Mobile Location Systems, Tools, and Services

… and Data Management Challenges

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Outline (1/2)

- Part I
  - Introduction
  - Mobile Location Systems (MLS)
    - Positioning technologies
    - MLS systems & protocols
    - Applications & services
  - Location-based Services (LBS)
    - LBS taxonomy
    - Fundamental LBS examples

Introduction
MLS
LBS
Data Mgmt Issues
Future / Vision
Resources

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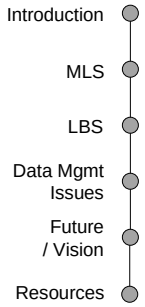
Outline (2/2)



- Part II
  - Data management issues and challenges
    - Advanced LBS
    - DBMS operations to be supported
  - Future / vision
    - Mobile location data mining
    - Privacy issues
    - Prototypes and tools
  - Resources
    - Useful links
    - Bibliographical references

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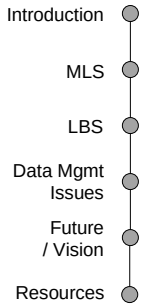

Part I

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Outline of Part I

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- Mobile Location Systems (MLS)
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Introduction (1/4)

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- Human needs …
  - … for communication
    - Who is nearby? How can I talk to (or find) someone?
  - … for orientation
    - Where am I? How can I get there?
- Current human needs …
  - Call for a taxi (ambulance, …) and wait for it to pick me up
  - Check out the closest restaurant (pub, gas station, etc.)
    - … and get information about how to get there
  - Feel lost and ask for information about where I am (and how to escape from there)

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Introduction (2/4)

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- Definitions:

  "Mobile Location System (MLS) is a location system, including applications, that determines the geographic position of mobile subscribers and provides them with relevant information and services"

  (Swedberg, 1999)

  "A location-based service (or LBS) in a cellular telephone network is a service provided to the subscriber based on her current geographic location

  (source: Wikipedia)

Introduction (3/4)

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- GSM (Global System for Mobile)
  - The most dominant of 2G digital telephony standards
- UMTS (Universal Mobile Telecommunications System)
  - Unified (text, voice, video, multimedia) very high rate (up to 2Mbps) data transfer system
  - Supported by 3G cellular phones
- GPS (Global Positioning System)
  - …

Introduction (4/4)

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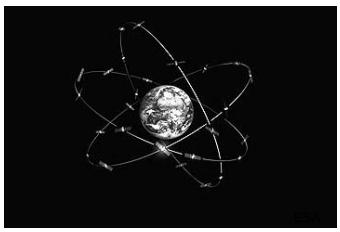
- GPS (Global Positioning System)

  (Kaplan, 1996; Hofmann-Wellenhoff et al. 1997; Dana, 2000; Bajaj et al. 2002)

  - Initiated 1978 by US DoD
  - Error-free for civilian applications since 2000
  - Location positioning (lat / lon / alt) based on a constellation of 24 satellites
    - At least 5 satellites are in view from every point on the globe
  - Satellites are monitored by 5 monitoring stations and 4 ground antennas
    - handled with (extremely precise) atomic clocks



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Services, Tools, Products (1/4)

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- Location-based Services (LBS) or Location-dependent services
  - Finder & Router – finds the nearest point of interest (POI) - restaurant, gas station, etc. - and suggests the optimal way to move there
    - 'optimal' in terms of minimum distance or minimum time or …
  - E-911 (US), E-112 (EU), E-119 (Japan) emergency call numbers
    - mandates require locating the caller within a few meters (150 feet, by FCC regulation)
    - (in US) E-911 call centers receive 15,000 calls from cellular phones per day

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Services, Tools, Products (2/4)

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- High-end smartphones with build-in GPS receiver
  - Nokia N95 (3G, Symbian OS)
  - Sony Ericsson P1i (Wi-Fi connection)
  - HTC P3600 i-go (Wi-Fi, WinMobile OS)

source: http://europe.nokia.com

Services, Tools, Products (3/4)

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- Dash express (source: www.dash.net)
  - Internet-connected automotive navigation system
  - Up-to-minute information about traffic
  - Yahoo! Local search for finding POIs

Services, Tools, Products (4/4)

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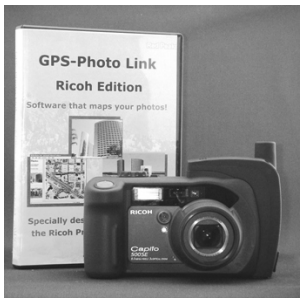
- GPS Wherifone, Wherify Inc. (source: www.wherify.com)
  - World's smallest GPS-equipped phone (3.2 by 1.6 by 0.7 inches; 2.4 ounces)
  - Embedded GPS; 911 panic button
  - $102,90 in Amazon



- RICOH 500SE camera (source: www.ricohsolutions.com)
  - GPS-ready digital camera
  - "turn-key geo-imaging solution"

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  - MLS systems & protocols
  - Applications & services
- Location-based Services (LBS)
  - LBS taxonomy
  - Fundamental LBS examples

Positioning technologies (1/8)

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- Recall MLS definition:

  "Mobile Location System (MLS) is a location system, including applications, that determines the geographic position of mobile subscribers and provides them with relevant information and services"

- Positioning technologies (all standardized in 1999-2000)
  - Using satellite information
    - GPS, Differential GPS (D-GPS), Assisted GPS (A-GPS)
  - Using the mobile telephone network
    - Time of Arrival (TOA), UpLink TOA (UL-TOA)
    - Cell Global Identity (CGI), CGI plus Timing Advance (CGI+TA)

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Positioning technologies (2/8)

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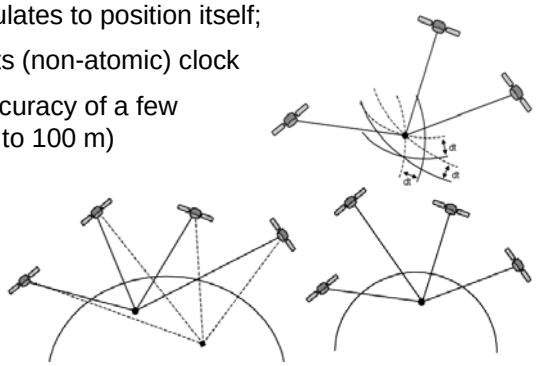
- Global Positioning System (GPS)
  - GPS receiver gathers information from 4 (or 3, the minimum) satellites and

