Reverse-K-Nearest-Neighbors aNN

▶ Nearest Neighbors Problem

Reverse-Nearest-Neighbor-Problem

▶ Nearest Neighbors Problem

Reversible and Convertible Lanes

▶ Contraflow for Evacuation Traffic Management

Revisit Period

▶ Temporal Resolution

RF Identification

▶ Radio Frequency Identification (RFID)

RFID

▶ Radio Frequency Identification (RFID)

Rich Client Internet Applications

▶ Scalable Vector Graphics (SVG)

rkNN

▶ Nearest Neighbors Problem

RMS Error

▶ Photogrammetric Products

rNN

▶ Nearest Neighbors Problem

Road Maps

▶ Road Maps, Digital

Road Maps, Digital

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Synonyms

Digital road networks; Road maps

Definition

A digital road map is a representation of a physical road network that can be displayed or analyzed by a digital computer. Figure 1 shows a road map and its graph representation. Road intersections are often modeled as vertices and the road segments are connecting adjacent intersections represented as edges in the graph. For example, the intersection of 'SE 5th Ave' and 'SE University Ave' is modeled as node N1. The segment of 'SE 5th Ave' between 'SE University Ave' and 'SE 4th Street' is represented by the edge N1-N4. The directions on the edges indicate the permitted traffic directions on the road segments.
Digital road maps have gained importance due to the widespread use of location-based services such as route finding. They are essential in any location-based utility that involves route-based queries.

Historical Background

Traditionally, governmental agencies (e. g. state departments of transportation) were the primary sources of digital road maps. The initial efforts to formulate digital maps were undertaken by governmental agencies (e. g. state departments of transportation) through the digitization of paper maps from various sources. TIGER (Topologically Integrated Geographic Encoding and Referencing system) was conceived and developed in the 1980's in preparation for the 1990 Census by the US Census Bureau. Due to an increased popular demand, several private-sector companies have begun to offer digital road maps appended with additional points of interest and improve map accuracy.

Scientific Fundamentals

Data Model of Digital Road Maps

As in any database application, data modeling of digital road maps is critically important. The database design involves three steps namely conceptual modeling, logical modeling and physical modeling [2].

Conceptual Data Model The purpose of conceptual modeling is to adequately represent the data types, their

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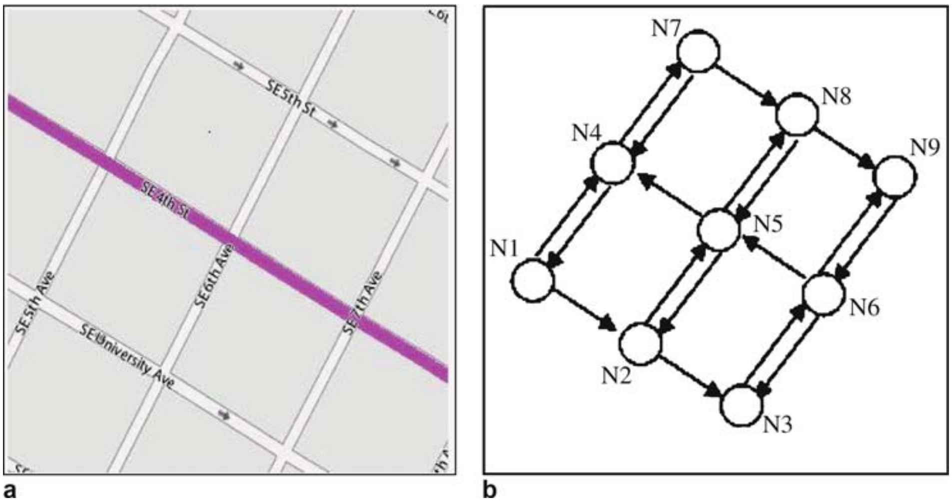
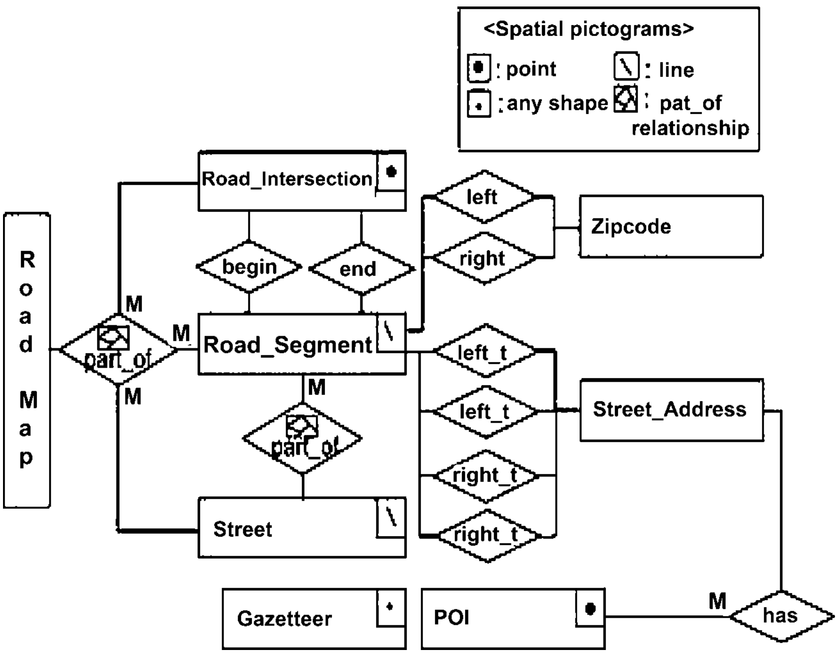


