IndoorML: A Data Model and Exchange Format for Indoor Navigation

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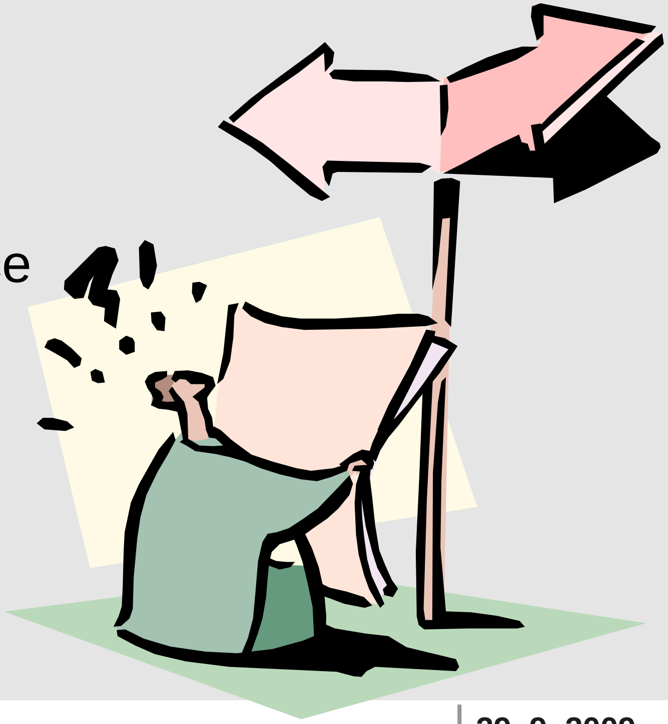

Indoor Navigation

Vision:

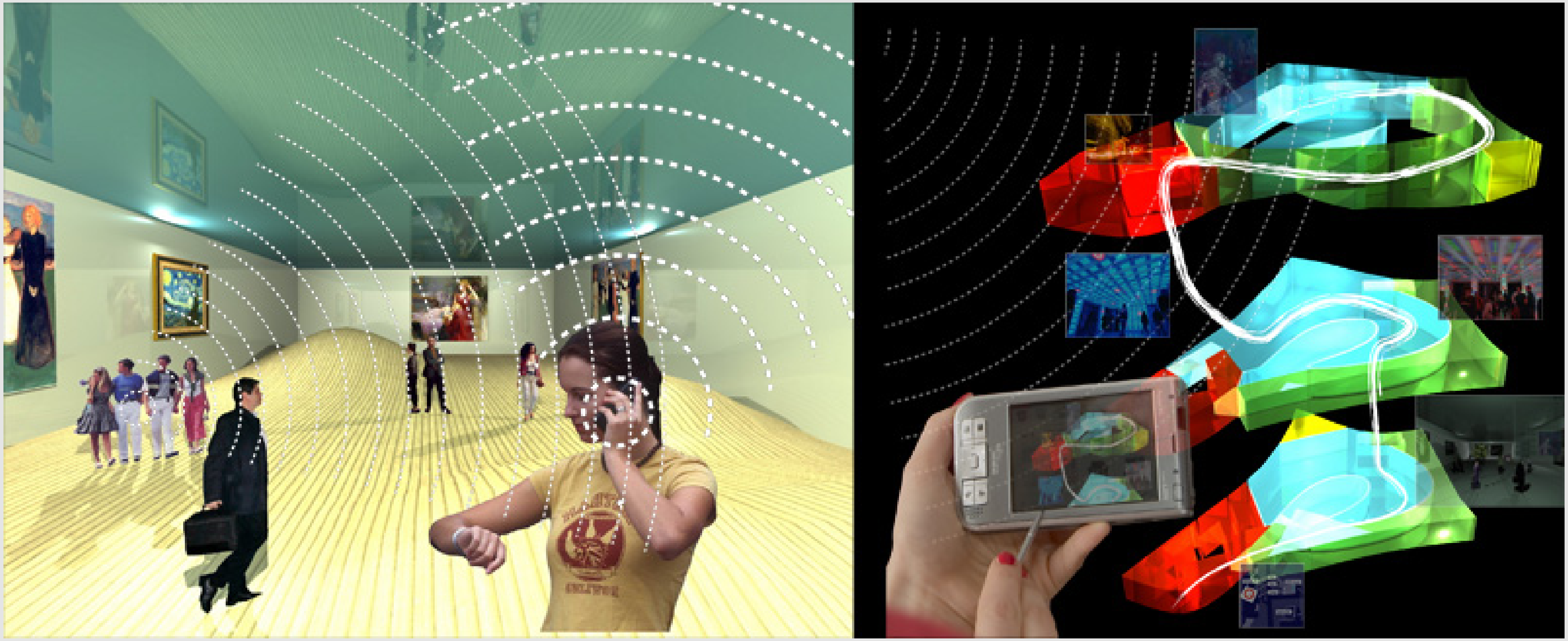

Illustration: Project u-GIS: Indoor Spatial Awareness, Korea

Applications for Indoor Navigation

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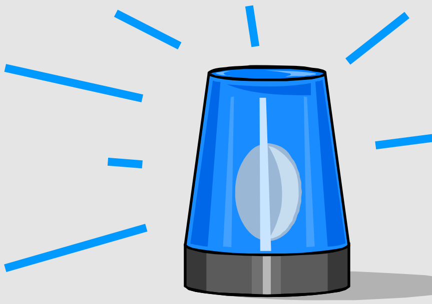

- **Emergency and Disaster Management**
  - escape route planning, simulation of evacuations
  - guidance of rescue personell in buildings
- **(Activity) Tracking** of persons (e.g. rescue personnel) and objects (e.g. goods, material, or robots)
- **Navigation in public buildings** like airports, museums, administrations, shopping malls
  - (check in) counters, exits, toilets, police station, exhibits, offices
- generally: **Location Based Services**

Navigation

Navigation comprises

- **Determination of position and (usually) orientation**
  - communication of position needs geoinformation (typ. maps)
- **Addressing and Route Planning**
  - requires geoinformation about the navigable space
  - requires addressing / georeferencing schema (naming of locations): coordinate reference systems and/or textual
- **Route Tracking (Homing)**
  - alignment actual position ←→ target position
  - motion control to reduce the distance, i.e. keeping on track
  - communication of navigation commands

What does a navigation system needs?

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- **Localization method / technology**
- **Geoinformation** about the navigable space
  - navigable route sections
  - list of localities (named places and their coordinates)
- Spatial reference systems (nowadays typically two!)
  1. **spatial reference system of the localization method**
     (often locale or world coordinate system)
  2. **natural spatial reference system of the user**
     (for naming of start and end points; often not a coordinate system but e.g. addresses, *Points of Interest*)
- Methods for **position and route communication**

Robot navigation

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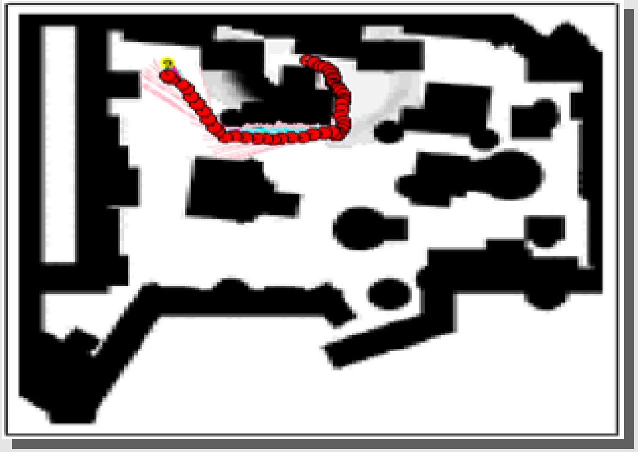
▸ Route planning

- geometric route planning, i.e. the exact trajectory of the robot has to be computed
- requires **topological and geometric** information about the navigable space, at least 2D floor plans / footprints



▸ Localization

- typically uses (laser / ultrasonic) range finders or photogrammetric / computer vision methods for localization
- often Simultaneous Localisation and Mapping (SLAM) is applied; nowadays 3D models are used

Picture:
CS Dept. III
Univ. of Bonn

Robot navigation

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- **Route planning**
  - geometric route planning, i.e. the exact trajectory of the robot has to be

Image: © Microdrones

- **L**
  - Mapping (SLAM) is applied, nowadays 3D models are used

Picture: CS Dept. III Univ. of Bonn

Geodata for Indoor Navigation

Problems of Indoor Navigation

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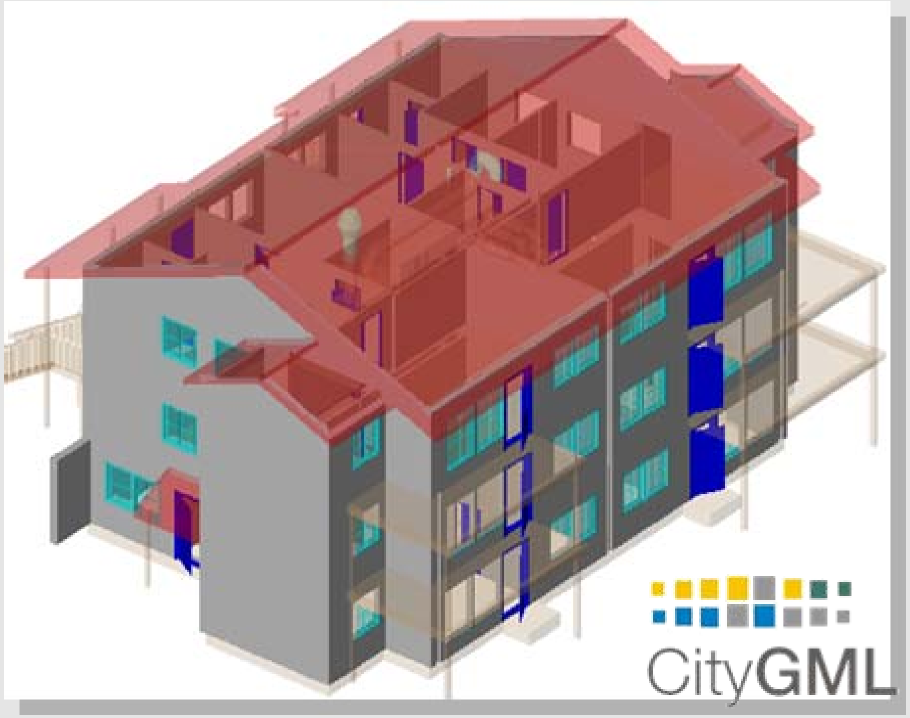
- Different, varying localisation methods
  - nevertheless: **sensors** are different,
  - but most **have comparable spatial characteristics** (visibility area, coverage area, signal propagation).
- Absolute position can be determined, if the locality of a sensor or sender and its covered area is known
  - uncertainty is equal to the size of the respective area
- Route network and addressing principle for navigation targets required (coordinates are unsuited)

Wanted: space model for localisation + route planning

The Project „Indoor Spatial Awareness“

- **Indoor Navigation, Simulations, Applications**
- funded by the ministry of transport of South Korea
- Partners:
  - Ki-Joune Li, Pusan National Univ., Korea
  - Jyeong Lee, Univ. of Seoul, Korea
  - Mike Worboys, Univ. of Maine, USA
  - Christian S. Jensen, Aalborg Univ., Denmark
- Research goals at TU Berlin:
  - Creation of a space model that integrates the notions of Euclidean space and cellular space as well as space + activity
  - Development of a data model comprising both 3D topography (of buildings) and the spatial characteristics of all sensors
  - Mapping to an exchange format: ***IndoorML***

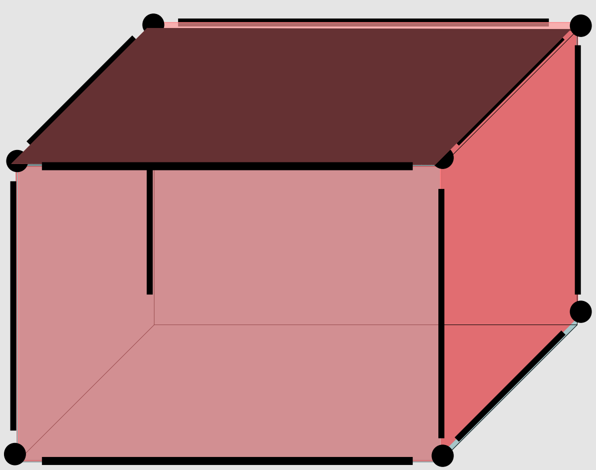
Modeling of Navigable Indoor Spaces



- Semantic 3D city and building models provide (nowadays)
  - the geometry and
  - a thematic differentiation of the indoor areas (at least separation in building parts, storeys and rooms)
- International standards **CityGML** and **IFC**
- Thematic differentiation already suitable for addressing, route descriptions and route tracking (homing)
  - e.g. by room numbers

Representation of spaces within buildings

Interiors will be represented in **Euclidean space** as **volumes** **(3D → IR³)** by using the boundary representation:



Euclidean space is a metric space and induces a natural topology.

- Adjacency;
  Interior, exterior, boundary

Geometrical-topological modeling of **volumes** by cell complexes

3-cell: Solid
U
2-cell: Face
U
1-cell: edge
U
0-cell: node

Poincaré Duality (Algebraic Topology)

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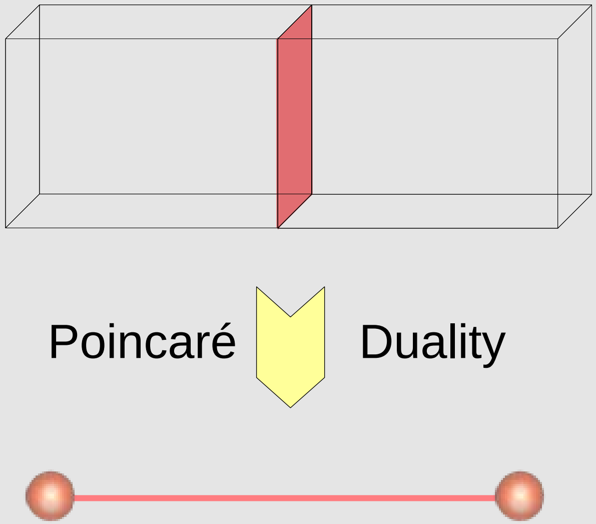
For a compact, orientiented manifold the i-th homology group is isomorphic to the (n-i)-th cohomology.

- **Mapping of i-dimensional cells** within cell complexes **in primal space onto (n-i) cells in dual space**
- Isomorphism preserves topological properties

Example: **Primal Space:**
Cell complex consisting of two volumes (e.g. rooms within building) and their bounding faces, edges, and nodes

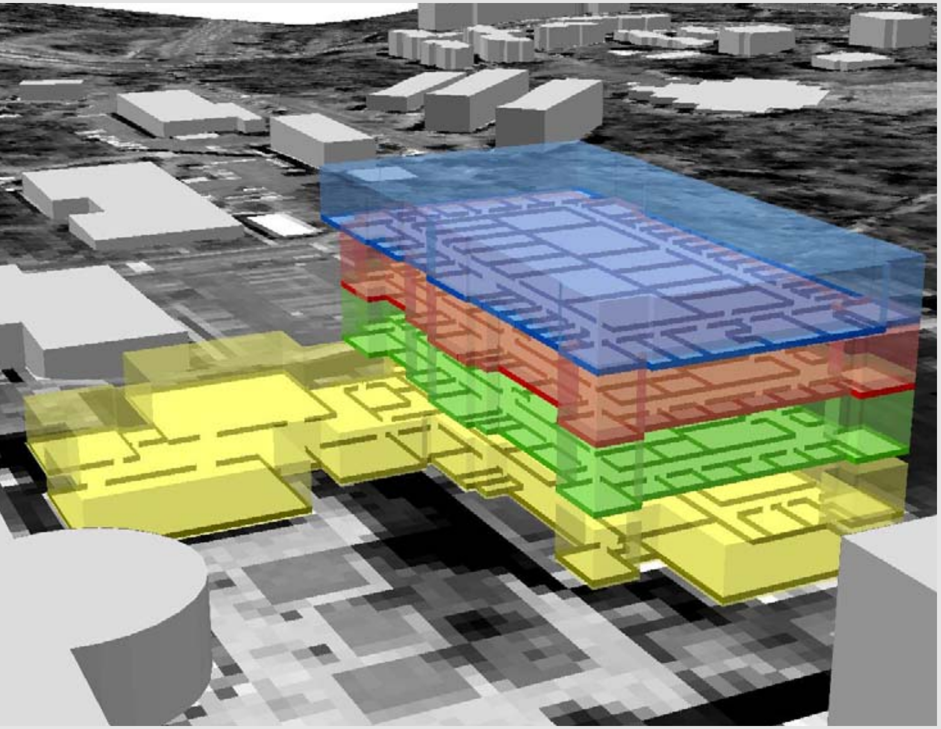


Dual Space:
Volume (3D) mapped onto node (0D), face (2D) onto edge (1D)

Example [from Lee 2004]