    (a) triangulates to position itself;

    (b) fixes its (non-atomic) clock
  - Position accuracy of a few meters (20 to 100 m)



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Positioning technologies (3/8)

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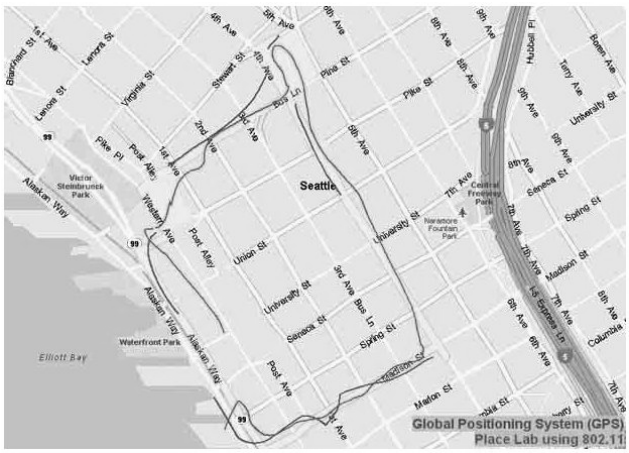

blue line: series of location estimates from a GPS receiver
red line: series of location estimates based on WiFi access points
source: (Borriello et al. 2005)

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Positioning technologies (4/8)

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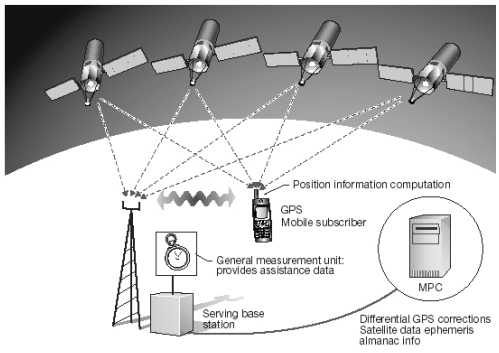
- Assisted GPS (A-GPS)
  - fastens the receiver-satellite communication procedure by providing pre-calculate satellite orbits to the receiver
  - Accuracy 10-20 m.
  - Adopted as a UMTS standard (hence, E-911 standard)
- Differential GPS (D-GPS)
  - accuracy down to 1 m



source: (Swedberg, 1999)

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Positioning technologies (5/8)

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- Galileo
  - EU's rival to US' GPS and Russia's Glonass
  - constellation of 30 satellites; to be in operation by ~~2010~~ 2013
    - 1st Galileo satellite launched in Dec. 2005
  - designed for civil use
  - GPS compatible
  - 1m accuracy

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Positioning technologies (6/8)

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- Cell Global Identity (CGI)
  - Positioning based on cell id
  - The network operator always knows which cell the user is in
    - A cell can be a circular or a triangular sector
  - Accuracy between 100 m and several Km
- CGI plus Timing Advance (CGI+TA)
  - TA measures the time of signal transmission ➔ distance between mobile station (user) and base station (antenna) can be calculated
  - Combining CGI with TA we get an arc of width up to 550 m

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Positioning technologies (7/8)

- Cell Global Identity (CGI), CGI plus Timing Advance (CGI+TA)

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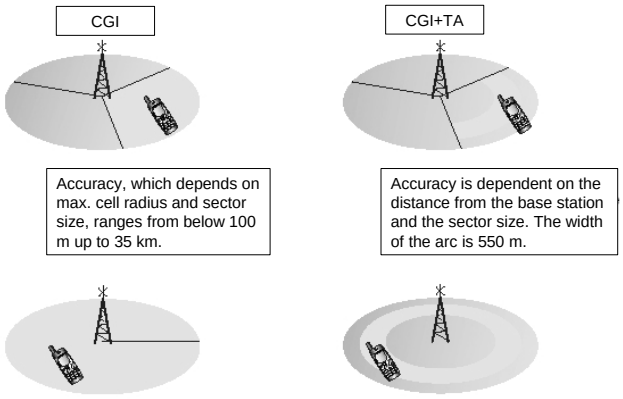

source: (Swedberg, 1999)

Positioning technologies (8/8)

- Uplink - Time Difference of Arrival (U-TDOA)
  - At least 3 receivers (located together with antennas) get signals from a user's mobile, triangulate and estimate its position
  - Accuracy: 30-120 m
  - Standardized by the 3GPP (3rd Generation Partner-ship Project)
  - Problem: Requires great investment in infrastructure

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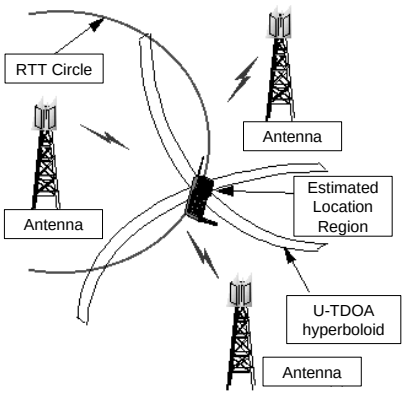

source: http://www.3gpp.org

MLS Systems & Protocols (1/3)

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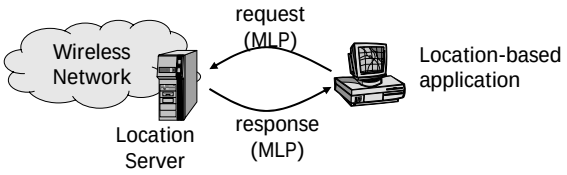
- Mobile Location Protocol (MLP) by the Location Interoperability Forum (LIF) *

  * later consolidated into the Open Mobile Alliance (OMA)



  - Wireless Application Protocol (WAP) by the WAP Forum
    - both based on HTTP
    - transmit request / response data in XML documents

MLS Systems & Protocols (2/3)

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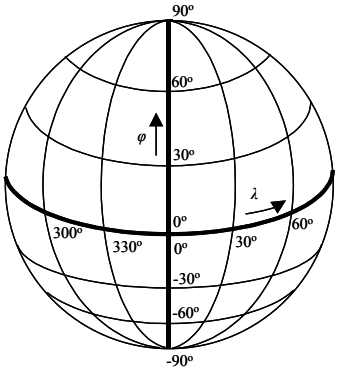
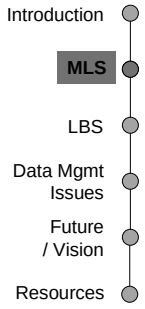
- Example functions supported by these protocols
  - geocoding: validate and convert human-friendly address format to lat/lon geographic coordinates
  - reverse (or de-) geocoding: convert geographic coordinates to human-friendly address format
  - mapping: generate location-dependent maps and provide scale, zoom, etc. operations

(cont.)



