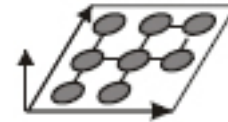
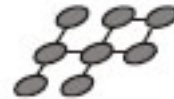
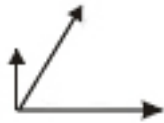


LOCATION MODELS



Distributed Systems Seminar 2006

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Overview

- Introduction
- Location models
- Design choices by examples
- Conclusions

Introduction - *Definitions*

- Location = a determination of the place where smth is. [<http://wordnet.princeton.edu/>] (a position or extent in space)
- Coordinate(s) = identifier which specifies the position of an object with respect to a given reference coordinate system [2]
- Location model = an expressive, flexible and efficient representation of location information [4]

Introduction - *Queries*

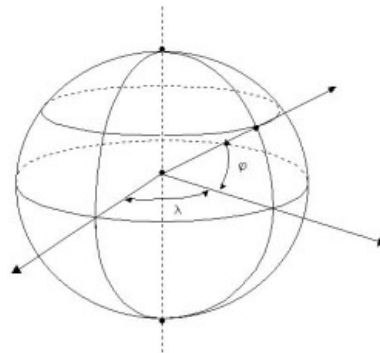
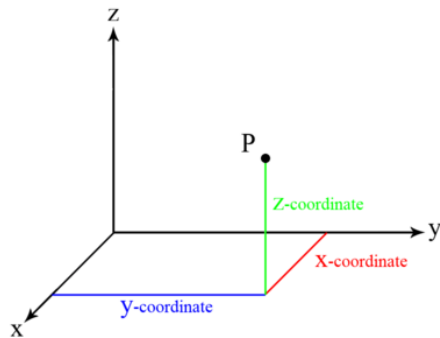
- **Position queries:** "Where am I? / Where is X?".
(result = current position of mobile or static entities)
- **Nearest neighbor queries:** "Where is the nearest hospital?" (result = the position of the closest object)
- **Navigation queries:** "How do I get to this hospital from my current location?" (result = several interconnected locations)
- **Range queries:** "What rooms are on floor C?"
(result = all objects inside to a certain area)

Introduction - *Requirements*

- **Object positions** in some form of coordinates
- **Distance functions** – modeled usually as Euclidean distance or cost distance
- **Topological relations** like connectivity, adjacency, overlapping and spatial inclusion/containment between spatial objects
- **Orientation** in the horizontal and/or vertical dimensions may be required by some applications

Introduction - *Coordinates*

- **Geometric coordinates** refer to a geometric point or figure in a multi-dimensional space
 - Cartesian vs. Geographic / Global vs. Local



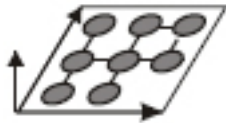
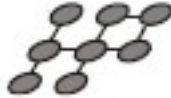
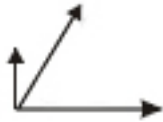
(8.545° E, 47.380° N, 421m)

- **Symbolic coordinates** define locations in the form of abstract symbols (names).
 - „Switzerland“, „Zurich“, „IFW building“, „IFW C42 “

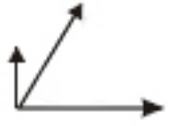
Introduction - *Coordinates*

Requirements / Coordinates	Geometric	Symbolic
Topological properties (reasoning about spatial properties like distance, connectivity, adjacency, overlapping and spatial inclusion/containment)	+	-
Semantics (locations` meaning or properties)	-	+

Location models

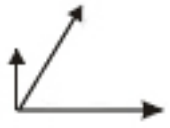


- **Geometric**
- **Symbolic**
- **Hybrid**



Location models - *geometric*

- **Geometric location models** are based on reference geometric coordinate systems.
- Locations are points, areas, or volumes within the coordinate system.
- Supported by an adequate mathematical model
- Topological relationships like distance, inclusion, overlap and adjacency derived from geometries
- “Connected to” relation cannot be derived only from location geometries (**modeled explicitly**)



