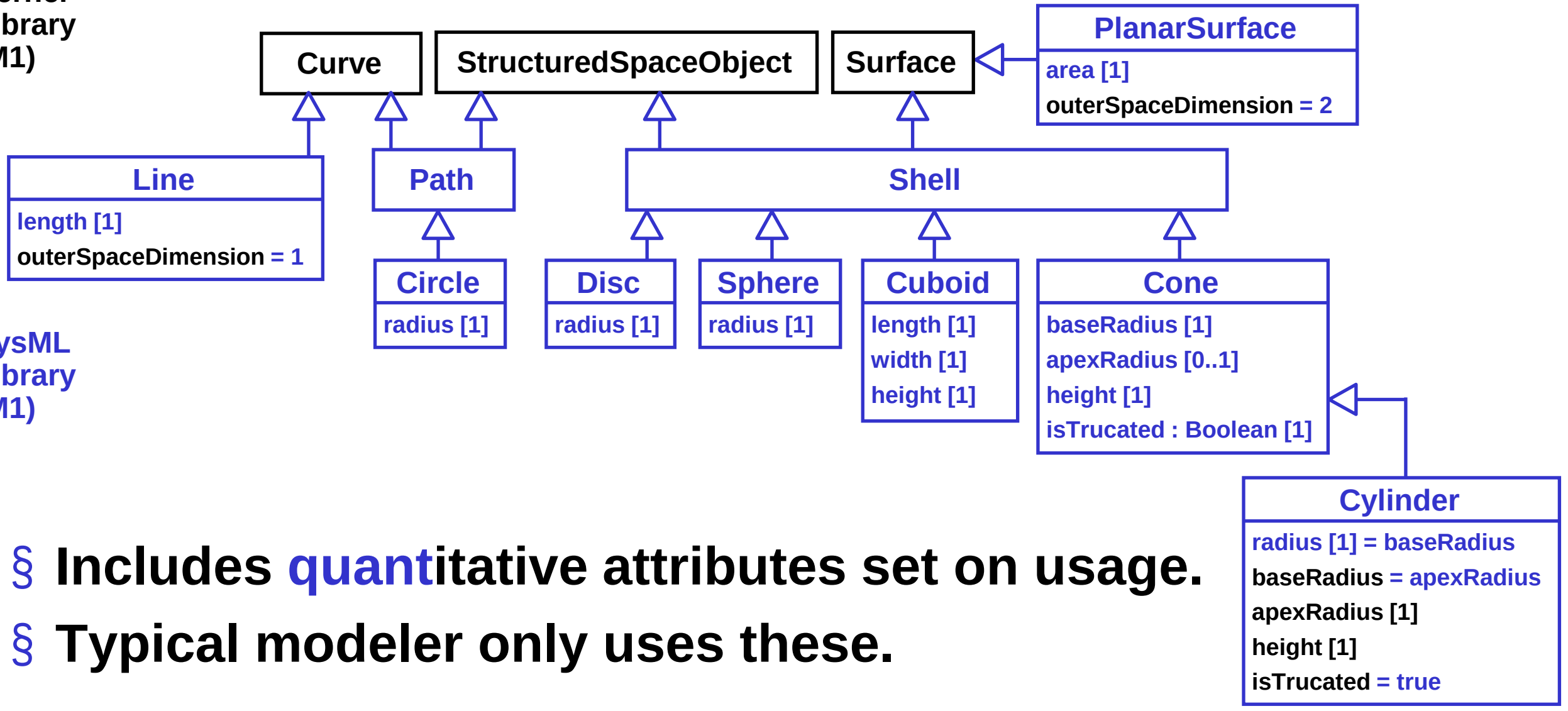
Overview

- Quantitative and Qualitative (Time)
- Space Modeling
  - Qualitative
  - Topology
    - Boundaries
    - Structure
  - **SST Library**
  - TBD
- Summary

SST Library (initial)