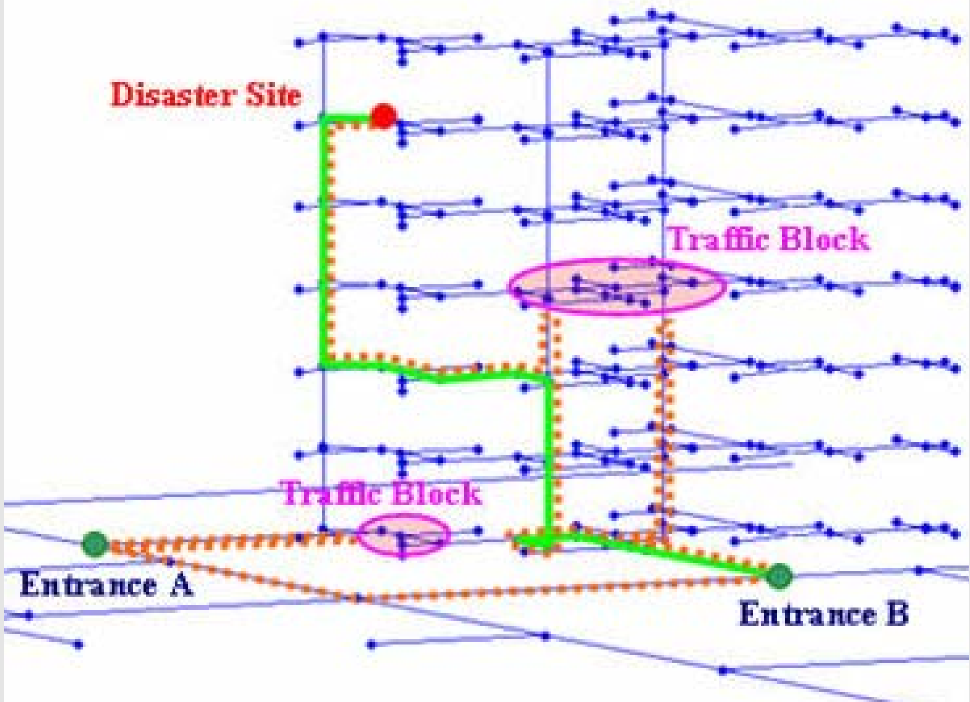
3D Building Model

- **Primal Space**



3D Connectivity Graph

- **Dual Space**



3D Node-relation-structure (NRS)

3D NRS is a topologic structure with (geometric) embedding in IR^3

- facilitates determination of shortest paths in the network

Structured Space Model

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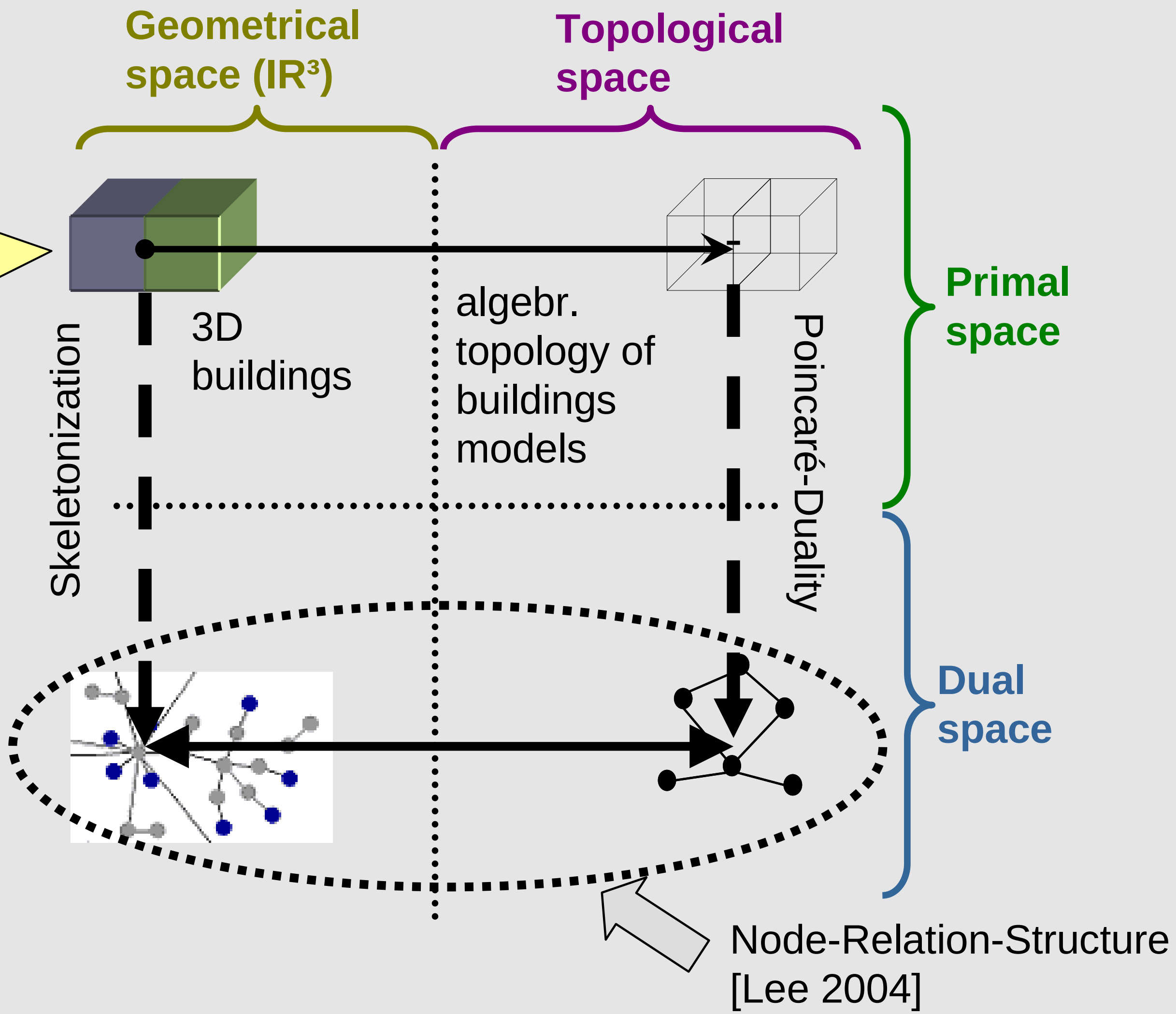
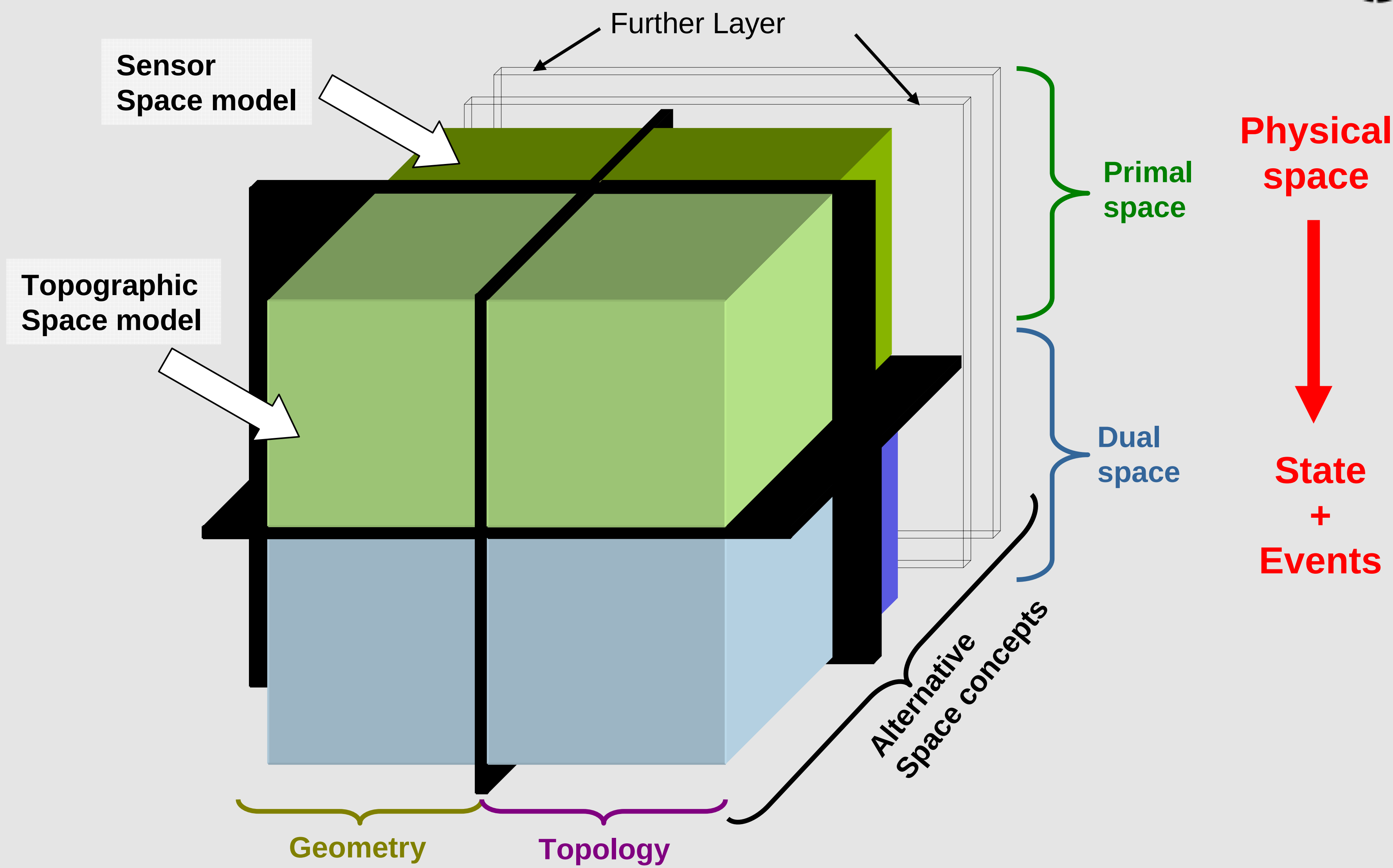
The size of the cells determines ambiguity of the absolute position



Multilayered Space Model



Multilayered Space Model

1st layer: **Topographic space model**

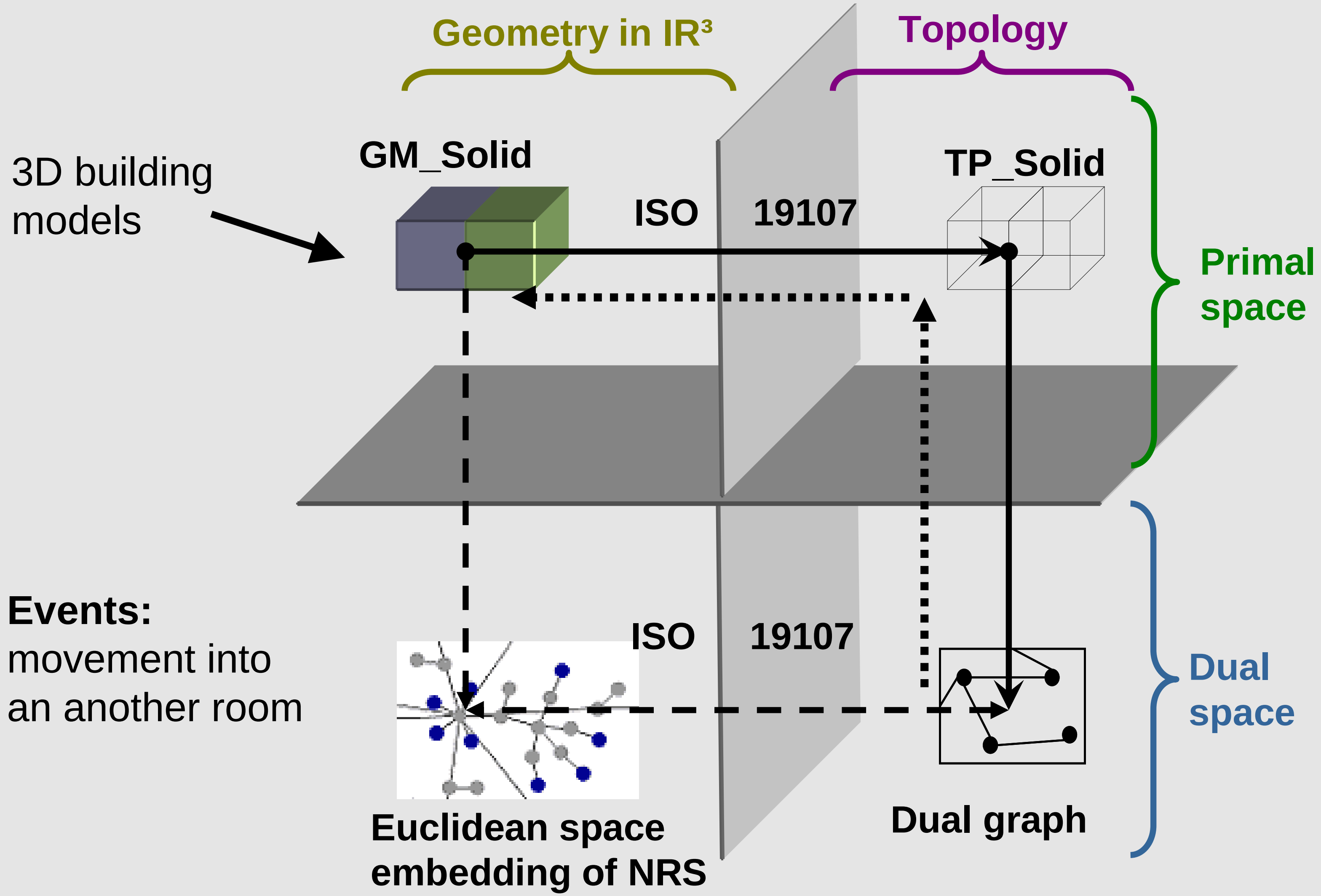
- modeling of the **building's structure** (topography)
- Primal space: geometric-topological model
- Dual space: network for route planning

2nd layer: **Sensor space model**

- Modeling of **sensor / transmitter structure**
- Primal space: coverage of sensor areas
- Dual space: transition between sensor areas

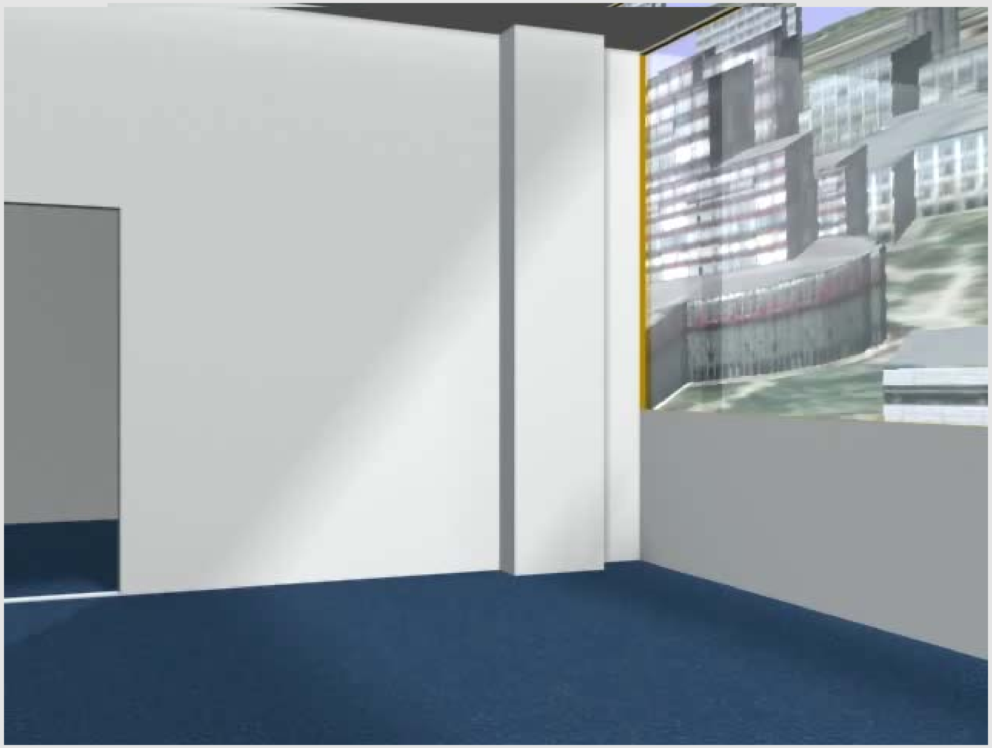
Further layers: i.e. further sensor space model

1st Layer: Topographic Space

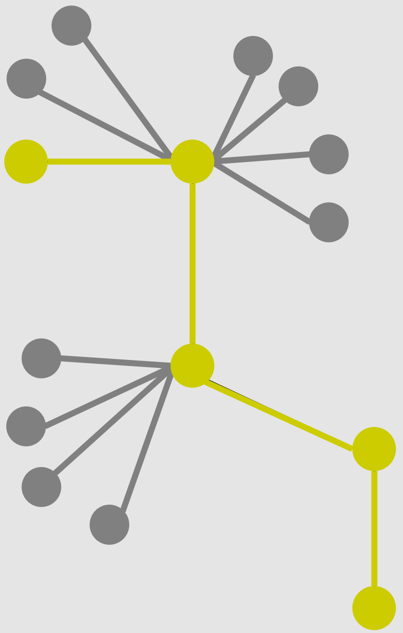


Example for Topographic Space (I)

Primal space, geometric model:



Dual space, topological model:



Rooms and their adjacencies resp. state transition graph (presence in a room and changes of rooms)

Planned route (e.g. an escape route)

Traced route

Example for Topographic Space (II)