MLS Systems & Protocols (3/3)



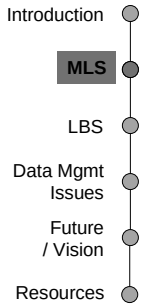
…

routing: (optimized) route and journey-time calculation; should take transport means into consideration

- (variation) travel planning: specify travel destination and intermediate waypoints
- (variation) route guidance: determines deviation from the route and sends a message to the user

- spatial querying: retrieve location-dependent information from a database
  - Examples: window search; nearest-neighbor search; etc.

Applications & Services (1/4)



Recall MLS definition:

"Mobile Location System (MLS) is a location system, including applications, that determines the geographic position of mobile subscribers and provides them with relevant information and services"

- Information services
  - Location-based yellow pages ("what-is-around", …)
- Navigation (vehicle or pedestrian)
  - Routing, finding the nearest POI, …

(cont.)

Applications & Services (2/4)

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…

- Tracing services
  - Tracing of a stolen car, locating persons in an emergency situation, …
- Resource management
  - (taxi, truck, etc.) fleet management
  - administration of container goods, …
- Other services
  - Location-based charging

Applications & Services (3/4)

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- Google Latitude
  See where your friends are in real time!
  launched by Google Feb.09
- or the "inverse" service offered by Jphone in Japan:
  "Get a map of your own position and mail it to friends who are on the way to find you"

source: google.com

Applications & Services (3/4)

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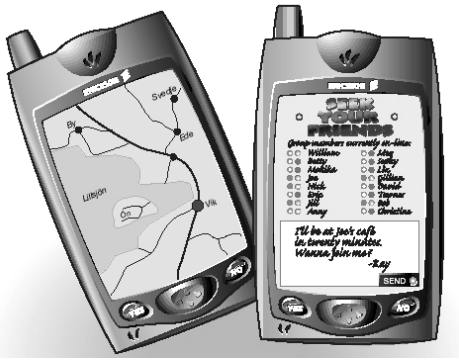
- "seek-your-friends" developed by Ericsson
- or the "inverse" service offered by Jphone in Japan:
  - "Get a map of your own position and mail it to friends who are on the way to find you"



source: (Swedberg, 1999)

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Applications & Services (4/4)

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- LBS examples (with respect to range) by the 3GPP (source: www.3gpp.org)

Regional (up to 200km)	weather reports, localized weather warnings, traffic information (pre-trip)
District (up to 20km)	local news, traffic reports
Up to 1 km	targeted congestion avoidance advice, rural and suburban emergency services, manpower planning, information services (where are we?)
100m (67%) 300m (95%)	U.S. FCC mandate (99-245) for wireless emergency calls using network based positioning methods
75m-125m	urban SOS, localized advertising, home zone pricing, information services (where is the nearest?)
50m (67%) 150m (95%)	U.S. FCC mandate (99-245) for wireless emergency calls using handset based positioning methods
10m-50m	asset location, route guidance, navigation

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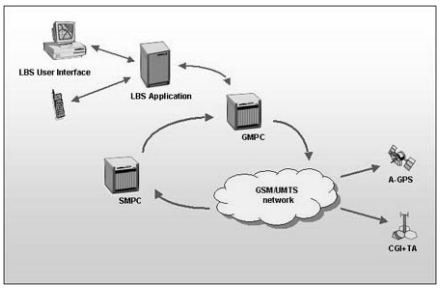
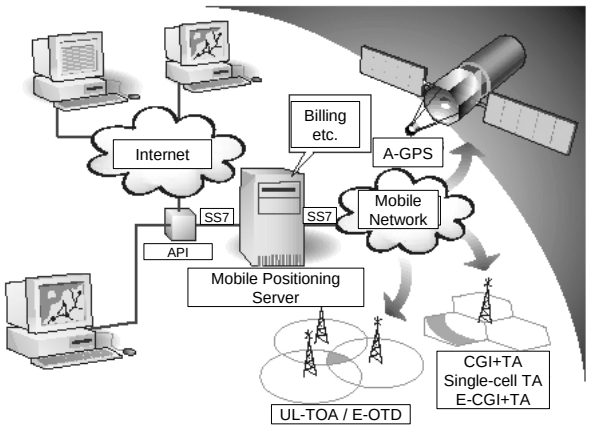
The MLS 'big picture'

- The 'big picture' -- MLS actually involves four components:
  - Mobile network
  - Positioning center
  - Application / Database servers
  - User



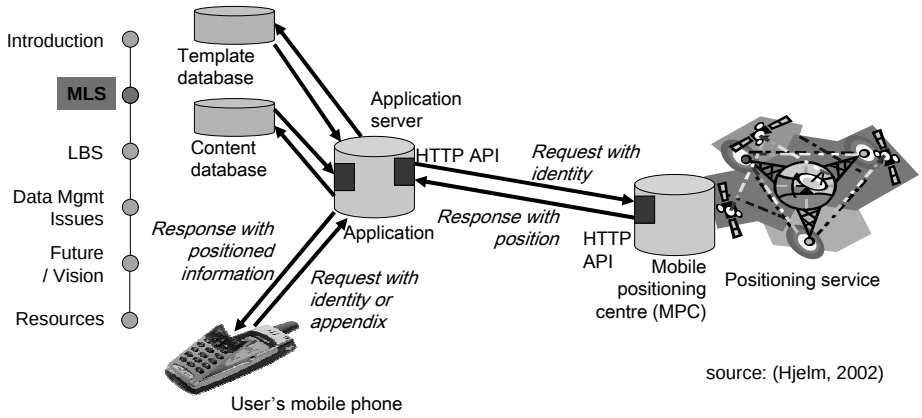
  - Real-world example:
    - Ericsson's Mobile Positioning System (MPS)