Location models - *geometric*

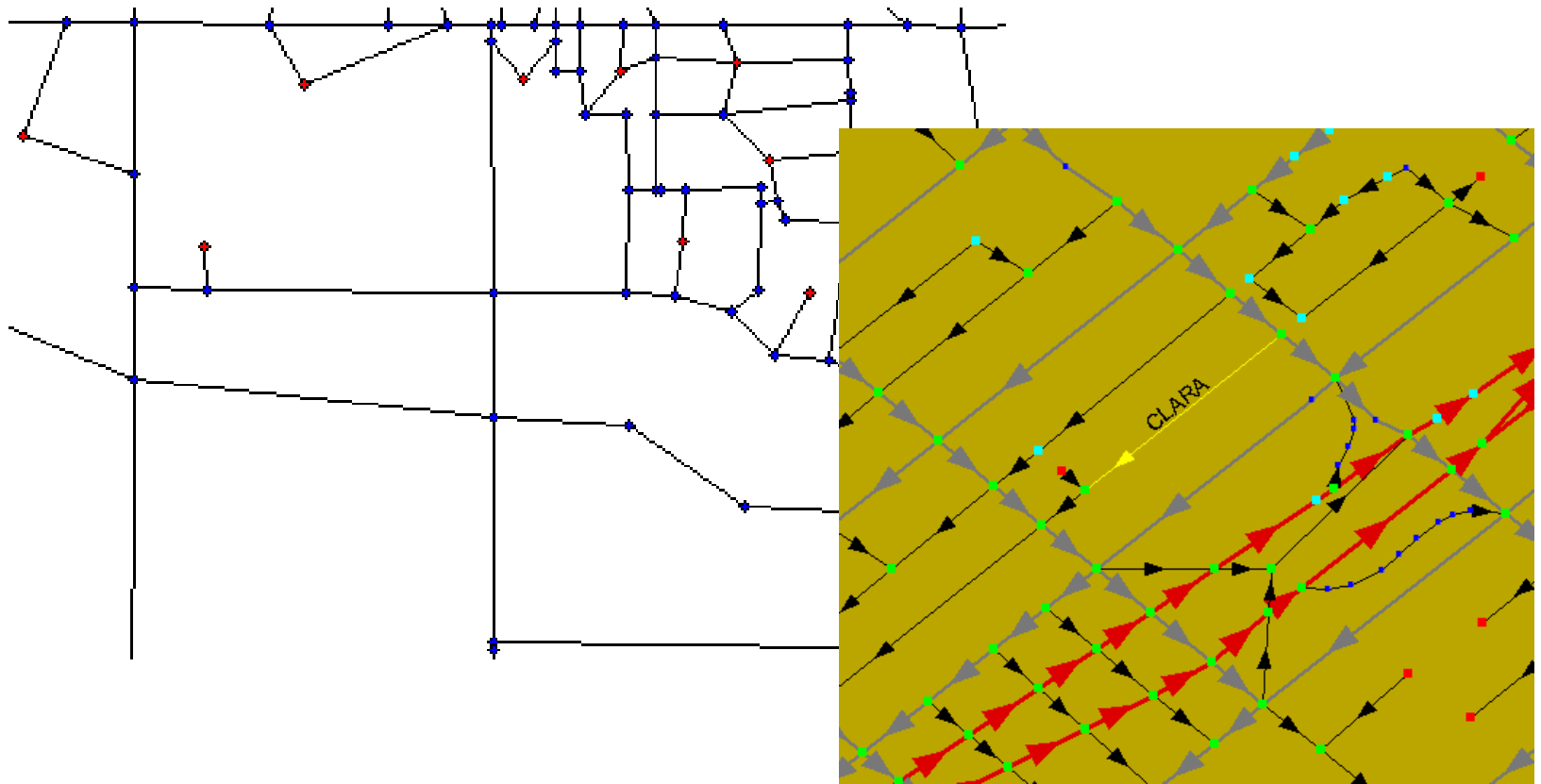


Image copyright: gis.washington.edu

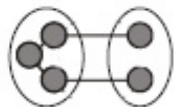
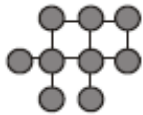
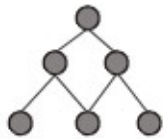
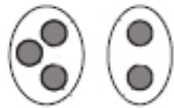


Location models - *symbolic*

- **Symbolic location models** are based on symbolic coordinates.
- A symbolic location is a symbolic name which loses any reference to its geometry [4].
- A list of coordinates is grouped into a single symbolic location (e.g. “IFW building”).
- Constructed starting from geographic areas:
 - identify all units of the geographic space
 - define a **structure** in which these units can be arranged



Location models - *symbolic*



- **Set-based**
- **Hierarchical**
- **Graph-based**
- **Combined symbolic**



Location models - *symbolic*

- **Set-based location models**
- Based on a set of symbolic locations L comprising a list of the smallest location units identified. All locations comprising several symbolic units are then defined as subsets of L .