Road Maps, Digital, Figure 1 Road map and its graph representation (Source for Figure 1a: www.maps.yahoo.com)



Road Maps, Digital, Figure 2 A PEER diagram for a digital road map [1]

relationships and the associated constraints. Entity Relationship (ER) model, that has been widely used in conceptual modeling does not offer adequate features to capture the spatial semantics of road maps. Several extensions to address this limitation have been proposed. The pictogram enhanced ER (PEER) model [3] models road maps as graphs. Figure 2 shows a PEER diagram for a digital road map. In a digital road map, vertices represent road intersections and edges represent road segments. Labels and weights can be attached to vertices and edges to encode additional information such as names and travel times. A road segment is modeled using a range of street addresses, which are divided into left-side and right-side addresses.

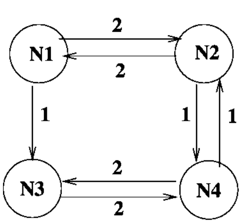
Each side of the road segment is represented using the two end-addresses. The zip code information of a street address can be used when the exact address is not known. Zip codes corresponding to the left and right sides of the streets are also stored. Two edges are considered to be adjacent if they share a common vertex. A PEER diagram can also represent points of interest.

Logical Data Model In the logical modeling phase, the conceptual data model is implemented using a commercial database management system. Among the various implementation models such as hierarchical, network, relational, object-relational data models and object-oriented models, the object-relational model has been gaining popularity in the representation of spatial applications. This model is supported by SQL3 and provides a mechanism for user-defined data types, thus allowing the definition of user defined complex data types such as point, line and polygon. [3] provides the grammar-based translation scheme to translate the PEER model into an object relational (OGIS/SQL3) model. In general, entity pictograms translate into appropriate data types in SQL3 and the relationship pictograms translate into spatial integrity constraints [1].

Physical Data Model The physical data modeling phase deals with the actual implementation of the database application. Issues related to storage, indexing and memory management are addressed in this phase. Very often, queries that are posed on a network database such as a road map, involve route finding. This means the database must provide adequate support for network computations such as finding shortest paths. Figure 3 shows three representations of a graph. Adjacency-matrix and adjacency list are two well-known data structures used for implementing road networks [4], represented as graphs. In an adjacency-matrix, the rows and columns of a matrix represent the vertices of the graph. A matrix entry can be either 1 or 0, depending on whether there is an edge between the two vertices as shown in Fig. 3b. An adjacency list (shown in Fig. 3c) consists of an array of pointers. Each element of the array represents a vertex in the graph and the pointer points to a list of vertices that are adjacent to the vertex. Directed graphs can be implemented in the relational model using a pair of relations, one for the nodes and the other for the edges. The 'Node' (R) and the 'Edge' (S) relations are shown in Fig. 3d and a denormalized representation is shown in Fig. 3e. The denormalized representation of a node table contains the coordinates of the node, a list of its successors and a list of its predecessors. This representation is often used in shortest path computations.