Ericsson's Mobile Location Solution



source: (Swedberg, 1999)

Ericsson's MLS data flow



source: (Hjelm, 2002)

The MLS/LBS market

- Money, money, money …

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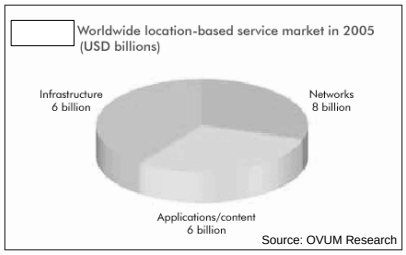
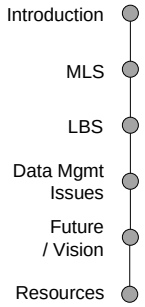
- 72 million users of 3GSM services
  (source: RTD Info)



- Over 2 billion GSM devices owners in June 2006 (one out of three humans !!)
  - 370 million users in China,
  - 145M in Russia, 83M in India, 78M in US

Outline of Part I



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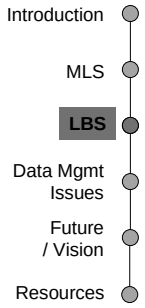
Location-based Services



- Fundamental user requirements
  - Where am I ? How do I receive/transmit my location?
  - Where is this or that POI ? How do I get there?
  - Where are other people (“friends”) located? Among them, who is closest to me ? How can I meet him/her?
- also …
  - Who is aware of my location ? Is my location monitored?
  - How can I avoid ‘spam’ related to my location?

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LBS taxonomy

- According to (Gratsias et al. 2005; Frentzos et al. 2007)

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Data objects \ Reference object (user)	stationary	mobile
stationary	⇒ what-is-around ⇒ routing ⇒ find-the-nearest	⇒ guide-me
mobile	⇒ find-me	⇒ get-together

Routing (1/2)

- Find the optimal route between a departure and a destination point
  - optimization criterion: the minimal network distance traveled or the minimal traveled time
  - Smallest travel time path between the two points is perhaps different from shortest distance
    - e.g. driving on a highway
- Relates to the well-known shortest path problem from graph theory and network analysis
  - Several solutions, e.g. Dijkstra's algorithm

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Routing (2/2)

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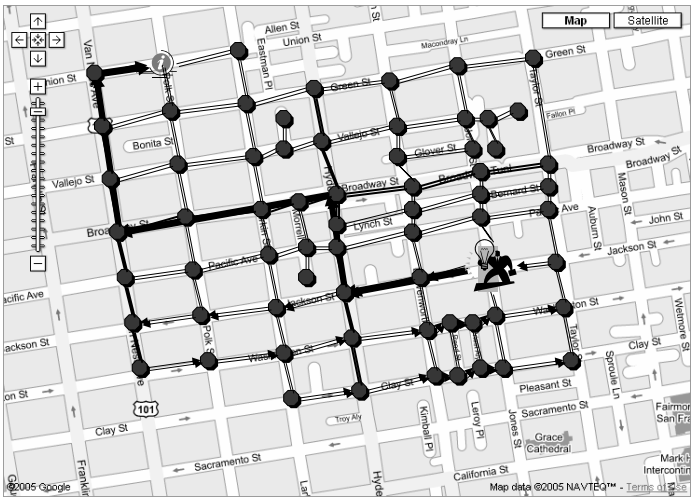

What-is-around & Find-the-nearest

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- Retrieve and display POI located in the surrounding area (according to user's location or an arbitrary point)
  - Example: "*Get me all the gas-stations and ATMs within a distance of 1km*"
- Retrieve and display the nearest POI (restaurants, museums, gas stations, hospitals, etc.) with respect to a reference location
  - Example: "*find the two restaurants that are closest to my current location*" or "*find the nearest café to the railway station*"
  - Issue: closeness computed with respect to the network distance on the graph and not by the Euclidean one
  - State-of-the-art algorithm: "Euclidean Restriction" (Papadias et al. 2003)

What-is-around

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- **LBS**
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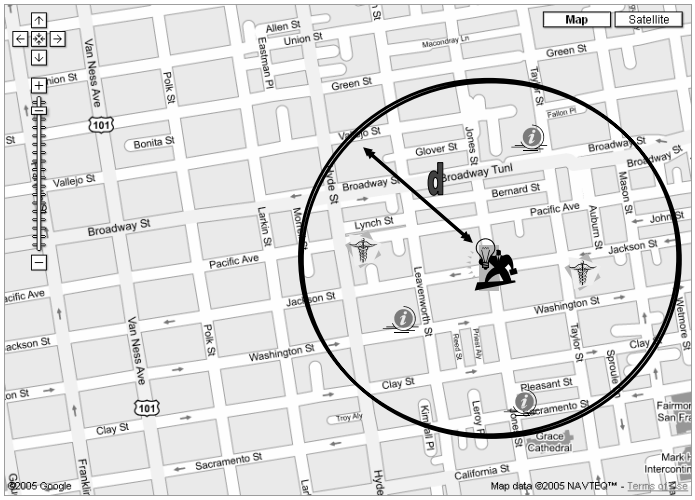
- Resources



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Find-the-Nearest (1/3)

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- **Data Mgmt Issues**
- Future / Vision
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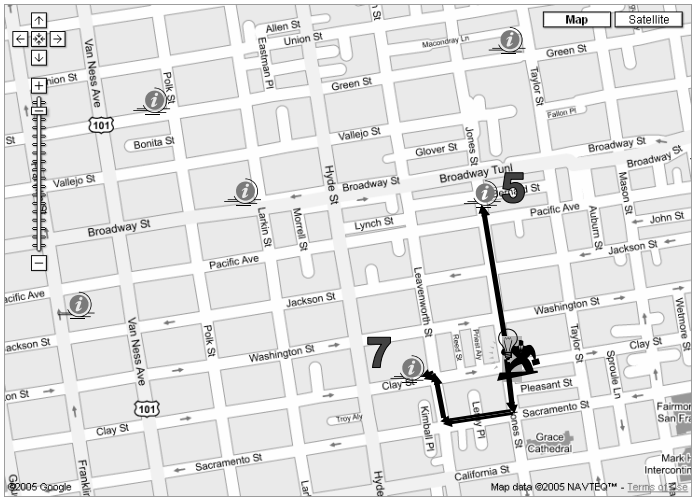