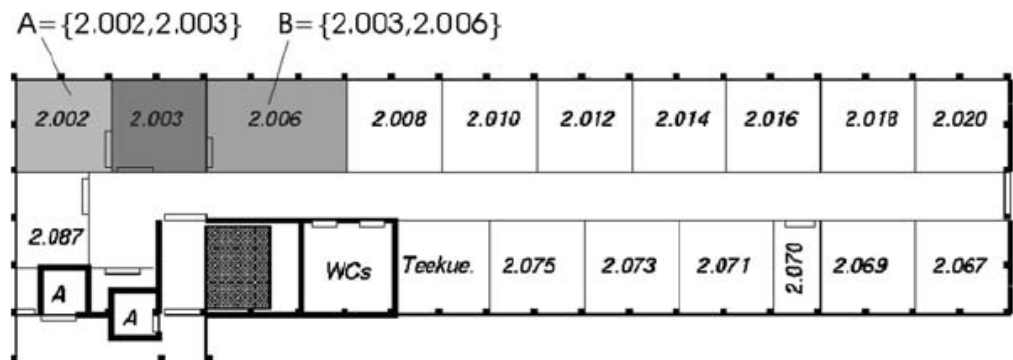


Image copyright: [2]



Location models - *symbolic*

- **Hierarchical location models**
- Consist of a set of symbolic locations L that are ordered based on “contained-in” relations. From these set of symbolic locations L we can form a lattice (hierarchical tree)

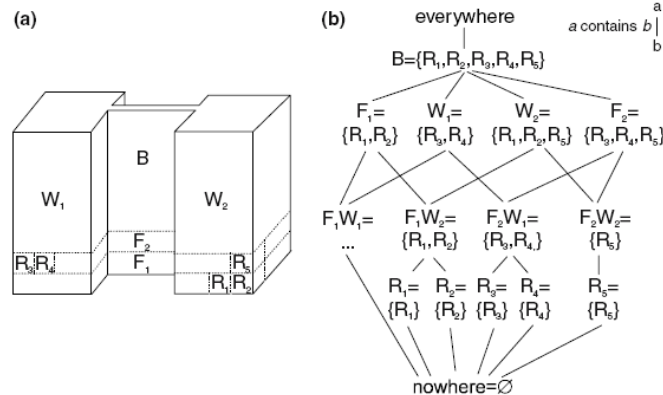
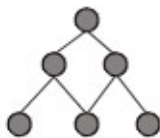


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Location models - *symbolic*

- **Graph-based location models**
- A graph of locations, in which vertices represent locations and edges represent connections between the locations.

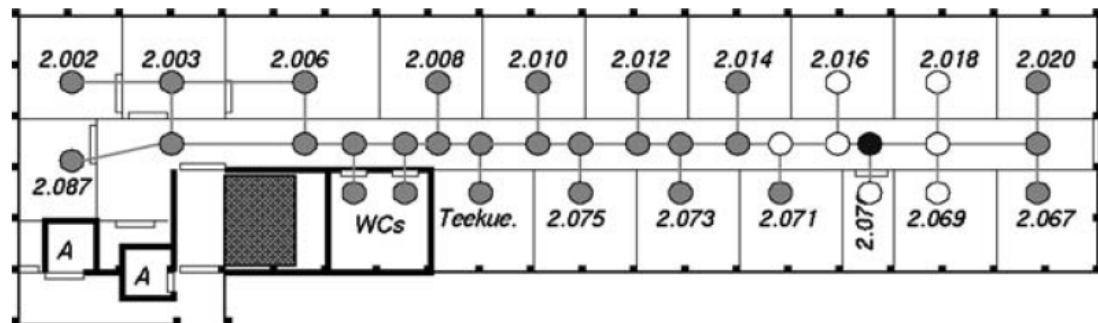
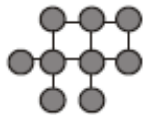


Image copyright: [2]



Location models - *symbolic*

- **Combined symbolic location models**
- Combines the best parts of graph-based (definition of connected locations) and set-based/hierarchical models (support for range queries): the connected graph's vertices are organized into sets identifying related locations.