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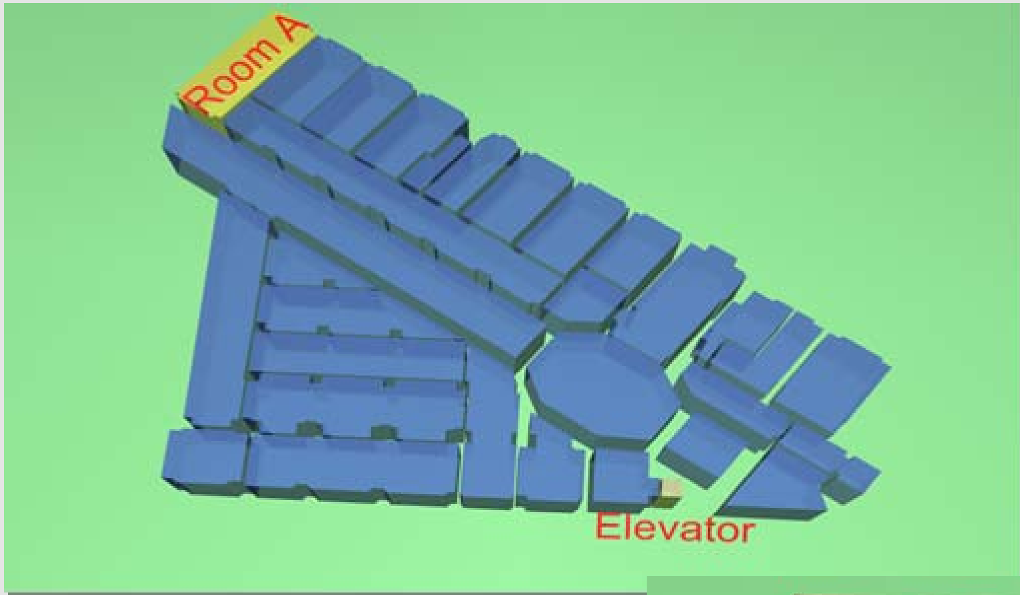
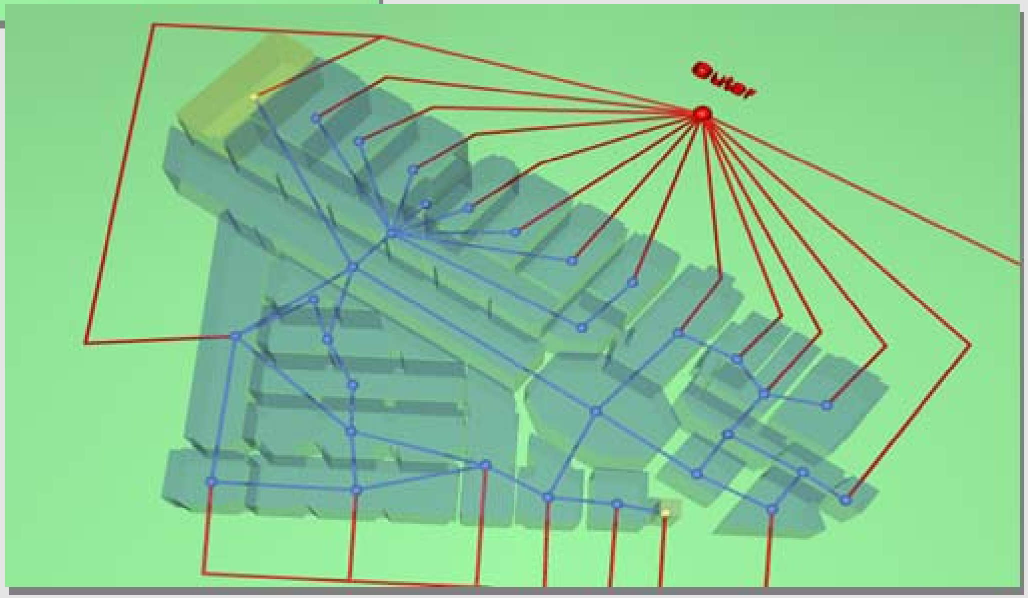


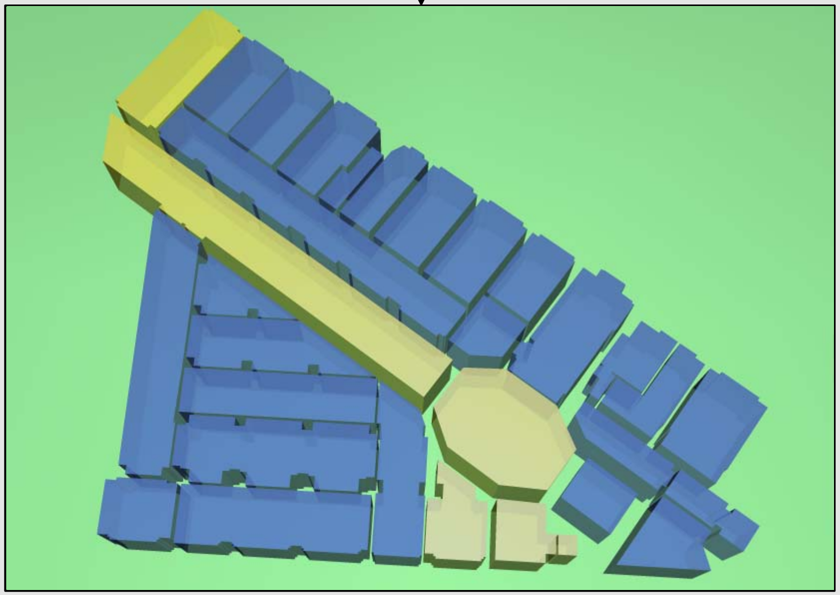
Topographic space
- *primal space*
- *as 3D Solids*
- *Rooms are connected via doors*



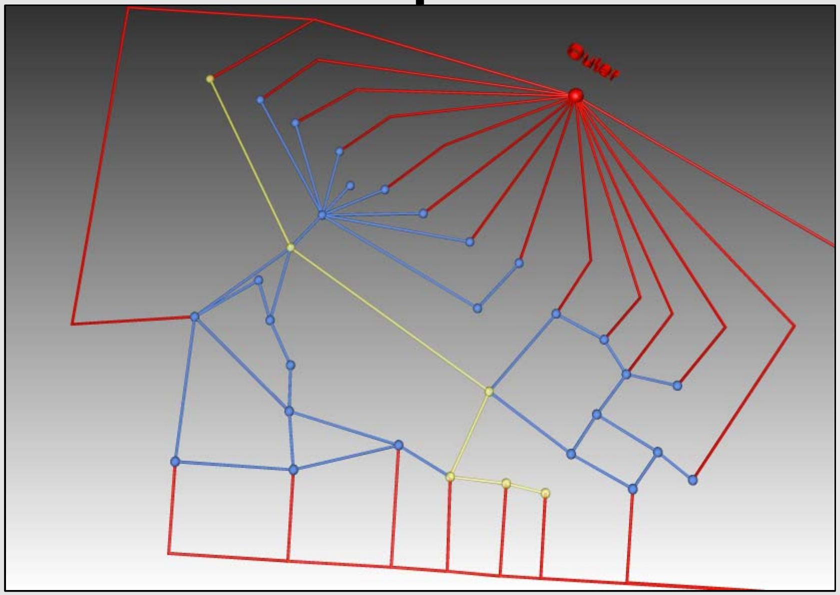
Topographic space
- *dual space*
- *as connectivity graph*
- *“Rooms” are connected via edges*

Example for Topographic Space (II)

Dual to primal connection



Affected spaces



State-transition diagram

- Rooms and their adjacencies resp. state transition graph (presence in a room and changes of rooms)
- Traced route

Relation of Space and Event

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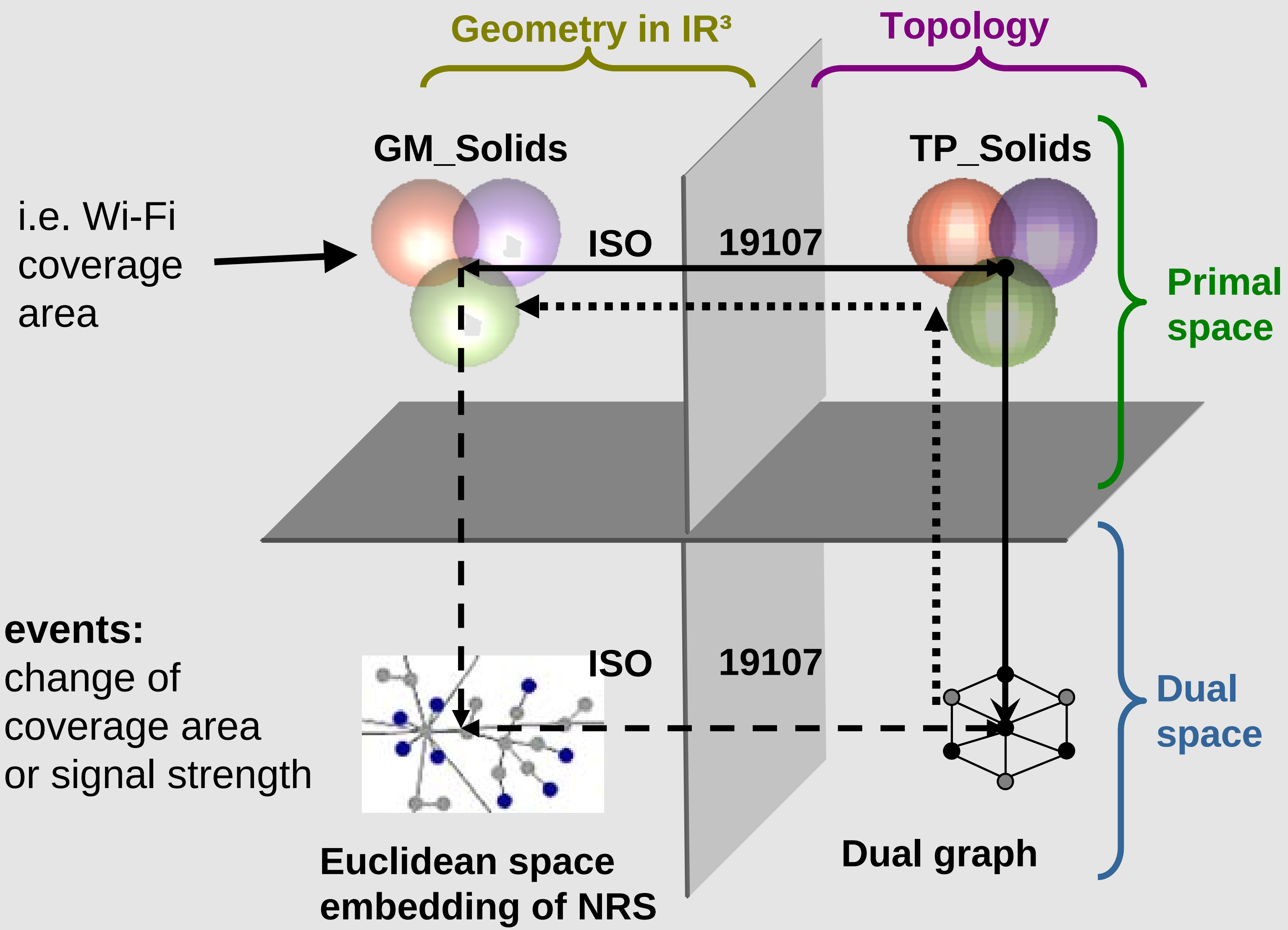
If spaces are represented in a non-overlapping way within a space model, then:

- a subject or object must be exactly in one cell
- the space model **dual graph** describes a **state transition diagram**
  - **Node** ≅ area (e.g. room within a building) in primal space; at the same time **state** of a subject or object with respect to space occupation
  - **edge** ≅ connections, adjacencies (e.g. doors, passages) in primal space; at the same time **event** indicating movement / transition from one area into another

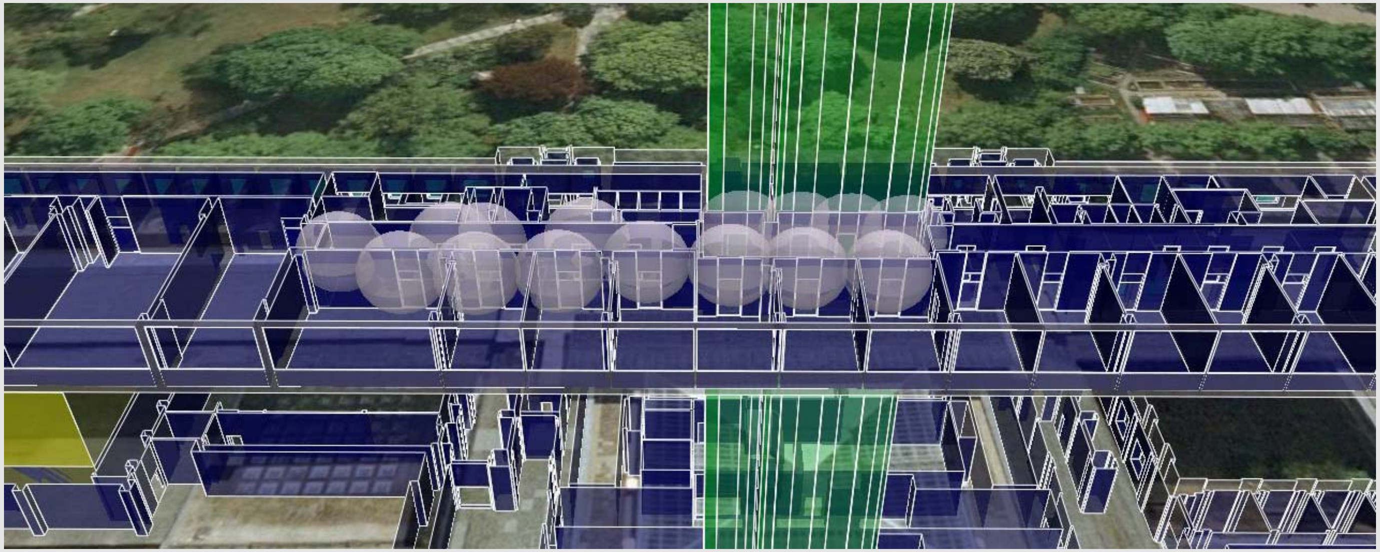
2nd Layer: Sensor Space



Examples for Sensor Space Model

Wi-Fi

RFID
Scanner



Examples for Sensor Space Model

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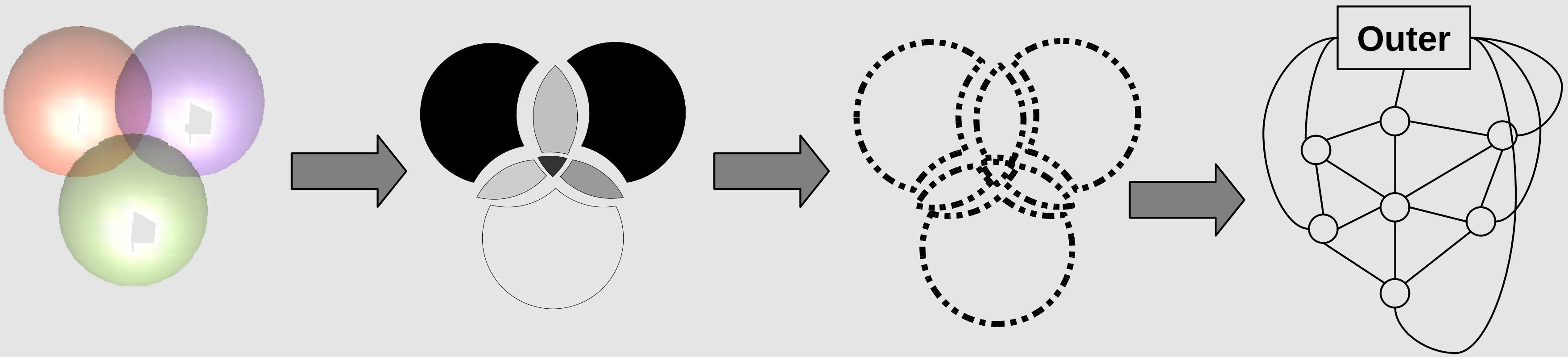
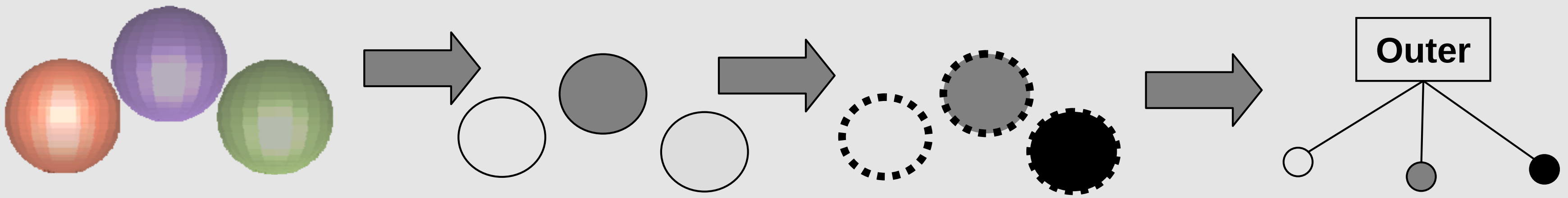
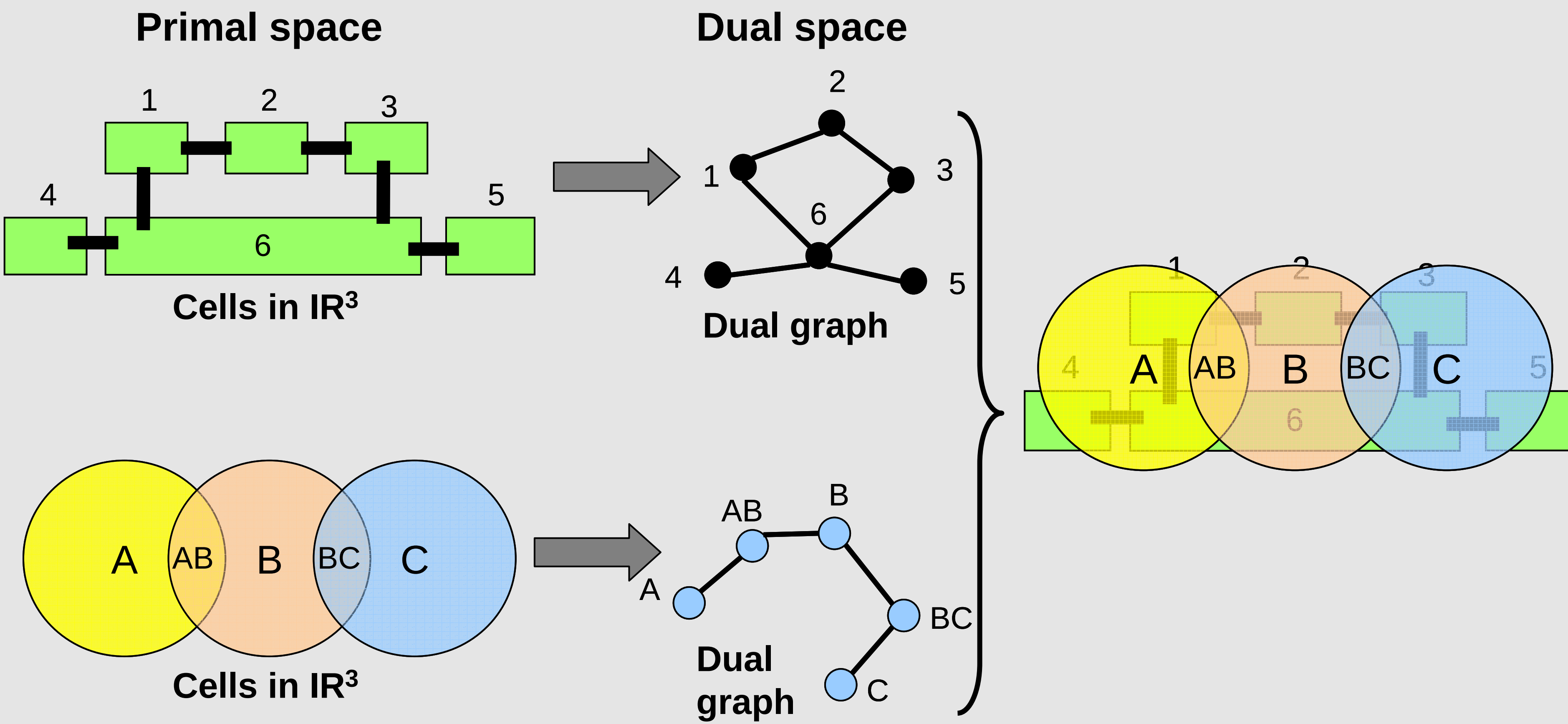
overlapping Wi-Fi reception areas