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Find-the-Nearest (2/3)

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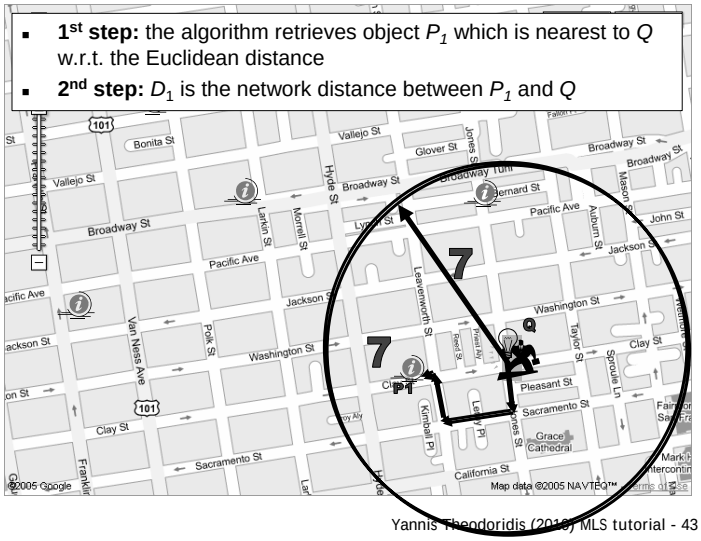
- **1st step:** the algorithm retrieves object P_1 which is nearest to Q w.r.t. the Euclidean distance
- **2nd step:** D_1 is the network distance between P_1 and Q



Find-the-Nearest (3/3)

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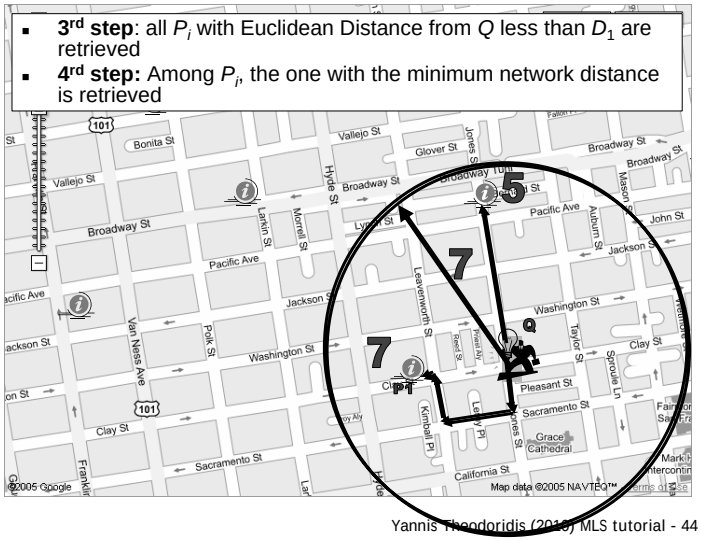
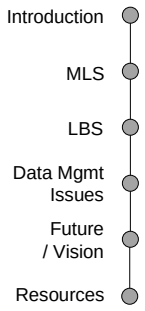
- **3rd step**: all P_i with Euclidean Distance from Q less than D_1 are retrieved
- **4rd step:** Among P_i, the one with the minimum network distance is retrieved





Part II

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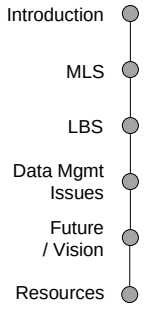
Outline of Part II



- Data management issues and challenges
  - Advanced LBS
  - DBMS operations to be supported
- Future / vision
  - Mobile location data mining
  - Privacy issues
  - Prototypes and tools
- Resources
  - Useful links
  - Bibliographical references

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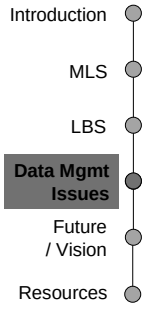
Database management issues (1/3)



- Database processing includes (among others)
  - Absolute and relative location of objects
  - Distance between geographic features
    - Euclidean, network, …
  - Topology between geographic features
    - Overlap, inside, approach, deviate, …
  - Movement (direction, heading) of objects
  - …

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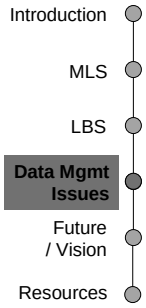
Database management issues (2/3)



- DBMS and GIS vendors (Oracle, Sybase, IBM, ESRI, etc.) provide
  - direct support for (stationary) spatial data but
  - … limited (and indirect) functionality for moving objects
- Examples:
  - MySQL supports OpenGIS elements
    - Point, LineString, Polygon, MultiPoint, MultiLineString, MultiPolygon, GeometryCollection
  - Oracle Spatial provides SDO_GEOMETRY object data type for spatial data
    - three primitive types: Point, LineString, Polygon

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Database management issues (3/3)

- Spatial data types in MySQL

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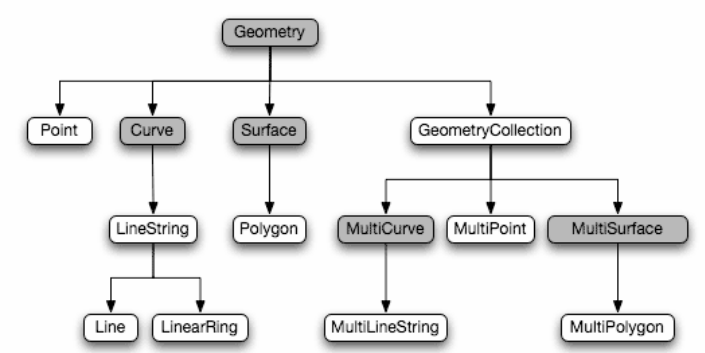