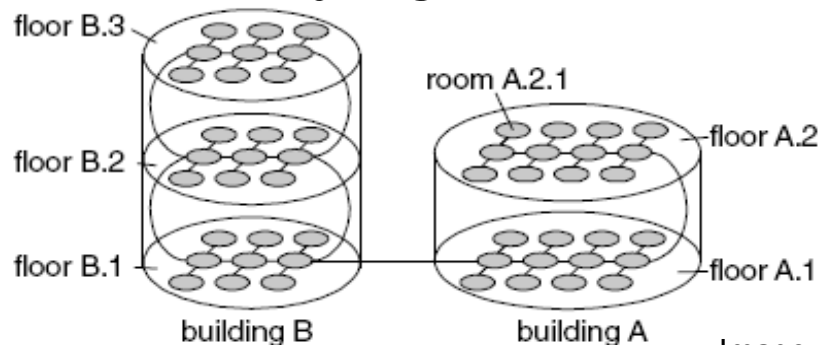
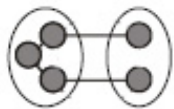
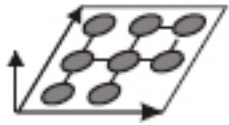


Image copyright: [2]



Location models - *hybrid*

- **Hybrid location models** obtained from the set-based, graph-based, or combined models by attaching coordinates in a reference system
- **Subspaces** approach stores geometric information for every modeled location.
- **Partial subspaces** approach only stores geometric information for some locations.

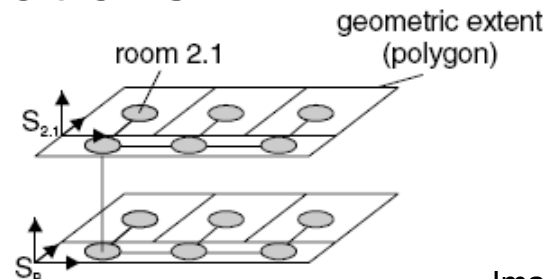
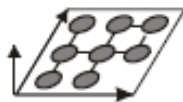









Image copyright: [2]

Location models - *Comparison*

Location model	Type	Position	Nearest neighbor	Navigation	Range	Modeling effort
Geometric 	geo	+	+	-	++	High
Set-based 	symb	+	-	-	+	High
Hierarchical 	symb	+	-	-	++	Medium
Graph-based 	symb	+	+	++	-	Medium
Combined symbolic 	symb	+	+	+	+ / ++	High
Subspaces (Hybrid) 	symb/ geo	++	++	++	++	Very high
Partial subspaces (Hybrid) 	symb/ geo	++	+ / ++	+ / ++	+ / ++	High

Design choices by examples

- **Design challenge:** to choose location models carefully with respect to the requirements for spatial reasoning and the involved modeling effort.
- To find the right balance between fulfilling the requirements and design costs!

Design choices by examples

A Hybrid Location Model with a Computable Location Identifier (project AURA)

- Starting point for the AURA hybrid model: the **hierarchical location model** (hierarchy of spaces and each level further refines and subdivides the spaces of the previous level).
- The campus of Carnegie Mellon University is decomposed into several **sub-spaces**: Wean hall, Smith Hall, Posner Hall, etc.
- Each sub-space divided into smaller composing sub-spaces, until enough precision is reached.

Design choices by examples

A Hybrid Location Model with a Computable Location Identifier (project AURA)

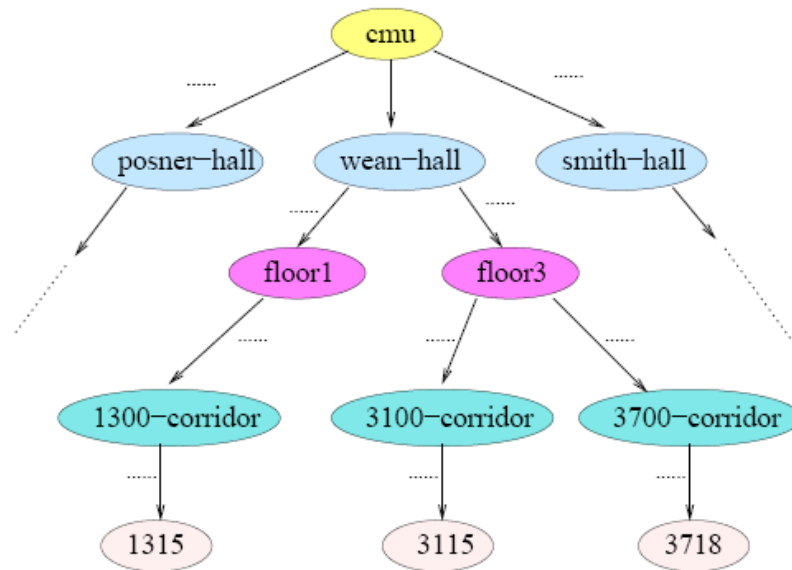


Image copyright: [3]

Design choices by examples

A Hybrid Location Model with a Computable Location Identifier (project AURA)

- Location model is enhanced with a **coordinate model** (allowing each space in the hierarchy to have geometric attributes in a coordinate system).
- Different spaces may use different coordinate systems (the location model allows each space in the space tree to have its own coordinate system)
- Each space coordinate system is defined by specifying the origin point and three axes of “x”, “y” and “z”.