Wi-Fi or RFID- areas without overlapping



Combination of Space Models (I)



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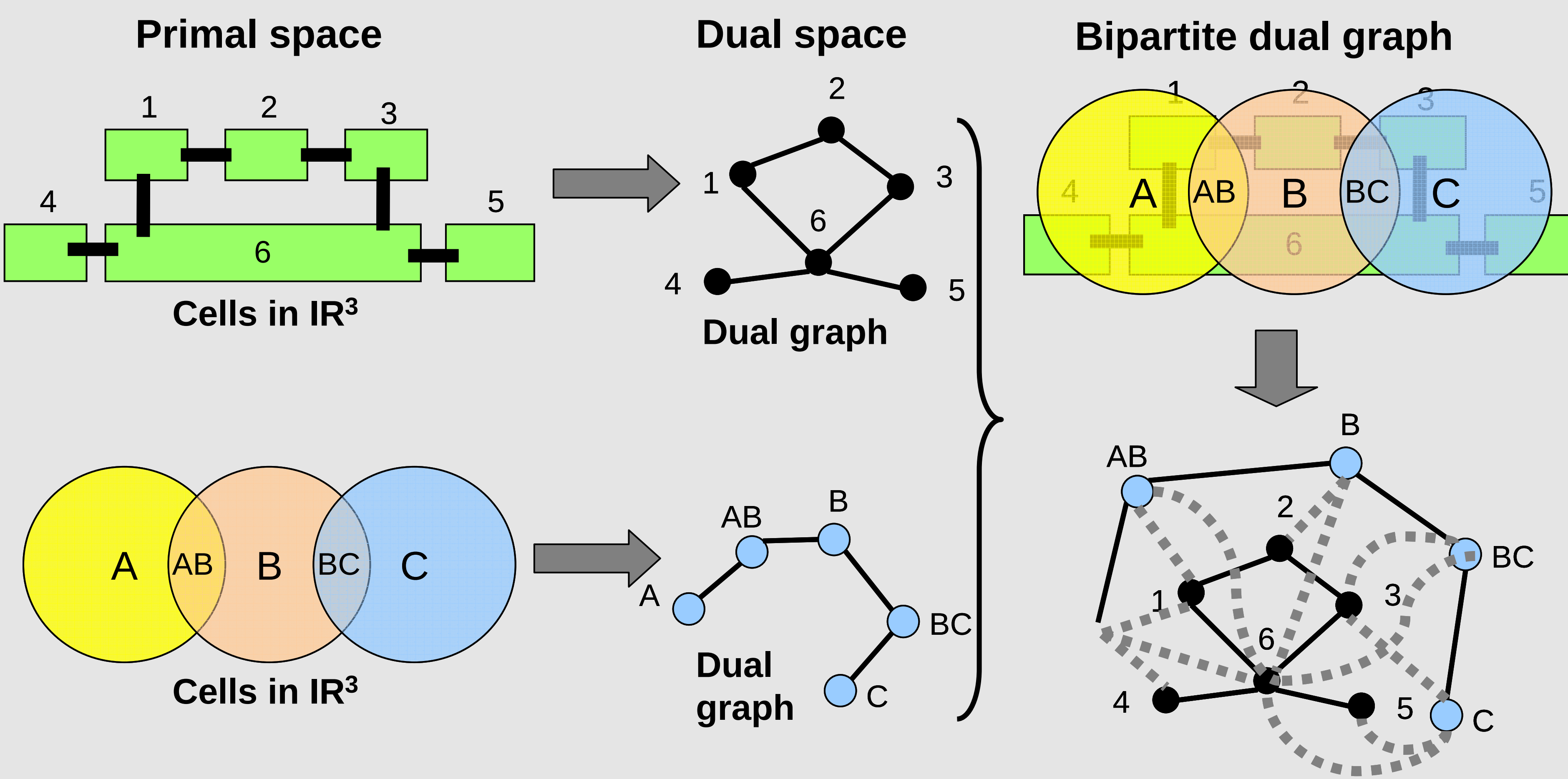

Combination of Space Models (II)

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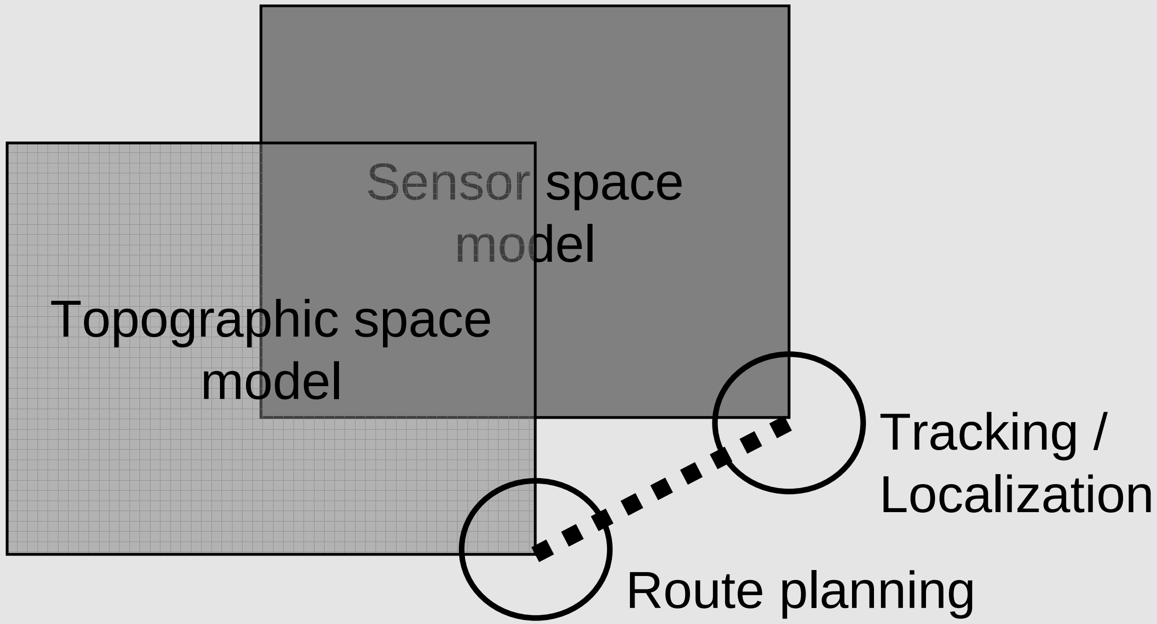
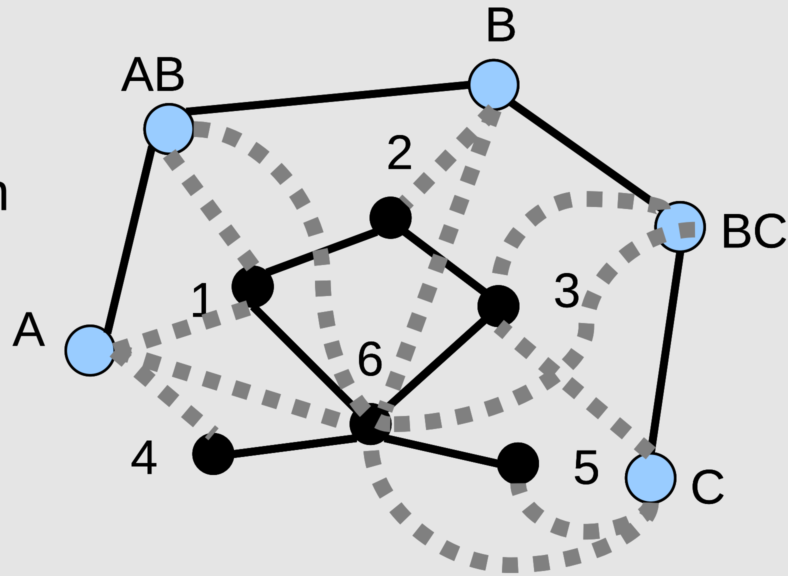


Connection of dual graphs of several layer in one **multi-layered graph**

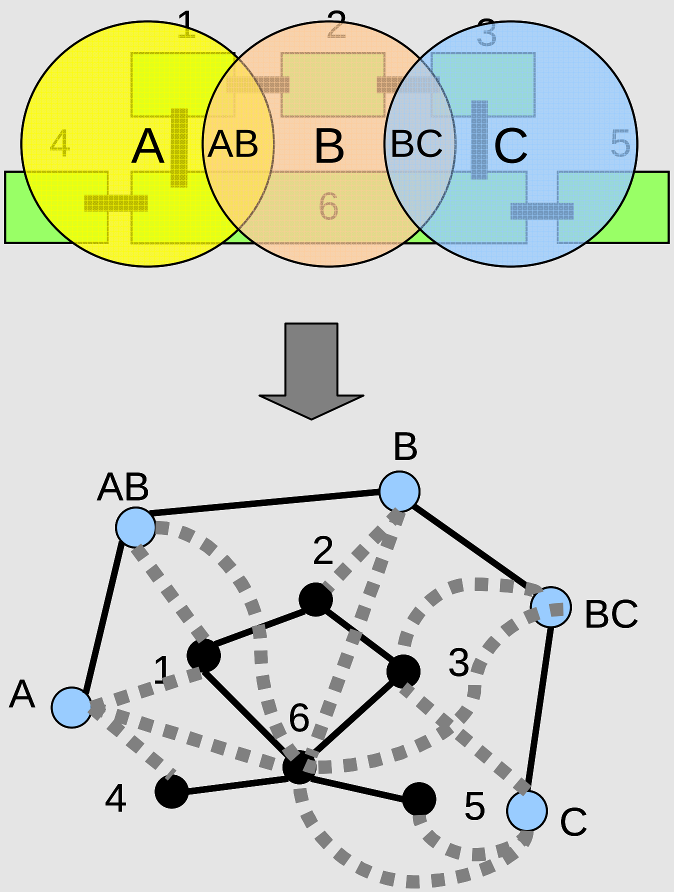
- the dashed edges express which states can be mutually active within the different space models



Formal Background of the *Multi-Layered Graph*

Definition using topology:

- Partitioning of nodes according to their membership to the different space models
  - *n* space models → *n* sets of nodes
- Edges within each partition express topologic adjacency (3D cells have a common face)
- Edges between nodes from different partitions express topological overlaps (intersection of the interiors of the corresponding cells is not empty)



Example for a *Multi-Layered Graph*

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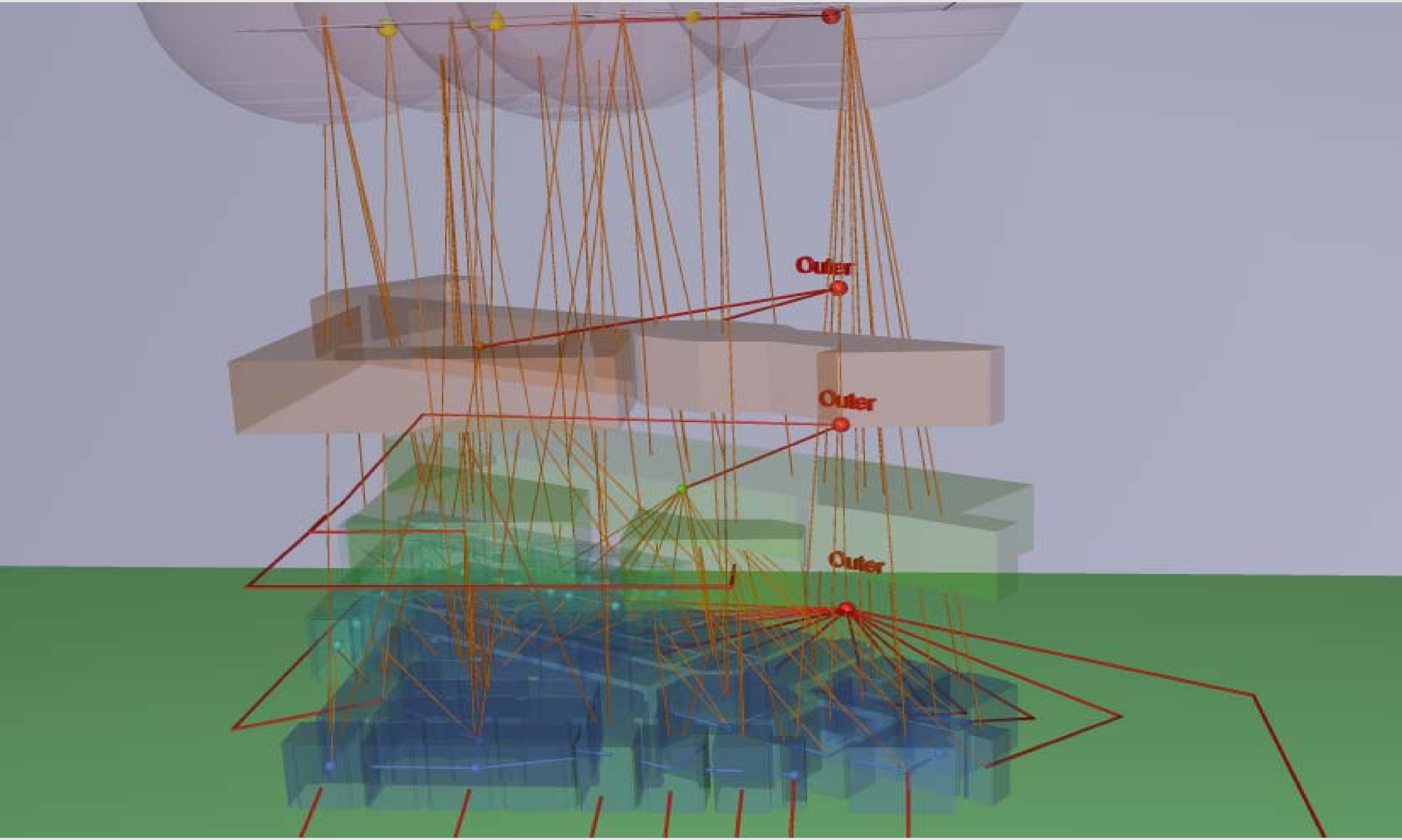