A spatial access method called the Connectivity-Clustered Access Method (CCAM) was proposed in [6], which clusters the vertices of the graph based on graph partitions, thus providing grouping of records into disk pages based on connectivity.

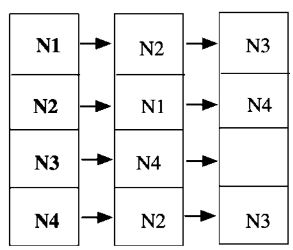
Turn Restrictions Turn restrictions are frequently encountered in road networks and they can affect the traversal in the network. A physical model that does not consider turn restrictions can lead to the computation of routes that are not entirely feasible. Turns have been modeled using a turn table where each turn restriction is represented as a row in the table that references the two associated edges [9]. Another proposed method to represent turn restrictions is node expansion [10]. The node that corresponds to a junction is expanded to a subgraph where permissible turns are represented as edges. This technique can lead to a substantial increase in the size of the network which adversely affects the performance. Another method involves the transformation of the road network to a line graph where the edges in the original network are mapped to vertices in the line graph and the turns are represented as edges in the line graph [9,11]. A representation that



a Example network graph

	N1	N2	N3	N4
N1	0	1	1	0
N2	1	0	0	1
N3	0	0	0	1
N4	0	1	1	0

b Adjacency matrix



c Adjacency list

Node (R)

ID	X	Y
N1	1	1
N2	3	1
N3	1	0
N4	3	0

Edge(S)

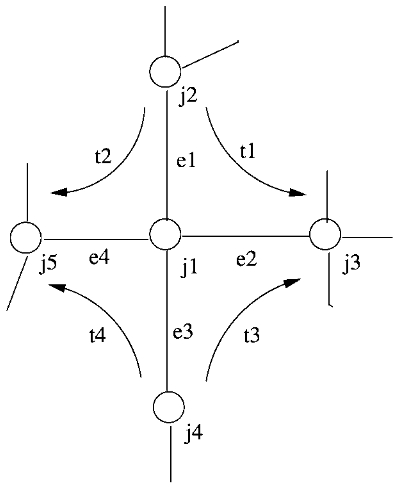
Src	Dst	Dist
N1	N2	2
N1	N3	1
N2	N1	2
N2	N4	1
N3	N4	2
N4	N2	1
N4	N3	2

d Node and Edge Relations

ID	X	Y	Succ	Pred
N1	1	1	(N2,N3)	N2
N2	3	1	(N1,N4)	(N1,N4)
N3	1	0	N4	(N2,N3)
N4	3	0	(N2,N3)	(N2,N3)

e Denormalized Node Table

Road Maps, Digital, Figure 3 Three different representations of a graph



a An example network

id	from–jn
e1	j2
e2	j3
e3	j4
e4	j5

b Edge Table

id	edge1	junc1	edge2	junc2	edge3	junc3	edge4	junc4
j1	e1	j2	e2	j3	e3	j4	e4	j5

c Junction Table

id	Turn id	First edge id	Last edge id	Turn id	First edge id	Last edge id	Turn id	First edge id	Last edge id	••••
j1	t1	e1	e2	t2	e1	e4	t3	e3	e2	

d Turn Table

Road Maps, Digital, Figure 4 Representation of Turn Restrictions (adapted from [5])

consists of a junction table, edge table and turn tables was proposed in [5].