Design choices by examples

A Hybrid Location Model with a Computable Location Identifier (project AURA)

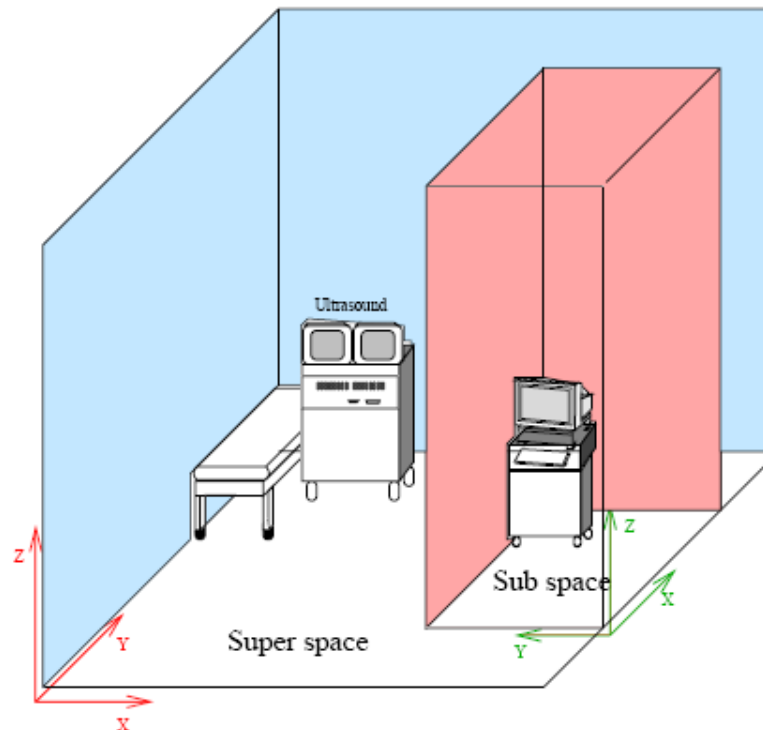


Image copyright: [3]

Design choices by examples

A Hybrid Location Model with a Computable Location Identifier (project AURA)

- Three types of location information were represented:
 - **Space location.** It is a physical space entity, e.g. “room 3115 of 3rd floor of Wean Hall at CMU”.
 - **Area location.** It is a space not physically demarcated, but virtually defined by applications, e.g. “the area covered by a particular wireless access point”.
 - **Point location.** It is a position of mobile user or object. Usually, we are not interested in the shape and extension of that user or object, but just in its position, e.g. “the location of printer ‘slate’”

Design choices by examples

A Hybrid Location Model with a Computable Location Identifier (project AURA)

- Aura Location Identifier (ALI) types are:
 - **Space Identifier:** “*ali://cmu/wean-hall/floor3/3100-corridor/3115*”. This identifier represents room 3115 on 3rd floor of Wean Hall at CMU. Its geometric attributes are stored in a centralized location data repository.
 - **Area Identifier:** “*ali://cmu/wean-hall/floor3#{(1,0),(-1.5,0.5),(0,3),(2,3.5),(3,1.5)-(1,5)}*” This identifier represents an area on the 3rd floor of Wean Hall at CMU.
 - **Point Identifier:** “*ali://cmu/wean-hall/floor3/3700-corridor/3718#(10,4,1)*”. This identifier represents the point (10,4,1) within room 3718. The coordinates are relative to room 3718’s space coordinate system.