Joint State

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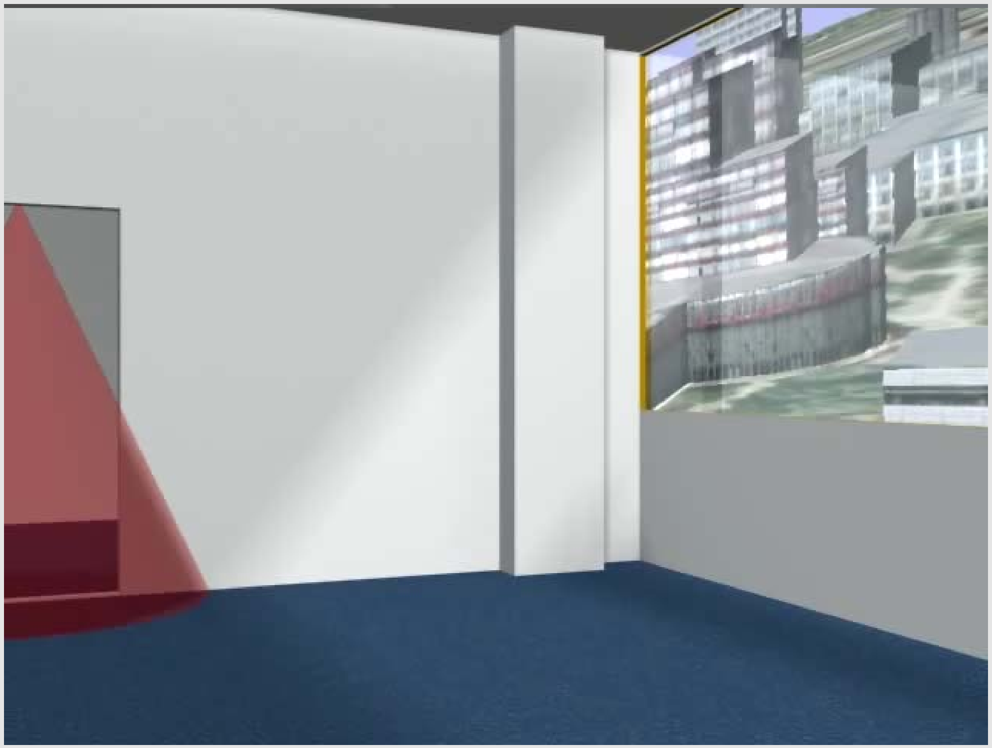
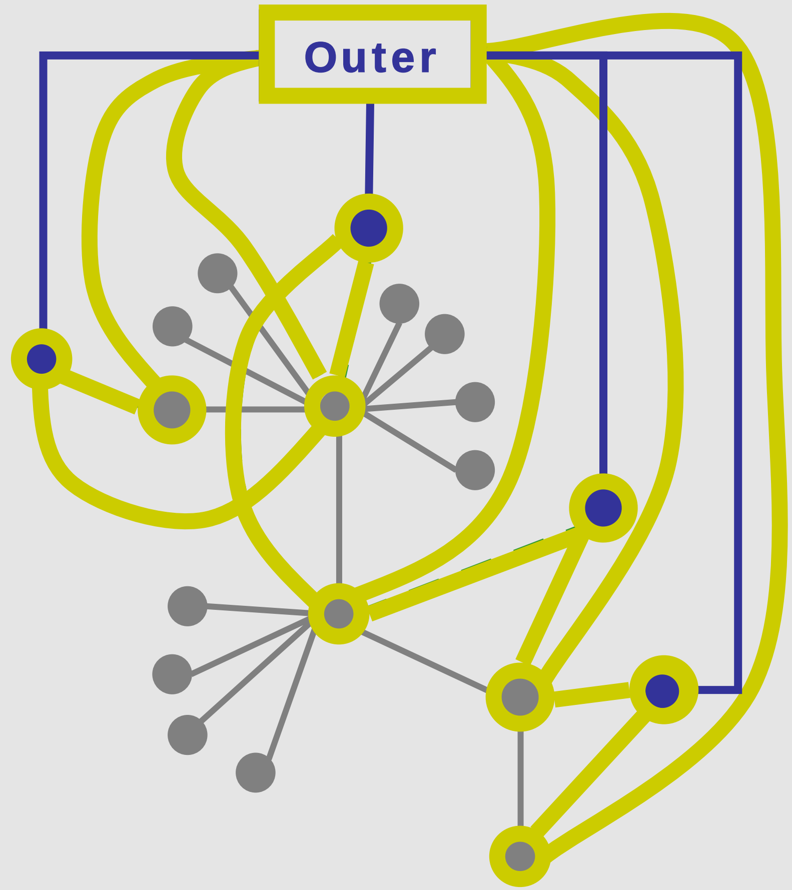
- Every dual graph of a space model describes a state transition diagram
  - If the partition of the space is non-overlapping, only one state is active at one point in time
- The existing **joint states** of several space models are represented in just one multi-layered graph
- The **joint state of navigation** is given by the simultaneously active states of all space models.
  - Combinations are constrained by the edges of the multi-layered graph.
  - Every clique of size *n*, where each node comes from a different space model, describes a possible joint state of navigation.

Example for Joint State





Rooms and their adjacencies within the topographic space model

RFID scanner coverage areas and their adjacencies within the sensor space model

Joint state

Example for Using the Joint State

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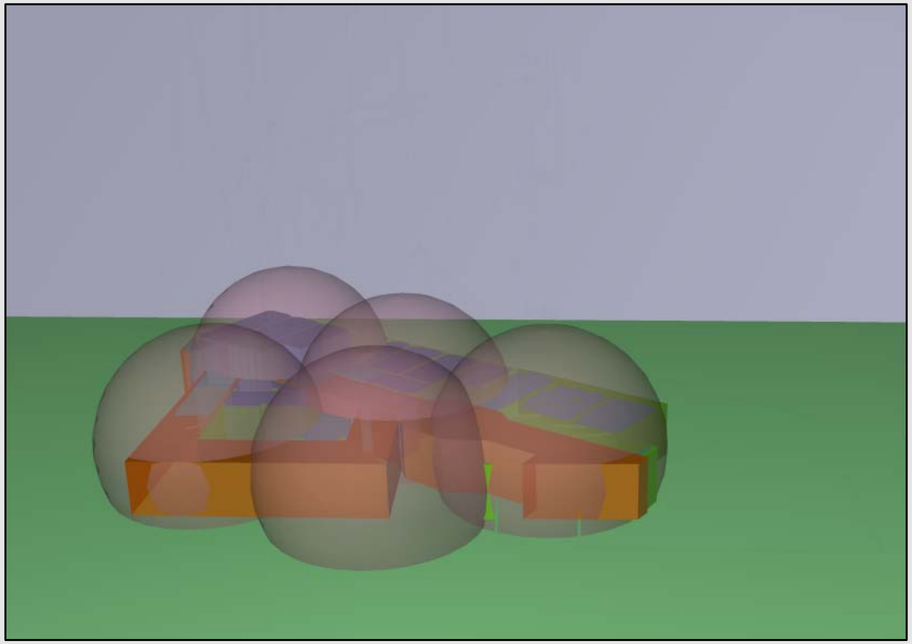
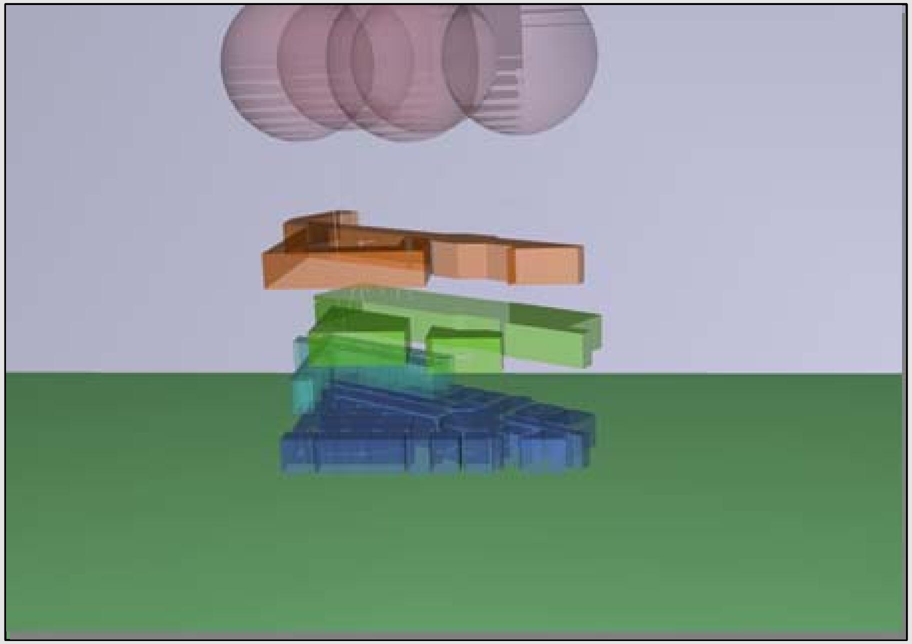


multilayered model (primal)

- *topographic space (blue)*
- *additional cell space (cyan)*
- *lower security zones (green)*
- *high security zones (orange)*
- *Wi-Fi transmitter (light red)*

Example for Using the Joint State



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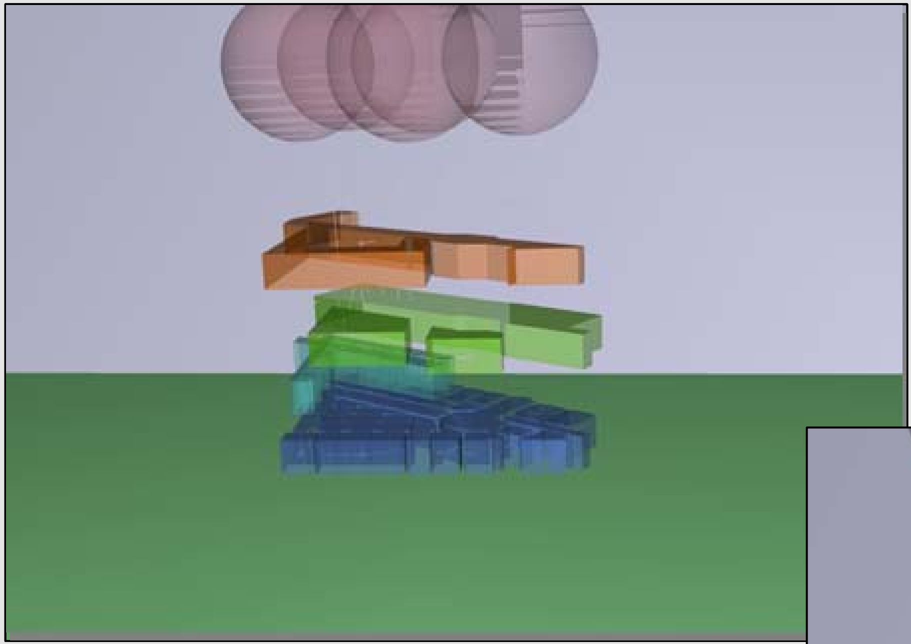

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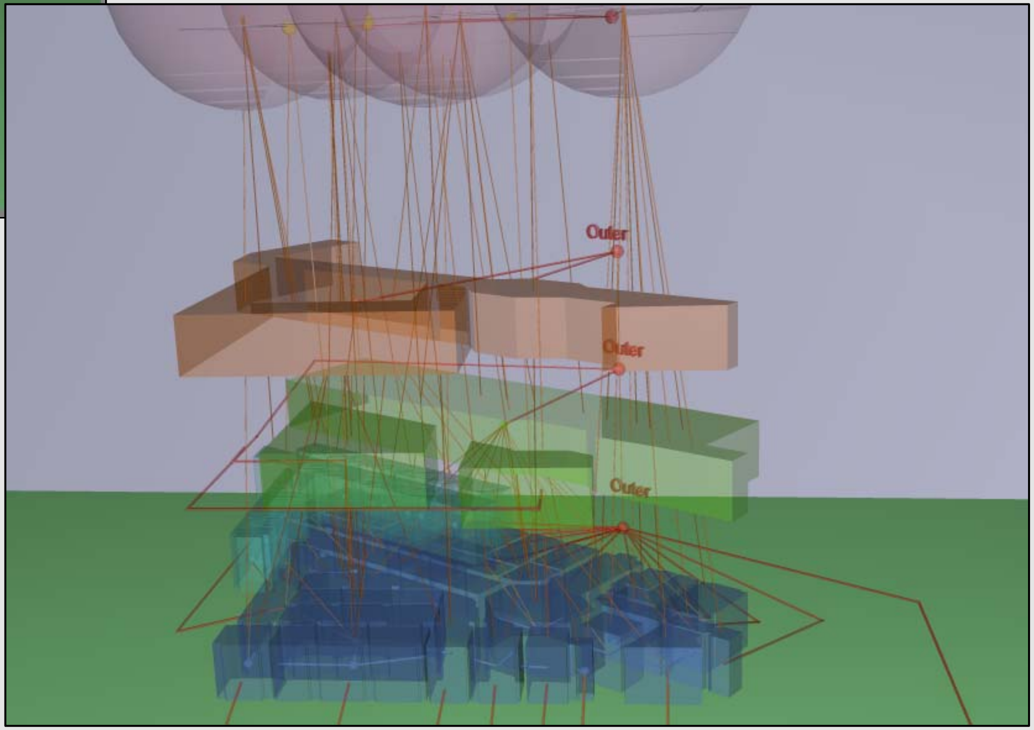

multilayered model (dual)

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- *additional: joint states between the layer*

Example for Using the Joint State

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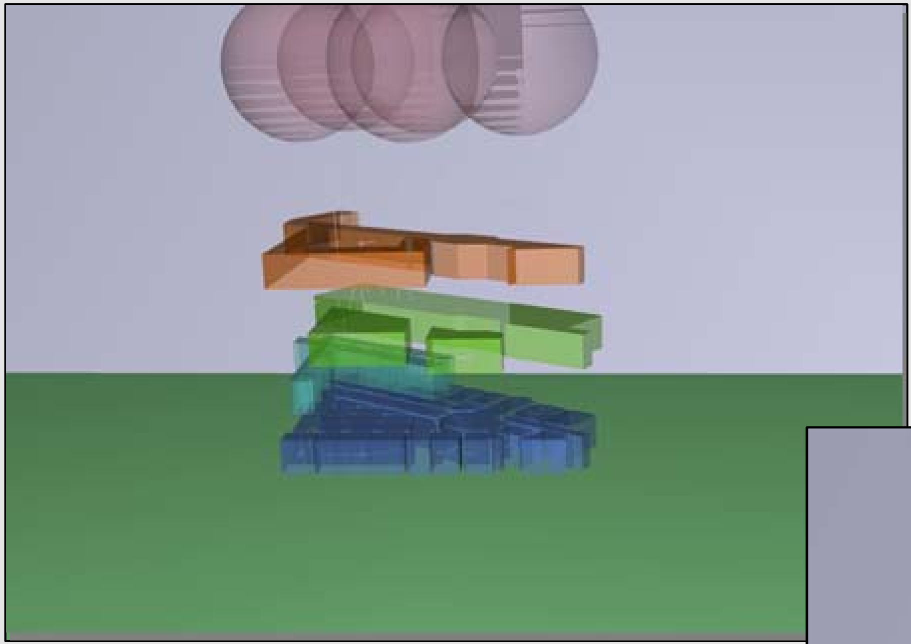

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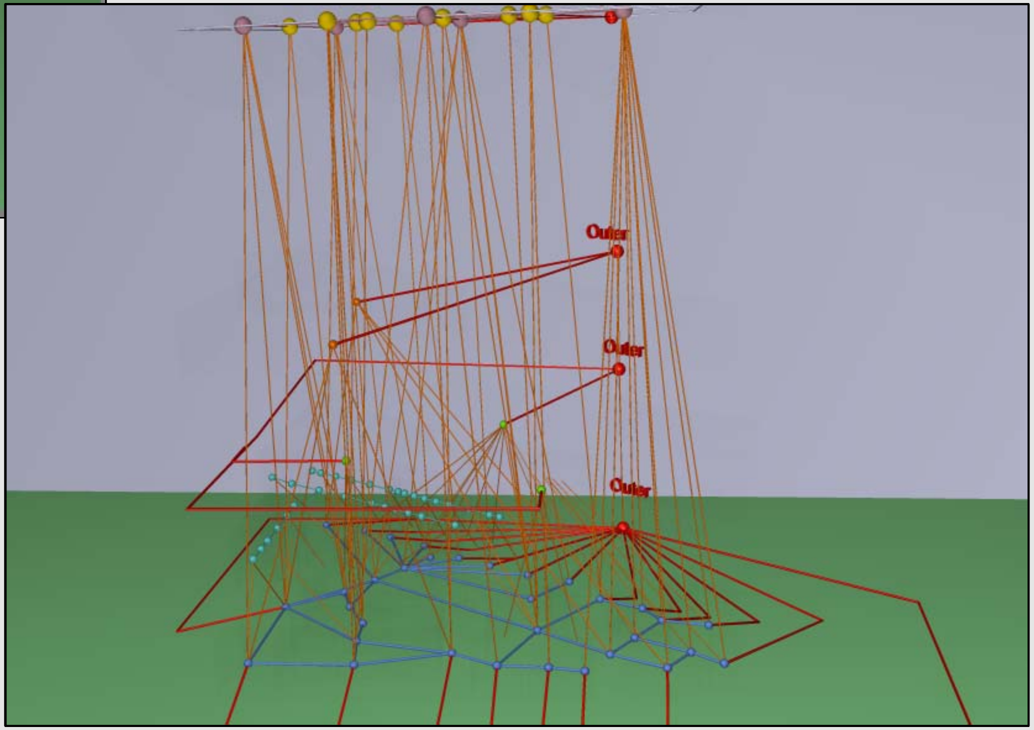

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Position Determination using the Joint State