Every junction is represented as a row in the junction table. A row corresponding to a junction stores the edges that converge at the junction and the junctions connected to the given junction. The edge table stores edge identifiers and the junction where the edge originates (from-junction). A tuple in the turn table corresponds to a junction in the network. Each tuple consists of a junction identifier, and a triplet (turn identifier, first edge-id, last edge-id) corresponding to each turn associated with the given junction.

Figure 4 illustrates the representation of turn restrictions in a road network. Figure 4a shows a part of a road network around a junction *j1* where the edges *e1, e2, e3* and *e4* meet. The curved arrows indicate the permitted turns at the junction. For example, a turn is allowed from edge *e1* to edge *e2*. Figure 4b, c and d show the edge, junction and turn tables respectively, corresponding to turn *t1* in the example network. The junction table lists the edges that converge at junction *j1* (*e1, e2, e3,* and *e4* and the junctions connected to it (*j2, j3, j4,* and *j5*). The turn able shows the permitted turns at junction *j1* and the edges that participate in each turn. For example, turn *t1* represents a turn from edge *e1* to edge *e2* as illustrated by the *'first edge id'* and *'last edge id'* entries in the turn table in Fig. 4d.

Data Quality

Given the significant number of sources for the road map data and the heterogeneity across the data, it became necessary to define data quality in the context of digital road maps. Data quality refers to the relative accuracy and precision of a particular road map database. The purpose of the data quality report is to provide adequate information to the users to evaluate the fitness of the data for a specific use. There are several map accuracy standards, including the well-known National Map Accuracy Standard (NMAS) and the American Society for Photogrammetry and Remote Sensing (ASPRS) standard [1]. The standards consist of four components namely:

1. Lineage: This component deals with the narrative of the source materials used and procedures adopted to build the product.
2. Positional Accuracy: This defines the error in position of features. In digital road maps, this component is the most critical.
3. Attribute Accuracy: This represents the expected error in attributes such as road names.
4. Completeness: This defines the fraction of the real-world features represented on a map.

In addition, topological consistency is of concern for digital road maps in the context of navigation systems to facilitate graph computations such as shortest path algorithms.

Key Applications

Location-based Services

Digital road maps are indispensable for any location-based service that involves position or route based queries. Location-based services (LBS) provide the ability to find the geographical location of a mobile device and subsequently provide services based on that location. A digital road map is a key component of spatial database servers that provide efficient query-processing capabilities such as finding the nearest facility (e. g. a restaurant) and the shortest path to the destination from a given location [14,15]. Route-finding queries typically deal with route choice (shortest route to a given destination), destination choice (the nearest facility from the given location) and departure time choices (the time to start the journey to a destination so that the travel time is minimized). Though a significant amount of work has been done to find best routes and destinations, the problem of computing the best time to travel on a given route (time choice) needs further exploration.

Digital road maps are critical in in-vehicle navigations systems [12,13] where the maps would be used to compute the required routes on user-demand or to find points of interest.

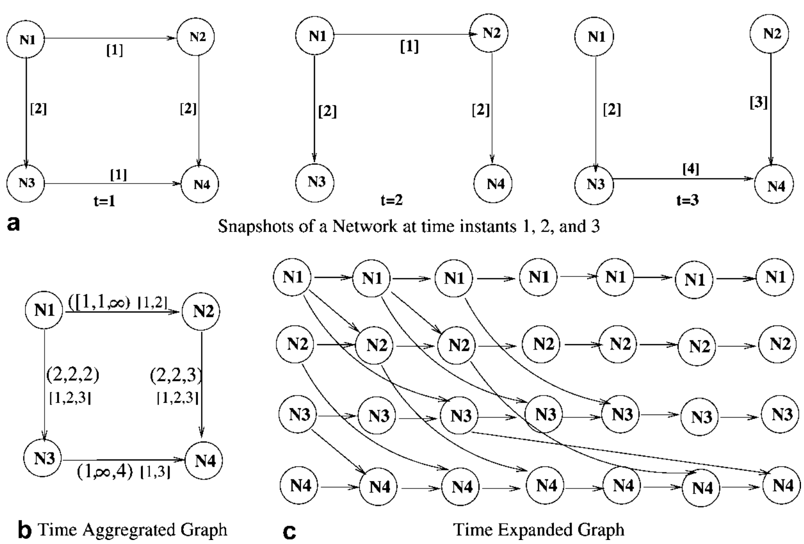
Emergency Planning

One key step in emergency planning is to find routes in a road network to evacuate people from disaster-stricken areas to safe locations in the least possible time. This requires finding shortest routes from disaster areas to destinations. In metropolitan-sized transportation networks, manual computation of the required routes is almost impossible, making digital road maps an integral part in the efficient computation of these routes.