Design choices by examples

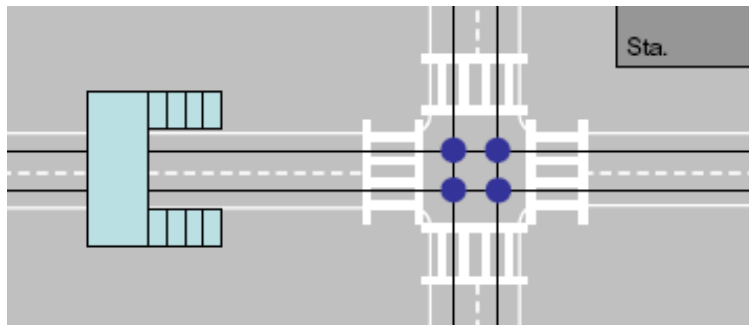
A Hybrid Location Model with a Computable Location Identifier (project AURA)

- Some operators on ALIs are:
 - `distance(ali, ali)` returns float - compute the distance between two locations.
 - `contains(ali, ali)` returns Boolean - tell whether one location contains another.
 - `within(ali,ali)` returns Boolean - tell whether one location is within another.
 - `super(ali)` returns ali - get direct super space containing the location
 - `sub(ali)` returns list of ali - get list of spaces which are direct sub space of input parameter

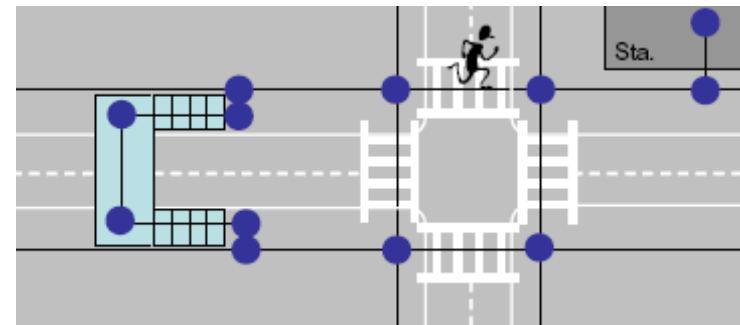
Design choices by examples

Sidewalk network databases

- Store ground and underground walks, footbridges and cross walks for pedestrians [1]
- Evolution from geometric model of road networks



Road networks
(car navigation)



Sidewalk network databases
(people navigation)

Images copyright: [1]

Design choices by examples

Sidewalk network databases

- Sidewalk network databases are structured as **nodes** and **links**.
- Nodes represented by **coordinate tuples** connected by links (sidewalks in a city).
- Nodes have attached **symbolic names**.

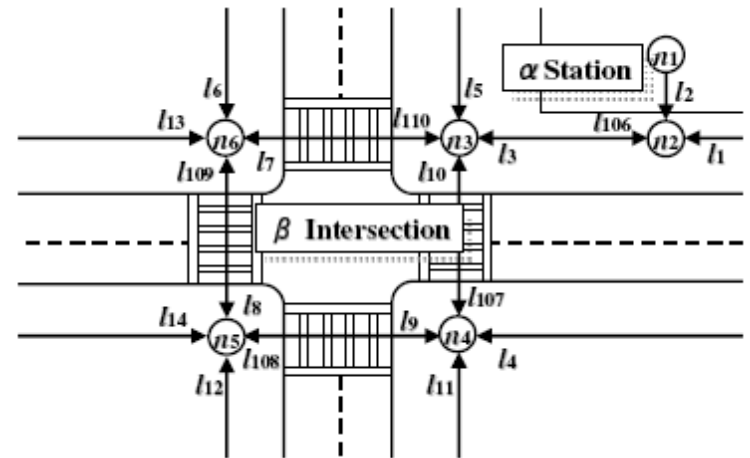


Image copyright: [1]

Design choices by examples

Sidewalk network databases

- Node elements:
 - - id: the identifier of the node
 - - $m(x,y)$: geographic coordinates
 - - name: a name of an instance of spatial objects
 - - class: a class of spatial objects
 - - uri: information for the point of interest
 - - in_link: list of identifiers for the incoming links
 - - out_link: list of identifiers for the outgoing links
- Link elements:
 - - start_node the identifier of the node which I starts from
 - - end_node the identifier of the node which I arrives at

Design choices by examples

Location model:	AURA location model (hybrid)	Sidewalk network databases (hybrid)
Basis:	symbolic model	geometric model
Refinement:	geometric model	symbolic model

Conclusions (1)

- Location model determined by application requirements (user queries)
- Usually a location model provides:
 - Object positions
 - Distance function
 - Topological relations
- Three main types of location models: geometric, symbolic and hybrid

Conclusions (2)

- In most applications a hybrid location model is required
- Hybrid model construction:
 - Symbolic + geometric (AURA location model)
 - Geometric + symbolic (Sidewalk network databases)
- Design challenge: find the right balance between what a model can do and its design costs

Selective bibliography

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