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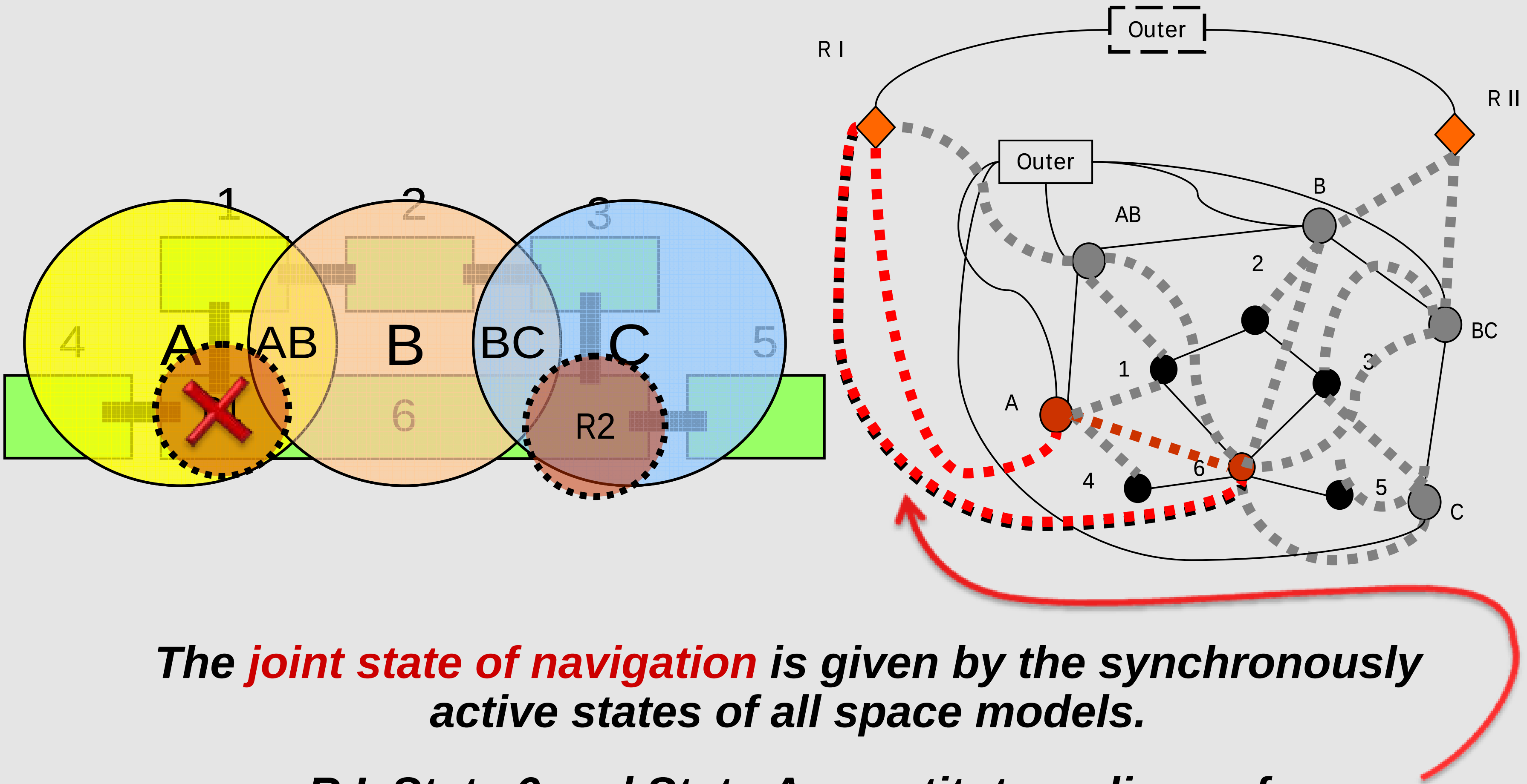

The joint state of navigation is given by the synchronously active states of all space models.

R I, State 6 and State A constitute a clique of Inter-Space connections, i.e. they overlap in primal space

Position Determination using the Joint State

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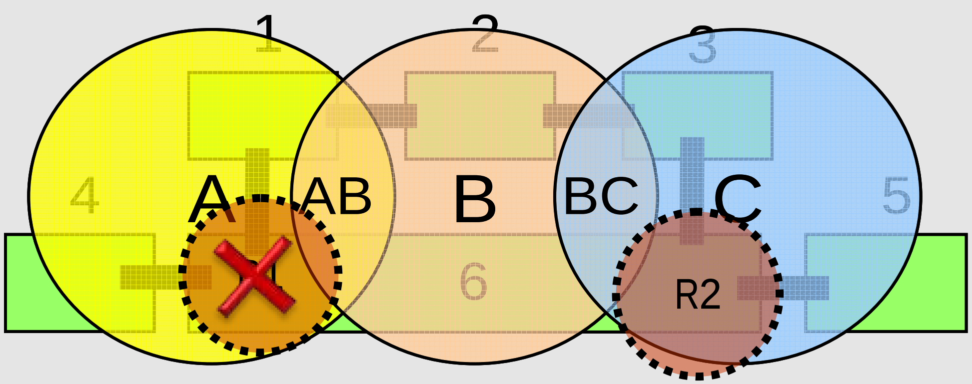
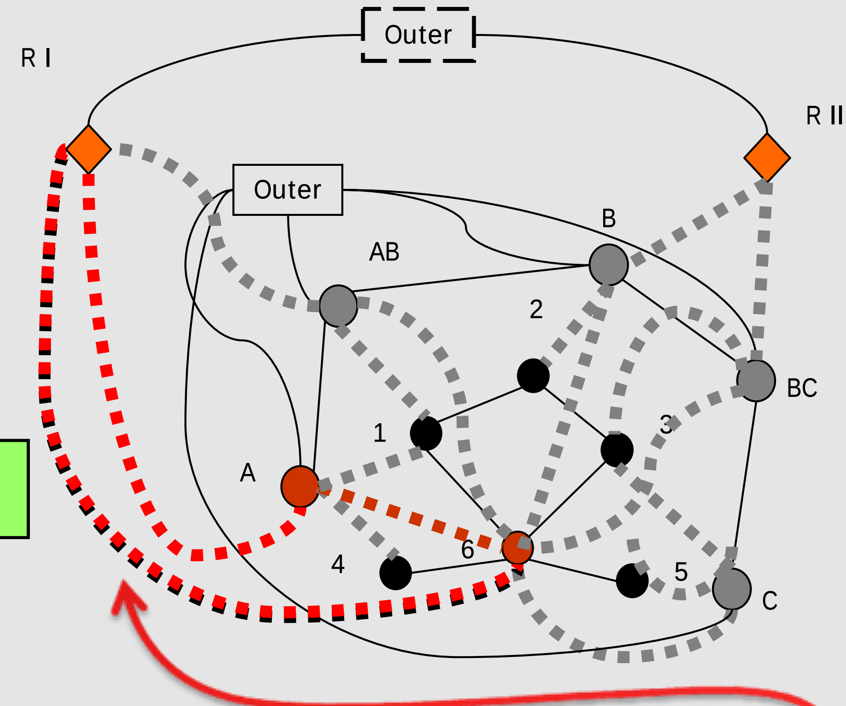
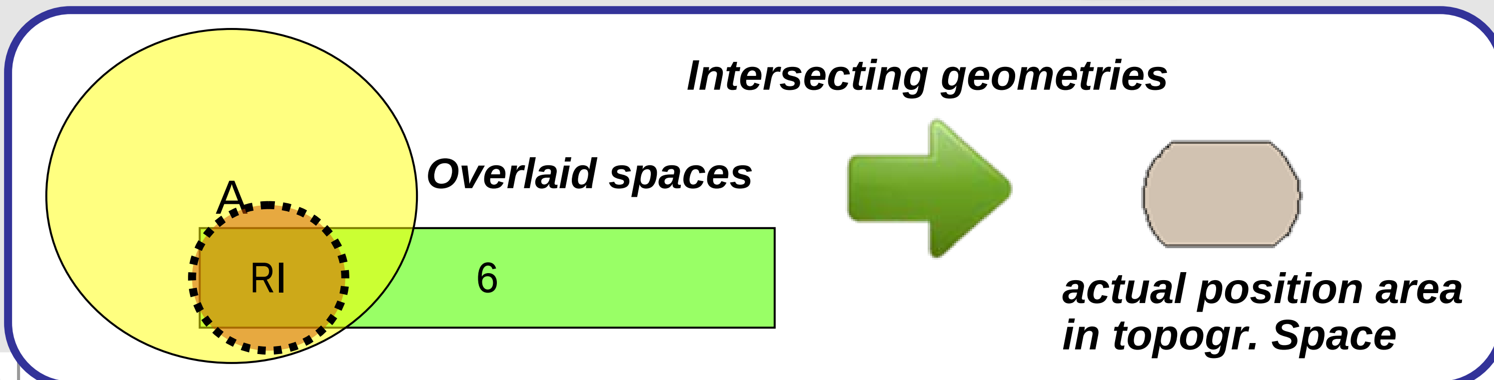






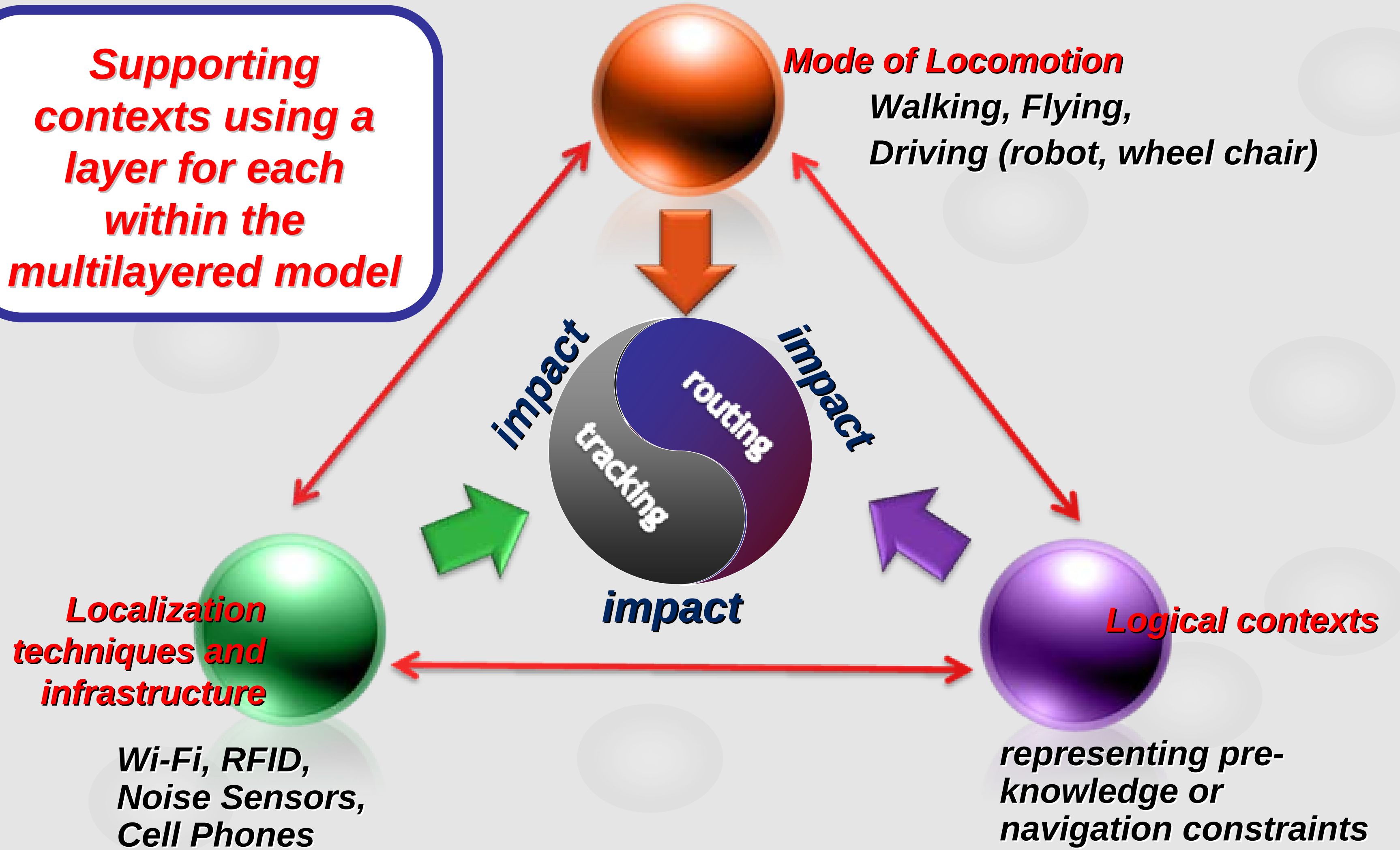
Summary of Multilayered Space Model

- The multilayered space model allows for **distinct spatial decompositions with respect to different semantics**
  - e.g. topography, sensors
  - changes (e.g. modifications, installation of new sensors) within one space model do not influence data within other space models
- The **multilayered graph** enables the **propagation of events between several space models**
  - i.e. when moving into an another sensor area, the possible locations in topographic space can be constrained
- the joint state **reduces the uncertainty of the absolute position** of an object or subject

Context of Navigation

three main factors constitute the context of navigation

Supporting contexts using a layer for each within the multilayered model



Mapping Context to the Multilayered Graph

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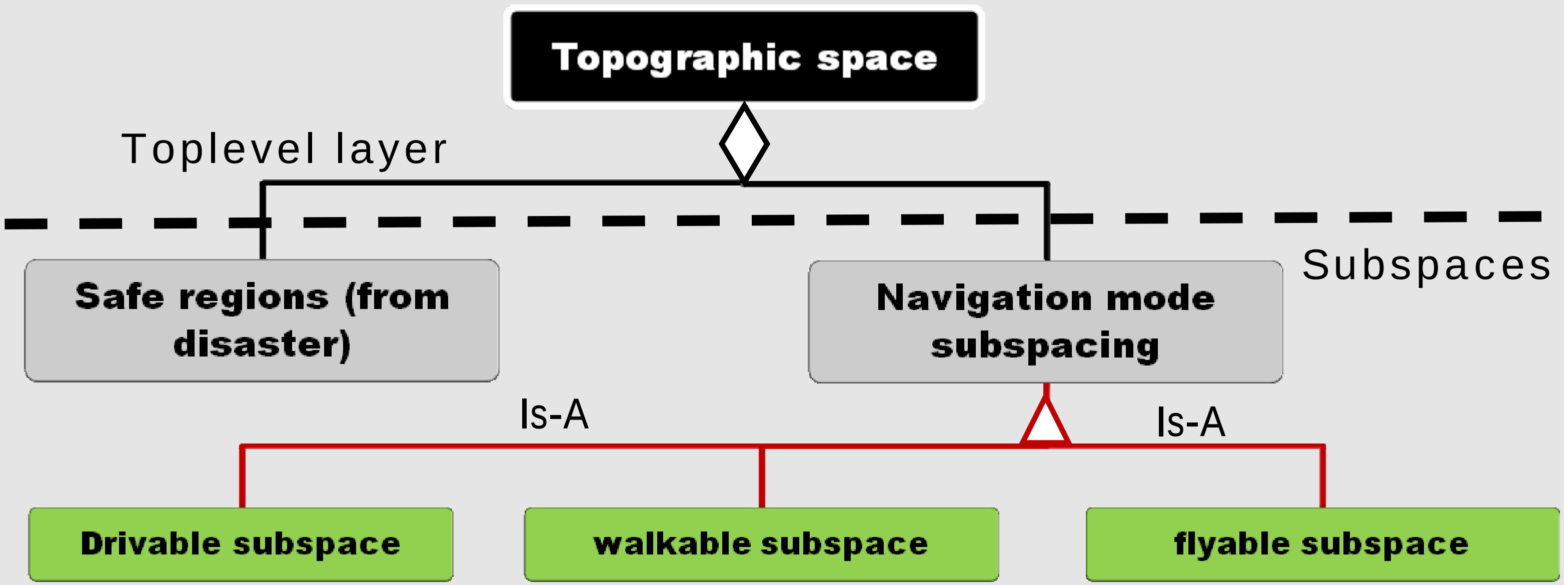
- Spaces within a space model may be subdivided due to specific considerations
  - e.g. by the mode of locomotion
  - each specific consideration or context leads to an new layer within the model
  - … but they **are not independent** of the higher level layer
  - therefore the inter-space connections can be topological qualified as **contains** or **equals**