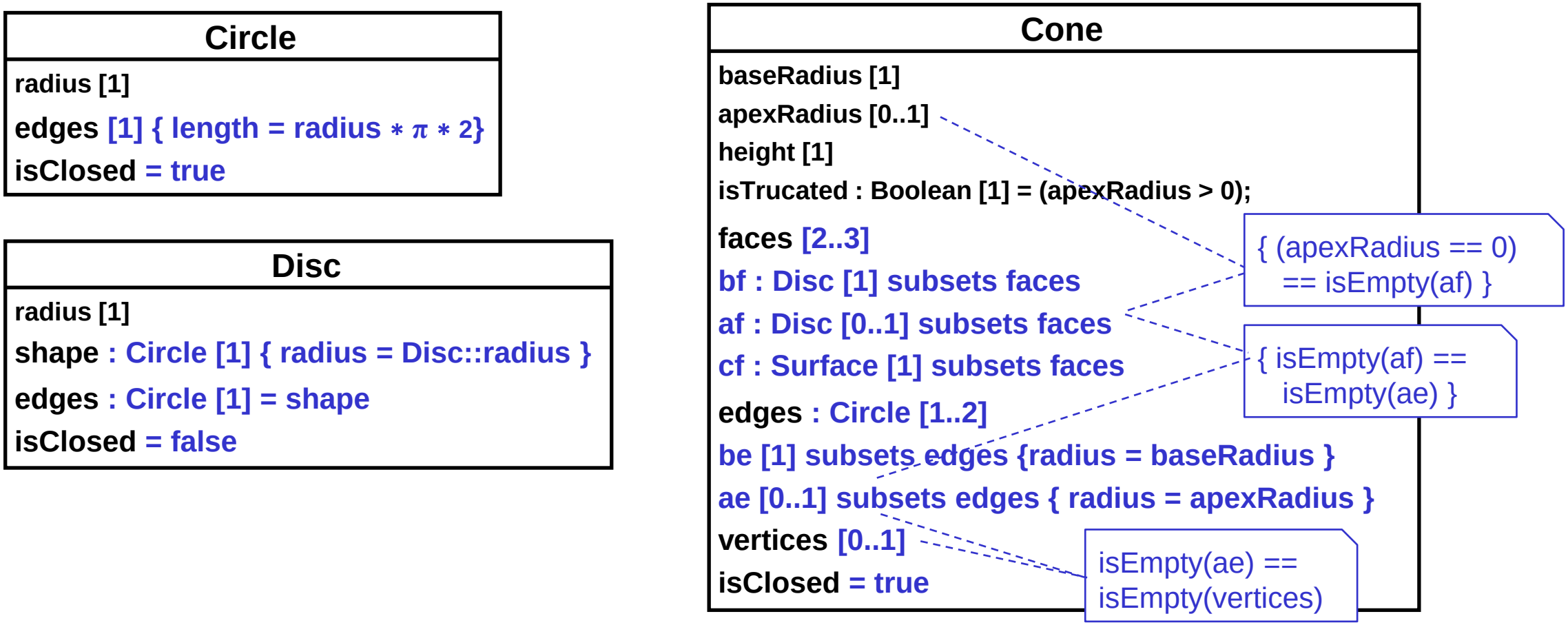
Kernel Library (M1)

SysML Library (M1)



- Includes quantitative attributes set on usage.
- Typical modeler only uses these.

SST Library (topo)



- Topo structure bound into quantitative attributes.
- Typical modeler doesn't see this.

Textual Notation, Quantification

```
item def Car :> CompoundSpatialItem {
    item :>> shape : Cuboid [1] {
       /* ↑↑ Specify height, etc, here. ↑↑ */ }
    part powerSource : Engine [1] :> componentItems; }

part def Engine :> SpatialItem {
    item :>> shape [1];

    /* CSG intersection of c1 and c2. */
    attribute :>> intersectionsOf [1] {
            item :>> elements = (c1, c2); }

    private item c1 : SpatialItem [1] {
        item :>> shape : Cylinder [1] {
      /* ↑↑ Specify radius, etc, here. ↑↑ */ }
       attribute :>> coordinateFrame {
            attribute origin = c1Position; } }

    private item c2 : SpatialItem [1] {
          item :>> shape : Cylinder [1] {
     /* ↑↑ Quantify radius, etc, here. ↑↑ */ }
      attribute :>> coordinateFrame {
           attribute origin = c2Position; } }

        /* ↓↓ Specify positions of c1 and c2 here. ↓↓ */
    private attribute c1Position : VectorQuantityValue;
    private attribute c2Position : VectorQuantityValue; }
```

Reusing library shell for boundary, … customize with nested features

Specify space taken up by engine via CSG relations to others below.

Overview

- Quantitative and Qualitative (Time)
- Space Modeling
  - Qualitative
  - Topology
    - Boundaries
    - Structure
  - SST Library
  - **TBD**
- Summary

TBD, Spatial relations

- "Touches"
  - No space between (analogous to happens just before).
  - Needed for topo structure.
- "Encloses"
  - Car drivers aren't in the sheet metal, just surrounded by it.
- Bounding boxes
  - Touches object somewhere on every side of the box.
- Voids
  - Might help formalize isSolid (see STEP-42, brep_voids).

Overview

- Quantitative and Qualitative (Time)
- Space Modeling
  - Qualitative
  - Topology
    - Boundaries
    - Structure
  - SST Library
  - TBD
- **Summary**

Onto Space Modeling Summary

More specialized

- Quant- and Qual- itative (Time)
- Spatial relations (qualitative)
  - Analogous to qualitative time.
  - Set relations on occurrences (“CSG” in 4D)
- Topology
  - Space boundaries and interiors
  - Structured boundaries (faces, etc) and their relations.
- Space quantification
  - Length, position, etc, aligned with time quantification
- “Shape” library
  - Cuboid, etc, bound to topology, specialized from space.