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Advanced LBS

- Stationary vs. stationary data
  - In-route-Find-the-nearest
- Moving vs. stationary data
  - Guide-me
- Moving vs. moving data
  - Get-together

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In Route Find-the-Nearest (1/2)

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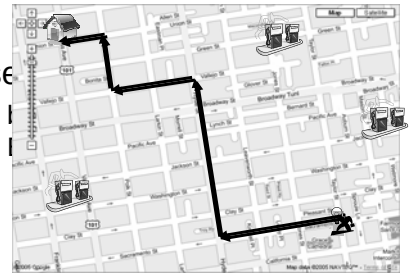
- Find the optimal route between a departure and a destination point
  - With the extra constraint to pass through one among a specified set of candidate points
  - Example: "*provide me the best route office to home constrained to pass from a gas station* "
- The algorithm is base
  - the network distance
    than or equal to their



In Route Find-the-Nearest (2/2)

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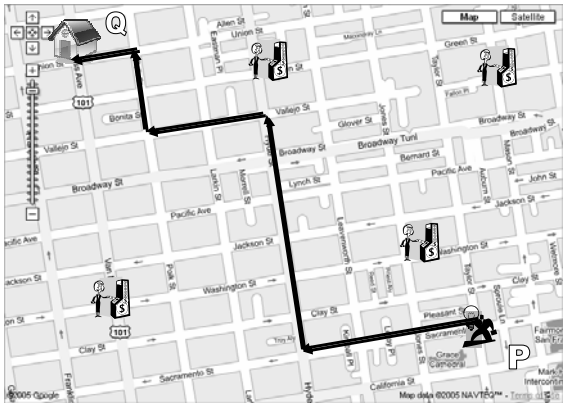
- 1st step: Retrieve the optimal route R between P and Q



In Route Find-the-Nearest (2/2)

- 2nd step: Retrieve the Euclidean NN w.r.t. route R (point N_1)

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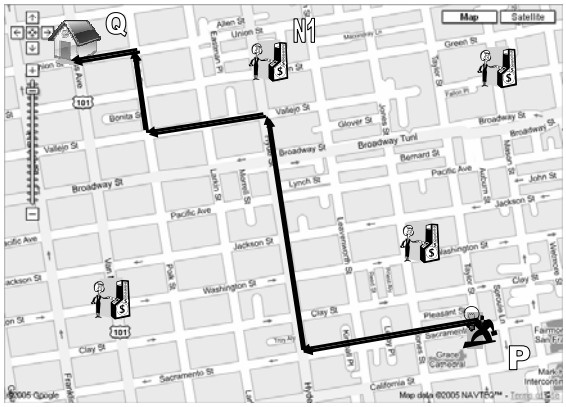

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In Route Find-the-Nearest (2/2)

- 3rd step: Calculate network distances L_1=Net_Dist(P,N1) and L_2=Net_Dist(N1,Q)

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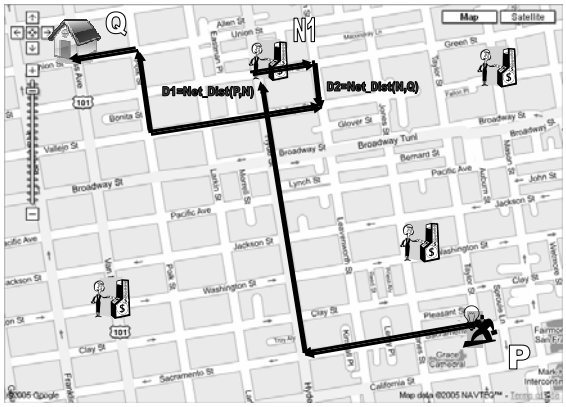

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In Route Find-the-Nearest (2/2)

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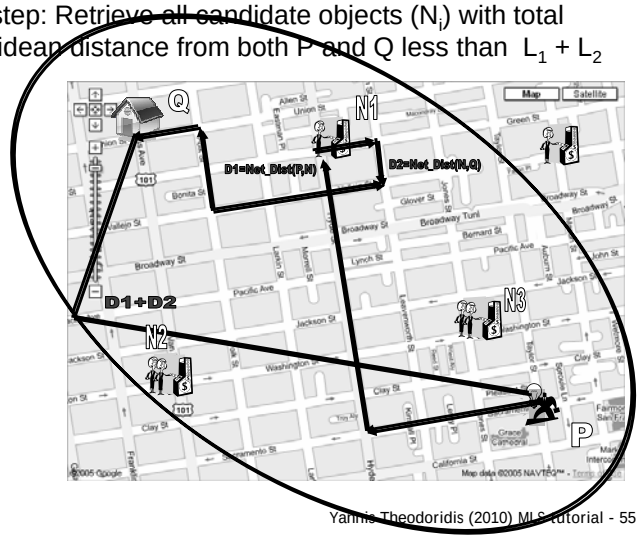
- 4th step: Retrieve all candidate objects (N_i) with total Euclidean distance from both P and Q less than $L_1 + L_2$



In Route Find-the-Nearest (2/2)

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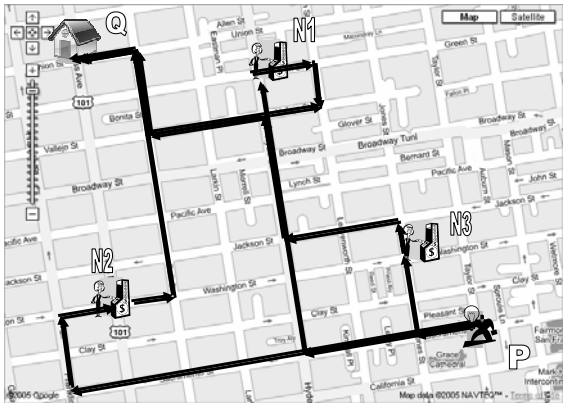
- 5th step: Calculate network distances L_{1i}=Net_Dist(P,Ni) and L_{2i}=Net_Dist(Ni,Q), and report the N_i with the smallest $L_{1i} + L_{2i}$



Guide-me (1/4)