Subspacing wrt. Mode of Locomotion

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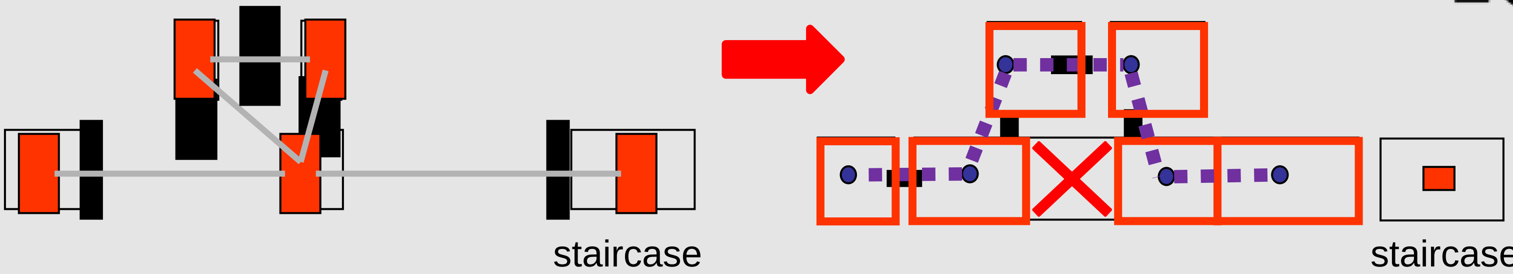
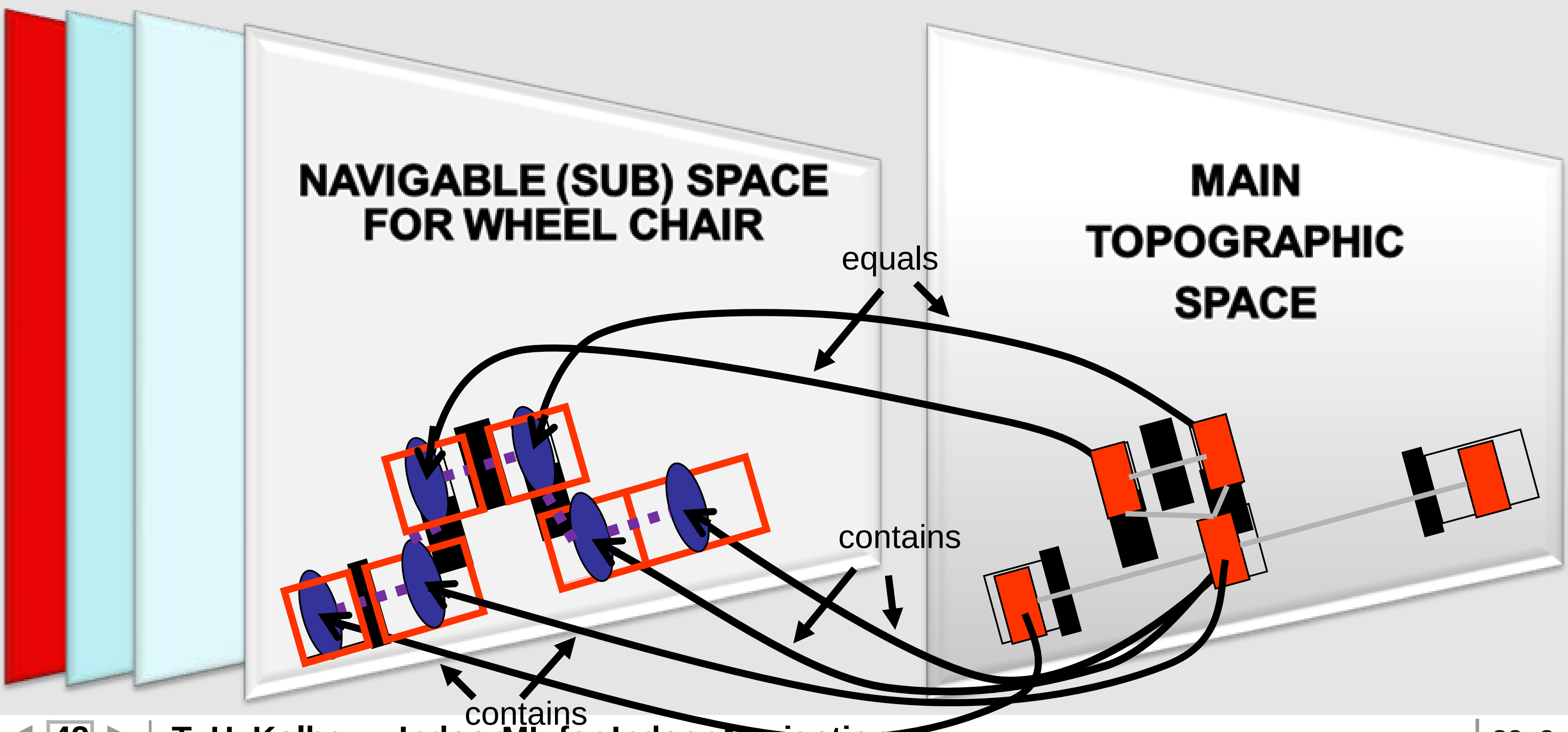


Use of Staircase and a part of the floor is prohibited in case of a wheel chair driver



Context Handling for Navigation Scenarios

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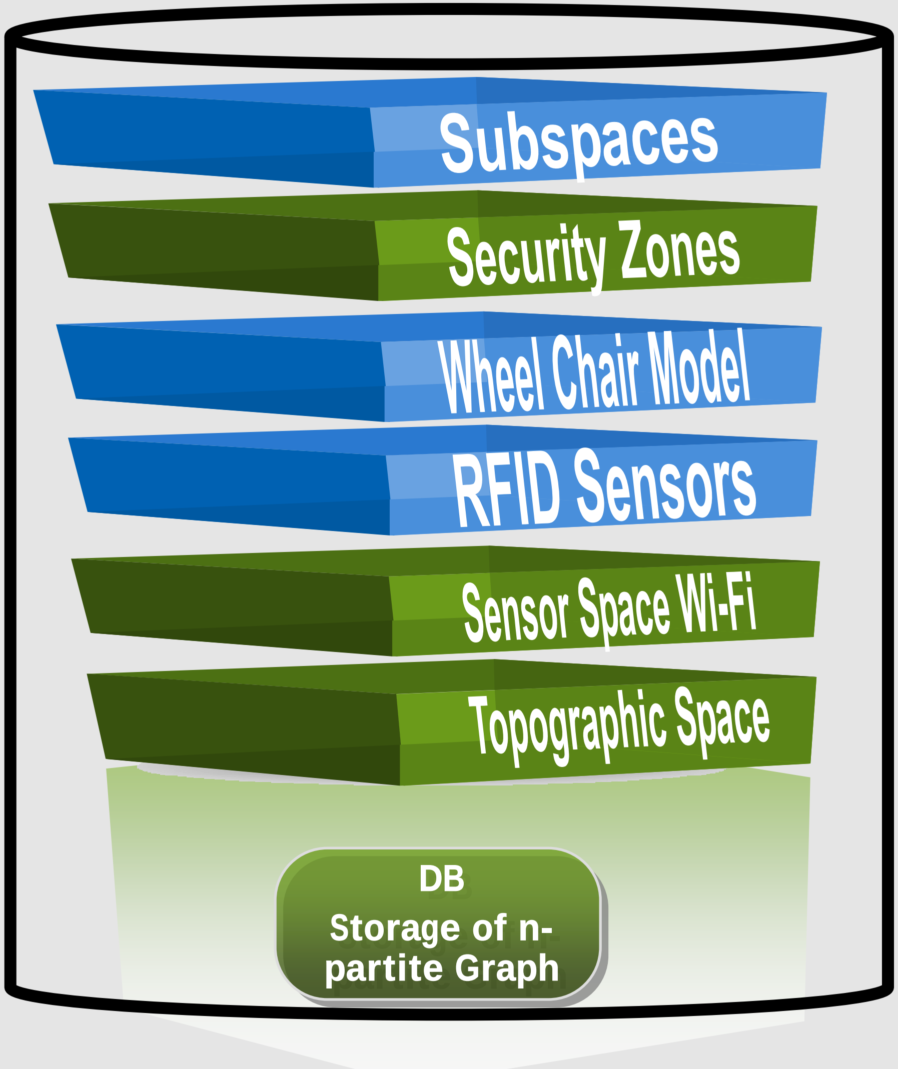

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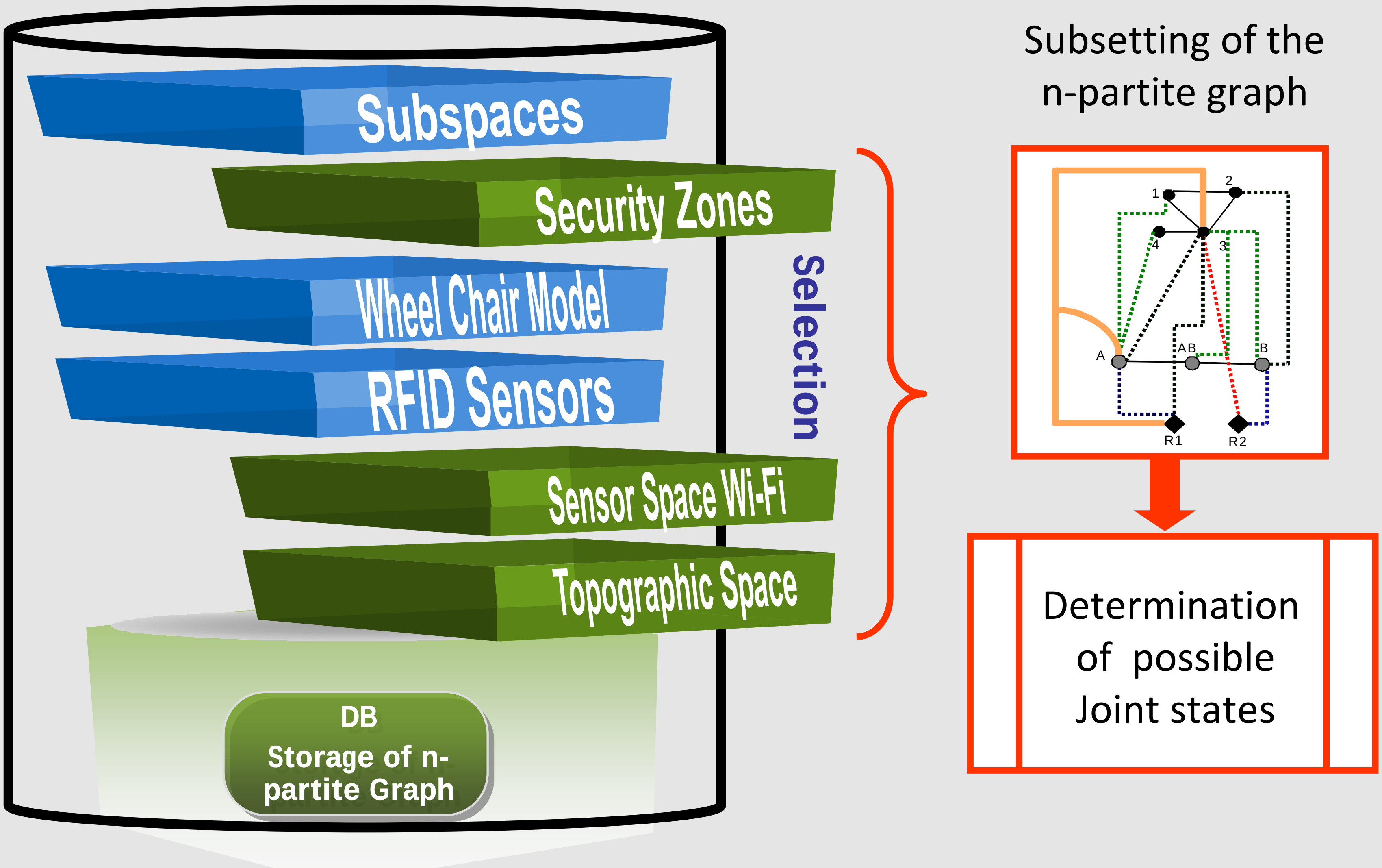

IndoorML - Data Model

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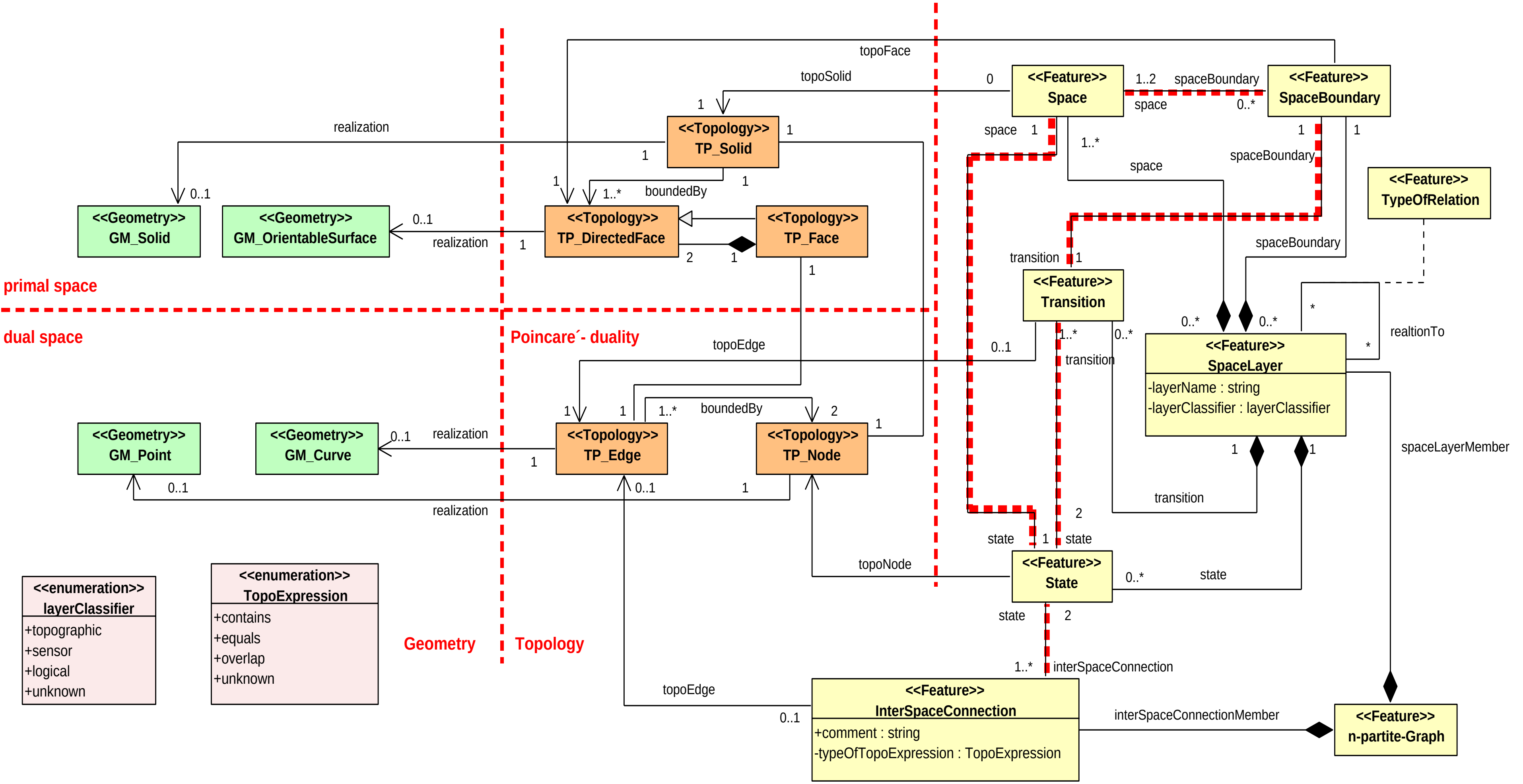
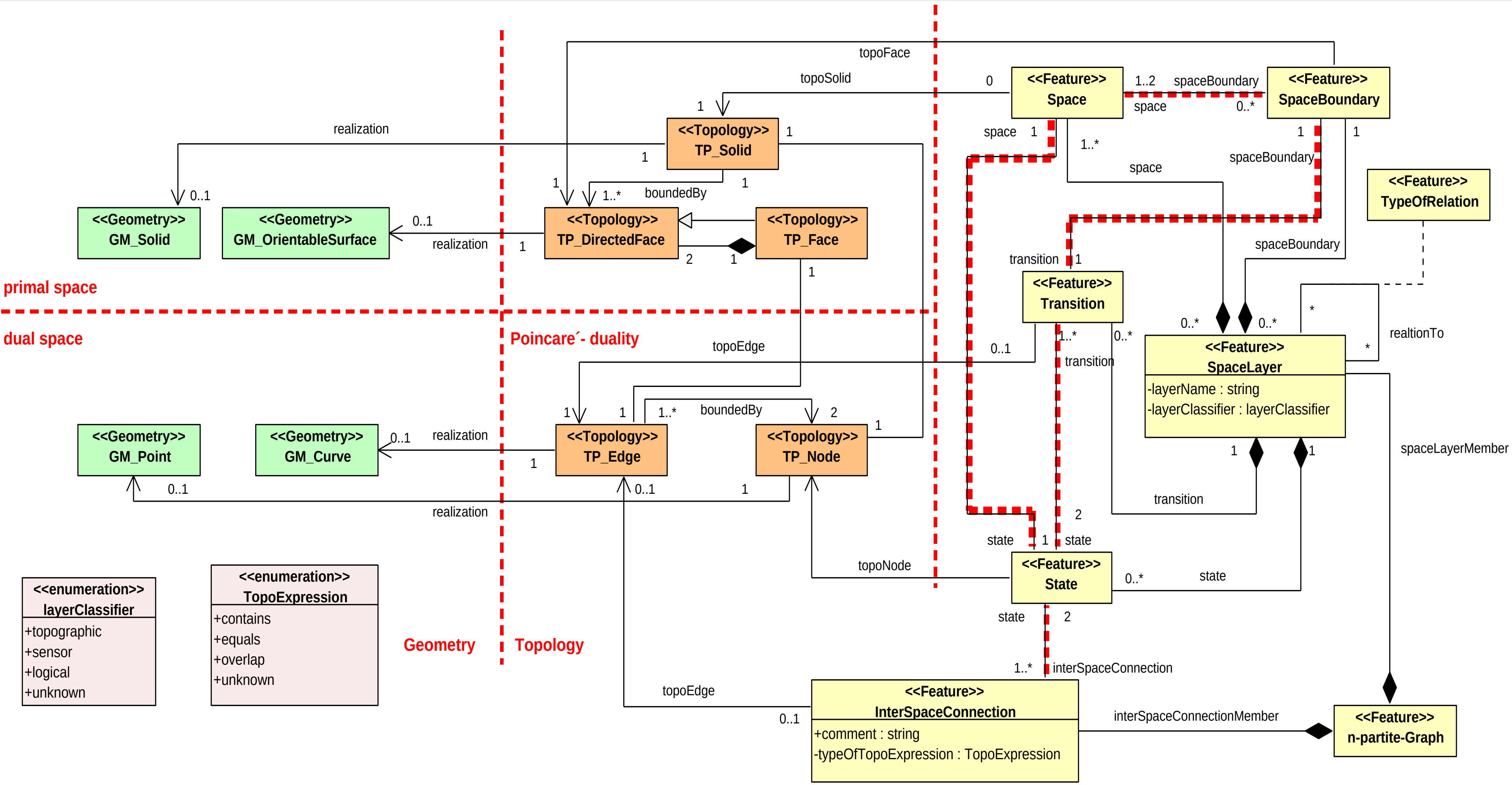
based on the ISO 191xx standards family and mapped to GML