Future Directions

A significant fraction of queries that are posed on a road network involves finding the shortest path between a pair of locations. Travel times on the road segments, very often depend on the time of day due to varying levels of congestion, thus making the shortest paths also time-dependent. Road networks need to be modeled as spatio-temporal networks to account for this time-dependence. Various models such as time-expanded networks [7] and time-aggregated graphs [8] are being explored in this context. Time expanded graph represents the time-dependence by copying the network for every time instant whereas in time aggregated graphs, the time-varying attributes are aggregated over edges and nodes.

Figure 5(a) shows a network at three time instants. The network topology and parameters change over time. For example, the edge N3-N4 is present at time instants $t = 1, 3$ and disappears at $t = 2$ and its weight changes from 1 at $t = 1$ to 4 at $t = 3$. The time aggregated graph that represents this dynamic network is shown in Fig. 5(b). In this figure, the edge N3-N4 has two attributes, both time series. The attribute [1,3] represents the time instants at which the edge is present and (1,∞,4) is the weight time series, indicating the weights at various instants of time. Figure 5(c) shows the time expanded graph that represents the same scenario. Edge weights in a time expanded graph are not explicitly shown as edge attributes; instead they are



Road Maps, Digital, Figure 5 Two different representations of a time-variant network represented by edges that connect the copies of the nodes at various time instants. For example, the weight 1 of edge N1-N2 at $t = 1$ is represented by connecting the copy of node N1 at $t = 1$ to the copy of the node N2 at time $t = 2$. The time expansion for the example network needs to go through 7 steps since the latest time instant would end in the network is at $t = 7$. For example, the traversal of edge N3-N4 that starts at $t = 3$ ends at $t = 7$, the travel time of the edge being 4 units.

Cross References

► Contraflow in Transportation Network
► Emergency Evacuations, Transportation Networks
► Nearest Neighbor Queries in Network Databases

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Road Network Data Model

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Synonyms

Transportation network model; Spatial network model; Network data model; Graph; Link-node model; Linear reference model

Definition

A road network data model is a notation that enables the modeling of pertinent aspects of a road-network infrastructure. Using such a notation, a schema of a road-network infrastructure may be designed. This schema may in turn be populated by data, yielding an instance that captures aspects of a specific road network.

Depending of the use context, different aspects of a road-network infrastructure are of interest. A road network data model may consist of several interrelated sub-models, each of which targets the capture of different, specific aspects of a road network. Important examples of such sub-models include the geographical and graph representations and linear referencing.

Geographical representations capture the embedding of a road network into geographical space. Specifically, a road is typically represented by a collection of polylines, where each polyline captures the centerline of part of a road.

Graph representations, also termed link-node representations, typically aim to capture the topology, or connectivity, of a road network in a compact and computationally efficient format. Graph representations are based on the concepts of undirected and directed mathematical graphs. A node, or vertex, typically models a location with a significant change of traffic properties. Such locations include road intersections. A link, or edge, models the part of the road network that enables travel between two nodes. In a directed-graph model, a directed edge captures that travel between the two nodes involved is allowed in the direction given by the edge. Edge weights capture travel distances or times. A binary so-called co-edge relation models the ability of vehicles to make u-turns in-between intersections. A binary so-called change-edge relation models the ability to make a lane change. To model roads with multiple lanes, multi-graphs that allow multiple edges between a pair of nodes are used.

With linear referencing, a road network is modeled as a collection of one-dimensional linear features that inter-