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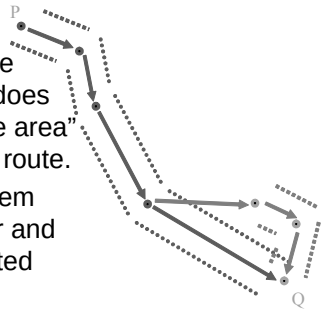
- Dynamic version of “routing”
  - The system routes the user (as in static router) and keeps track of the user’s movement towards the destination point.
  - The user is allowed to deviate from the optimal route as long as his / her location does not fall out a predefined “safe area” (buffer) built around his / her route.
  - In case of deviation, the system sends a message to the user and re-routes him / her, if requested



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Guide-me (2/4)

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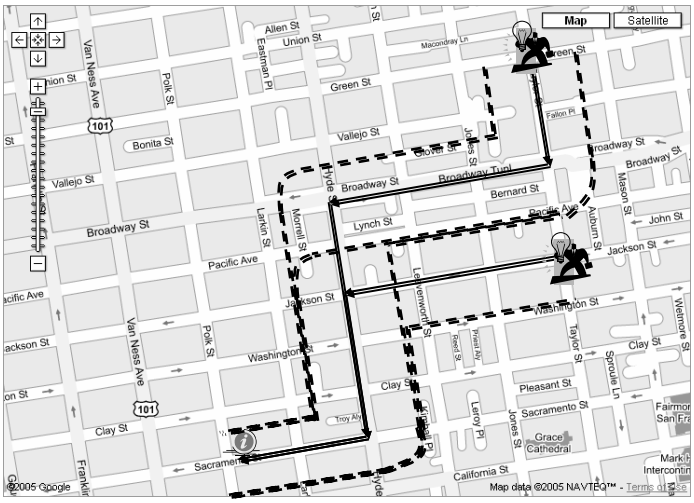

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Guide-me (3/4)

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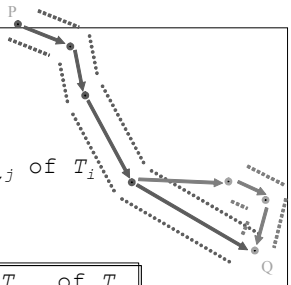
Algorithm Dynamic_Routing
(User Id T,
destination point Q,
distance D, time period Δt)

1. Retrieve current position $T_{i,j}$ of T_i
2. R=Route($T_{i,j}$,Q)
3. DO until $T_{i,j}$ reaches Q
4. Wait Δt: j=j+Δt
5. Retrieve current position $T_{i,j}$ of T_i
6. IF NOT $T_{i,j}$ lies on the buffer Buffer(R,D) THEN

```
SELECT * FROM CurentPosition WHERE User_id=UId AND
   Contains(Buffer(R,D),last_position_geometry)
```



Get together (1/3)

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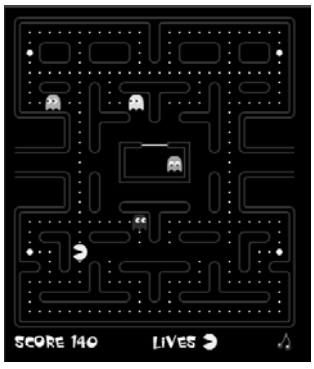
- A number of moving objects try to meet a moving object
- Methodology:
  - the meeting point is not known in advance since the target object keeps moving
  - other objects are routed to a point where the target object is estimated to arrive after a time interval
  - this “meeting point” is periodically refreshed
- Applications:
  - Pacman, Suspect chase,
  - buried treasure, …



Get-together (2/3)

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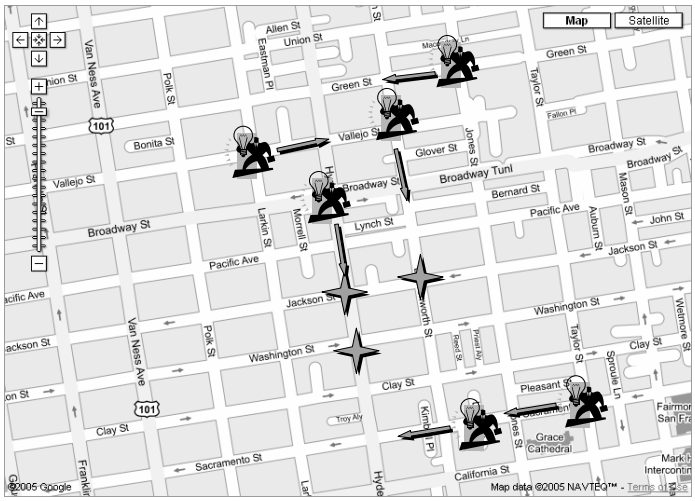

Get together (3/3)

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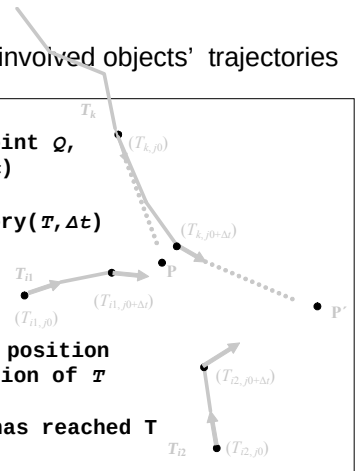
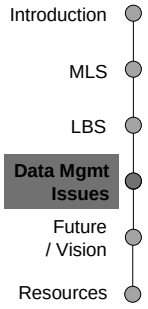
- Get together algorithm:
  - the DBMS keeps track of involved objects' trajectories

```
Algorithm Get_together
(User Id T, destination point Q,
distance D, time period Δt)
1. REPEAT
2.     T = Project_trajectory(T,Δt)
3.     FOR EACH T_i
         Report Route(T_i,T)
4.     Wait Δt
5.     FOR EACH T_i
         Update its current position
6.     Update current position of T
7. UNTIL ending criterion
         // e.g. one of T_i has reached T
```



Operations to be supported (1/3)



- Naïve database / computational geometry operations
  - Window search: selects points within a (circular or rectangular) window
  - Euclidean distance calculation: calculates the Euclidean distance between two points
  - Point-in-region check: checks whether a point is located within a region
  - Buffer routine: builds a buffer of specific width around a path
  - Path length routine: calculates the length of a path
- *Graph-based operations*
- *Trajectory management operations*
- *Pure MLS operations*