IndoorML



topoFace
topoSolid
realization
<<Topology>> TP_Solid
<<Geometry>> GM_Solid
<<Geometry>> GM_OrientableSurface
<<Topology>> TP_DirectedFace
<<Topology>> TP_Face
boundedBy
primal space
dual space
Poincare´- duality
topoEdge
<<Geometry>> GM_Point
<<Geometry>> GM_Curve
<<Topology>> TP_Edge
<<Topology>> TP_Node
<<Feature>> Space
<<Feature>> SpaceBoundary
spaceBoundary
space
<<Feature>> TypeOfRelation
<<Feature>> Transition
transition
<<Feature>> SpaceLayer
-layerName : string
-layerClassifier : layerClassifier
realtionTo
spaceLayerMember
<<Feature>> State
state
topoNode
interSpaceConnection
<<Feature>> InterSpaceConnection
+comment : string
-typeOfTopoExpression : TopoExpression
interSpaceConnectionMember
<<Feature>> n-partite-Graph
<<enumeration>> layerClassifier
+topographic
+sensor
+logical
+unknown
<<enumeration>> TopoExpression
+contains
+equals
+overlap
+unknown
Geometry
Topology

Linking IndoorML with CityGML

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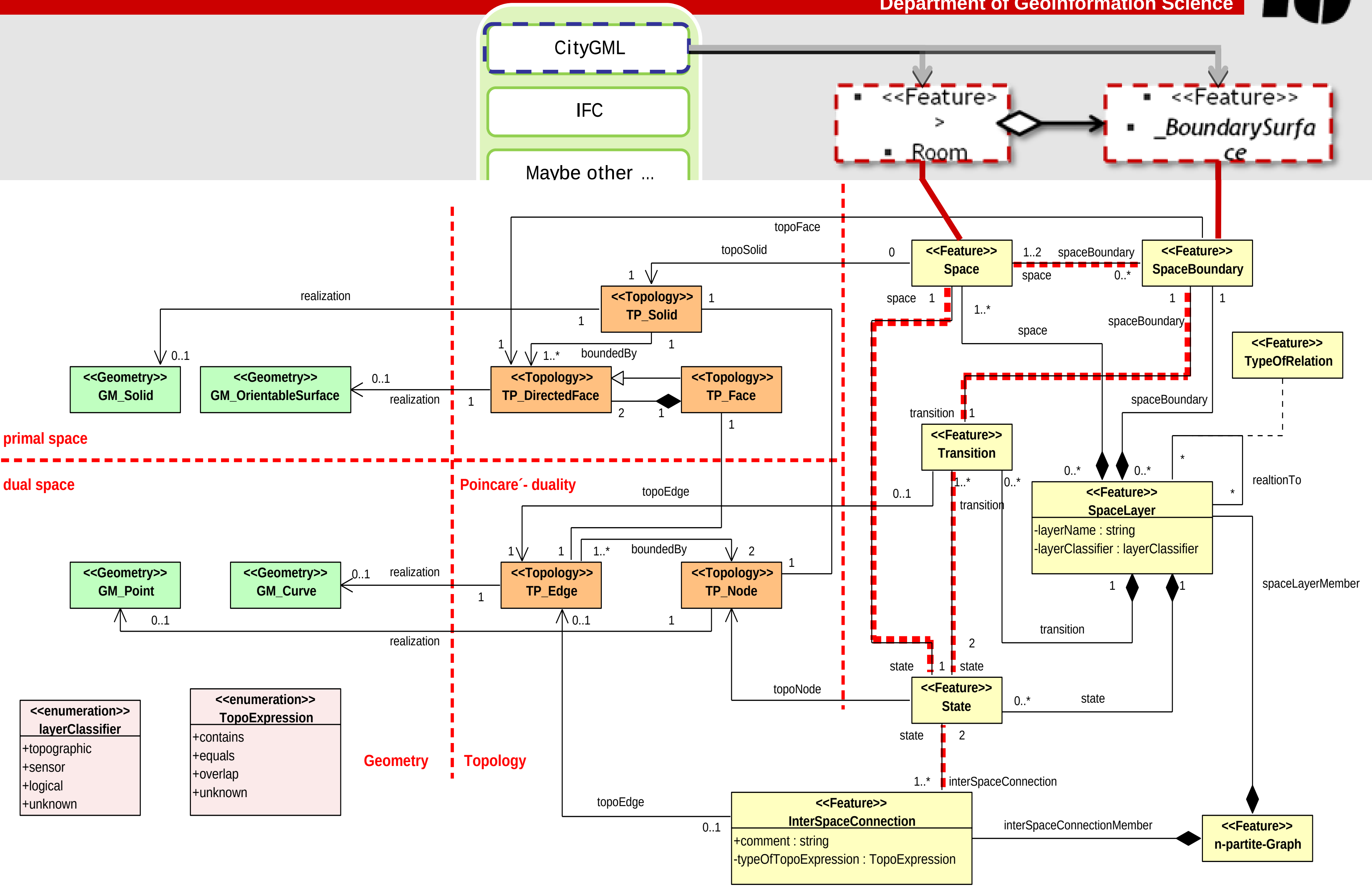
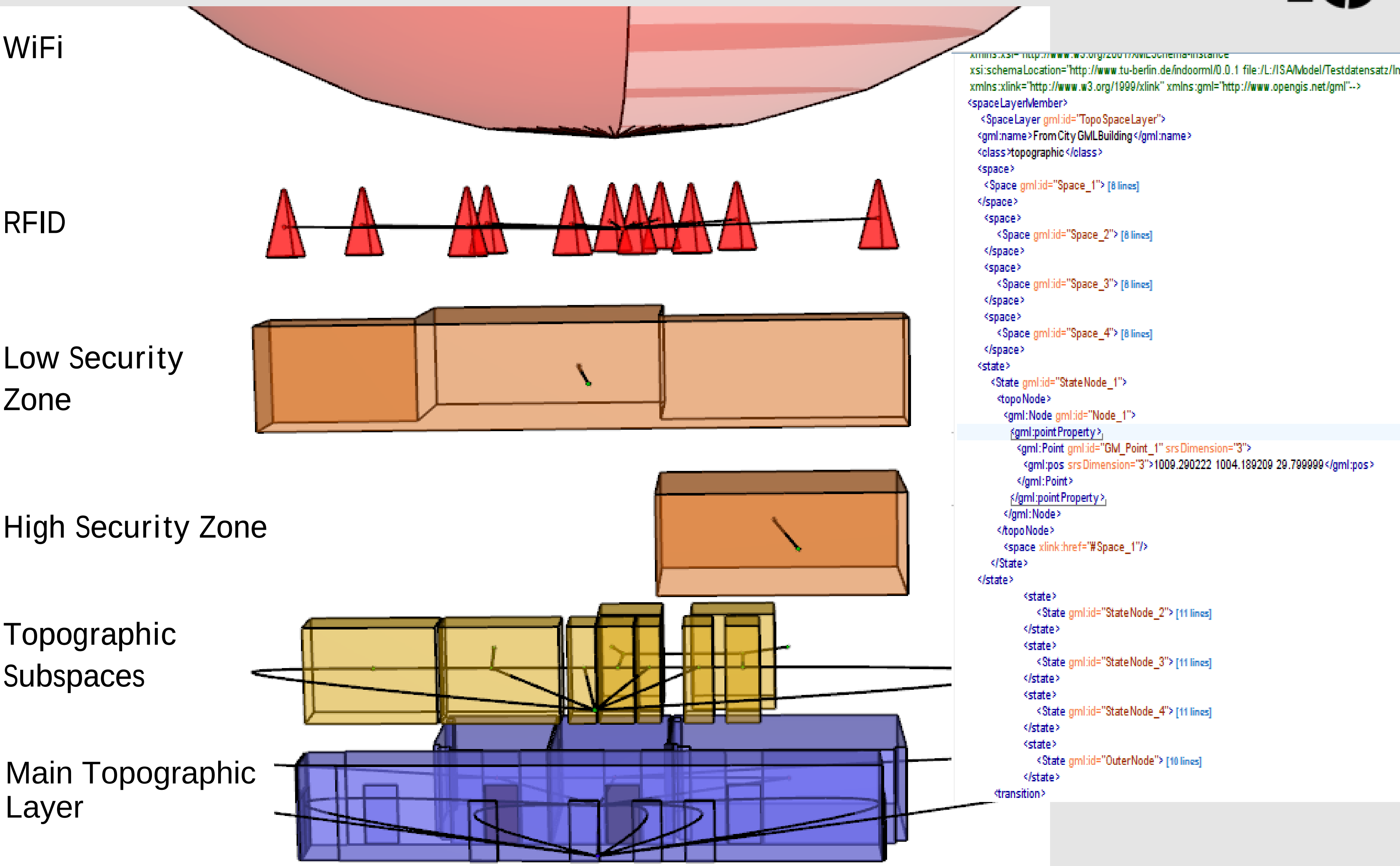
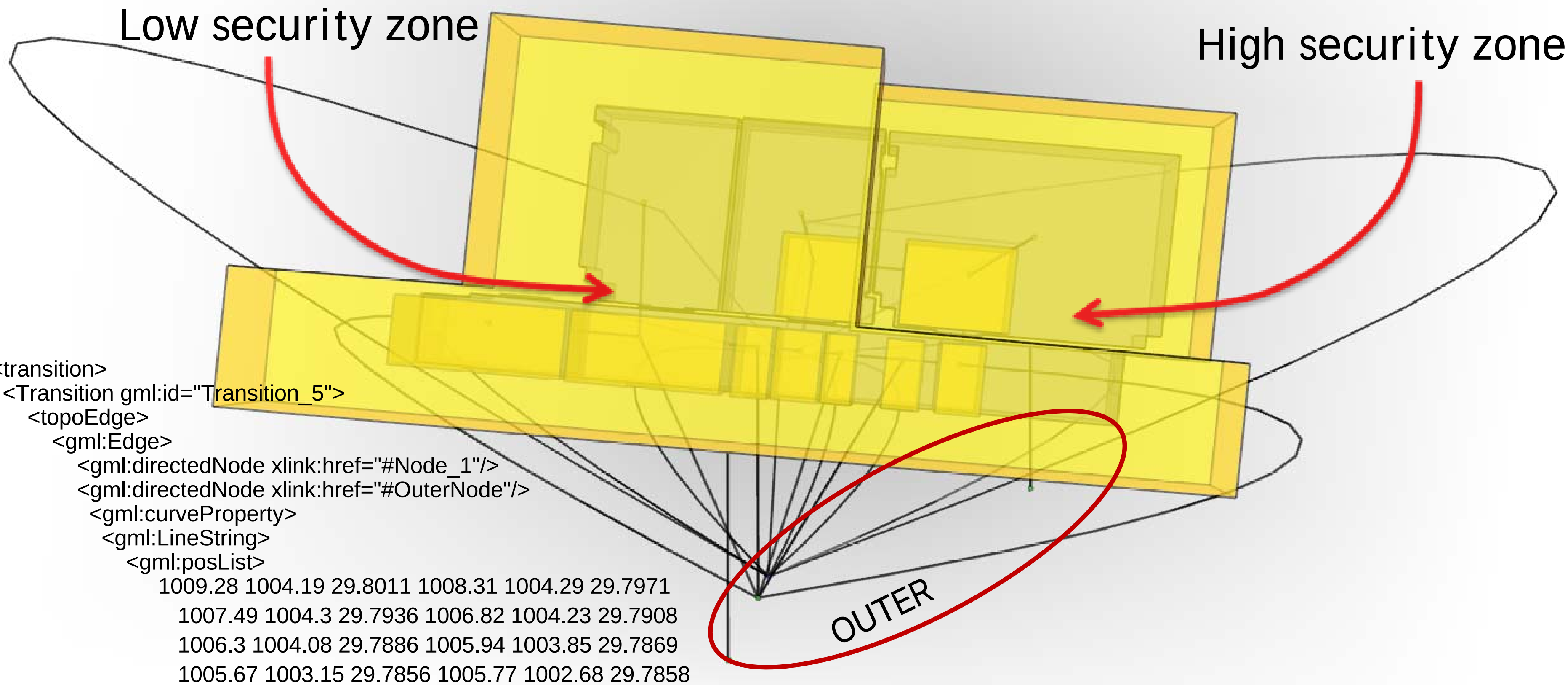


Example


WiFi
RFID
Low Security Zone
High Security Zone
Topographic Subspaces
Main Topographic Layer
xsi:schemaLocation="http://www.tu-berlin.de/indoorml/0.0.1 file:/L:/ISAModel/Testdatensatz/In
xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:gml="http://www.opengis.net/gml"-->
<spaceLayerMember>
<SpaceLayer gml:id="TopoSpaceLayer">
<gml:name>FromCityGMLBuilding</gml:name>
<class>topographic</class>
<space>
<Space gml:id="Space_1"> [8 lines]
</space>
<space>
<Space gml:id="Space_2"> [8 lines]
</space>
<space>
<Space gml:id="Space_3"> [8 lines]
</space>
<space>
<Space gml:id="Space_4"> [8 lines]
</space>
<state>
<State gml:id="StateNode_1">
<topoNode>
<gml:Node gml:id="Node_1">
<gml:pointProperty>
<gml:Point gml:id="GM_Point_1" srsDimension="3">
<gml:pos srsDimension="3">1009.290222 1004.189209 29.799999</gml:pos>
</gml:Point>
</gml:pointProperty>
</gml:Node>
</topoNode>
<space xlink:href="#Space_1"/>
</State>
</state>
<state>
<State gml:id="StateNode_2"> [11 lines]
</state>
<state>
<State gml:id="StateNode_3"> [11 lines]
</state>
<state>
<State gml:id="StateNode_4"> [11 lines]
</state>
<state>
<State gml:id="OuterNode"> [10 lines]
</state>
<transition>

Example (II)



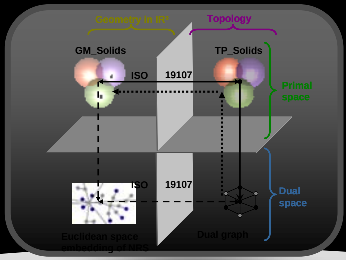

```
<transition>
  <Transition gml:id="Transition_5">
    <topoEdge>
      <gml:Edge>
        <gml:directedNode xlink:href="#Node_1"/>
        <gml:directedNode xlink:href="#OuterNode"/>
         <gml:curveProperty>
          <gml:LineString>
            <gml:posList>
              1009.28 1004.19 29.8011 1008.31 1004.29 29.7971
                1007.49 1004.3 29.7936 1006.82 1004.23 29.7908
                1006.3 1004.08 29.7886 1005.94 1003.85 29.7869
                1005.67 1003.15 29.7856 1005.77 1002.68 29.7858
                1006.02 1002.12 29.7866 1006.42 1001.49 29.7881
                1006.97 1000.78 29.7901 1007.68 999.986 29.7928
                 1008.54 999.112 29.7961 1009.55 998.159  29.8
            </gml:posList>
          </gml:LineString>
        </gml:curveProperty>
      </gml:Edge>
    </topoEdge>
  </Transition>
</transition>
```

Intra-space connections must have a topological and may have a geometrical Embedding!

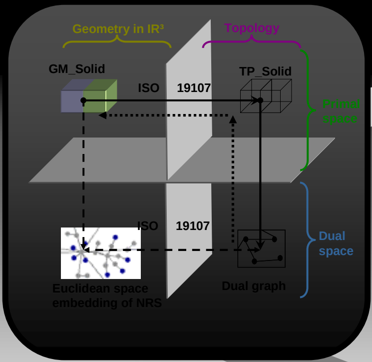
IndoorML: Review of Navigation Requirements

Localization

is now possible by using the sensor layers and the joint states

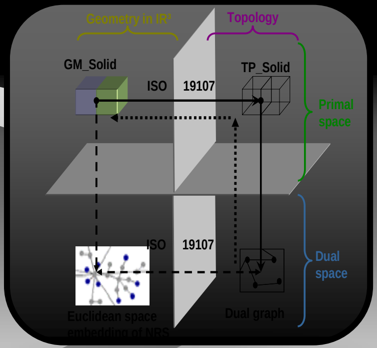


coordinate system / addresses points of interest can be derived from Geoinformation about the navigable space



navigable route sections

route network is required and now available



Geoinformation about the navigable space is available

Summary and Conclusions

- **Indoor navigation requires 3D models and 3D data**
  - for route planning and addressing
  - for position determination of persons or objects
- **Multilayered Space Model** assesses the combination of different space representations
  - important space models: topography space,
    sensor space (one per sensor type / localisation method)
  - different subspacing of topography wrt. mode of locomotion
  - logical spaces express navigation constraints / restrictions
- **IndoorML** is a data model and exchange format (based on GML) for the representation of the indoor navigation aspects
  - complementary to CityGML, IFC, GDF