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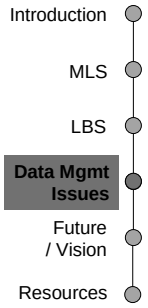
Operations to be supported (2/3)



- *Naïve database / computational geometry operations*
- Graph-based operations
  - Routing: finds the optimal route between two points (taking into consideration a number of constraints)
  - Network distance calculation: calculates the network distance between two points
  - Network k-Nearest Neighbor search: searches for the k-NN of a point with respect to network distances
- *Trajectory management operations*
- *Pure MLS operations*

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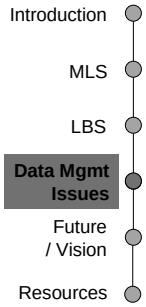
Operations to be supported (3/3)



- *Naïve database / computational geometry operations*
- *Graph-based operations*

- Trajectory management operations
  - Trajectory refresh: adds a new coming position to an existing trajectory
  - Trajectory projection: estimates the position of an object at a future time (taking into consideration its history)
- Pure MLS operations
  - Get-location: get the coordinates of the current location of an object

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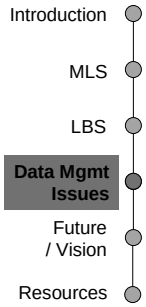
Trajectory-based operations



- Trajectory refresh:
  - Low complexity, straight-forward (?) operation
  - Issue: location-update strategy
    - Distance-based vs. movement-based vs. time-based update (Bar-Noy et al. 1995)
- Trajectory projection:
  - Very interesting, open issue
  - Not only consider the current position but the recent history as well !!
- Trajectory search:
  - Window search, Nearest-neighbor search, similarity search

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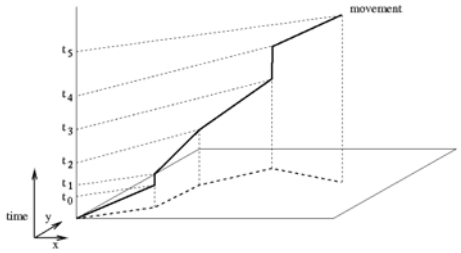
Trajectory representation (1/4)

- Absolute coordinates (in native space): a sequence of points in 3D space (2 spatial + 1 temporal dimensions)
  - linear interpolation in between results in 3D line segments (artificial movement)



source: (Pfoser et al. 2000)

- Relative coordinates (in parametric space): a sequence of functions (location at time t is a function of a reference location at time t_0 and a motion vector)

Trajectory representation (2/4)

- Relative coordinates representation
  - A trajectory T of an object O has the form

    $T(O) = \{id, t_0, t_1, \ldots, t_n, f_1(t), f_2(t), \ldots, f_n(t)\}$

    where $f_i(t)$ is a movement function representing movement during time interval $[t_{j-1} .. t_j]$, $1 \leq j \leq n$
- Example: Sliced representation …

Trajectory representation (3/4)

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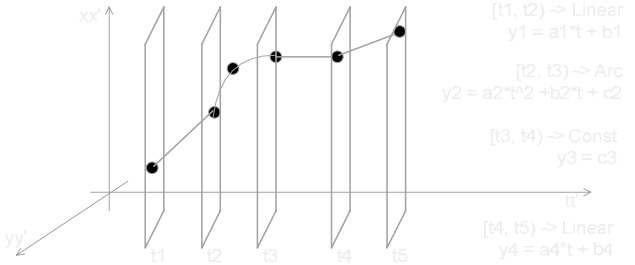
- Sliced representation
  (Güting et al. 2000; Lema et al. 2003)
  - Decompose the temporal development of a moving value into fragments called ‘slices’
  - Within the ‘slice’ describe the development by some kind of ‘simple’ function (const / linear / arc movement)



source: (Pelekis et al. 2005)

Outline of Part II

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- Data management issues and challenges
  - Advanced LBS
  - DBMS operations to be supported
- Future / vision
  - Mobile location data mining
  - Privacy issues
  - Prototypes and tools
- Resources
  - Useful links
  - Bibliographical references

Open research issues

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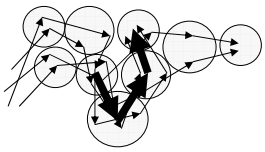
- 'Flexible' domains of validity
- Future queries
  - forecasting & continuous queries
- Location-dependent data streaming
- Trajectory mining
- Anonymity & Privacy issues
  - Privacy-aware Knowledge Discovery in Moving Objects Databases



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Domain of Validity

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(Gessler and Jesse; 2001)

- Extension of validity
  - 'Nearby' could be mapped either as a 5 blocks area or as a 1 block area with respect to time of request
- Shape of validity domain
  - Circular-shaped 'around' areas are not always appropriate (imagine a driver driving on a highway and asking for traffic jams 'around')
- Orientation
  - No driver is interested on jams behind him/her

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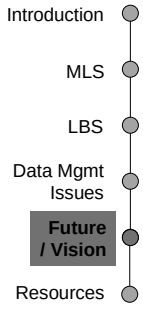
Future queries



- Forecasting queries:
  - Where will I be located after 10 min? Which POIs are located there?
    - issues: direction? speed? acceleration?
  - Where will other users (e.g. 'friends') be located after 10 min?
    - What is the probability for me to get together with one or more of them? When will it happen? Under which assumptions?
- Continuous queries: (requirement for real-time response)
  - Among the other users, who will be located nearest to me during the next hour or minutes?

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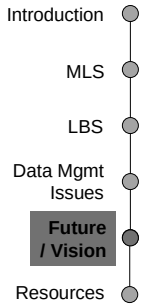
Location-dependent data streaming



- Motivation:
  - In MLS/LBS, high arrival rates of data and queries
- Spatiotemporal vs. traditional data stream (Mokbel et al. 2005)
  - Queries as well as data have the ability to change their locations continuously
  - Objects may be added to or removed from the answer set of a spatiotemporal query
  - Delay in processing spatiotemporal queries may result in an obsolete answer
- Project: PLACE @ Purdue (Aref et al. 2003; Mokbel et al. 2004)

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The PLACE Server

- Continuous evaluation of spatiotemporal queries

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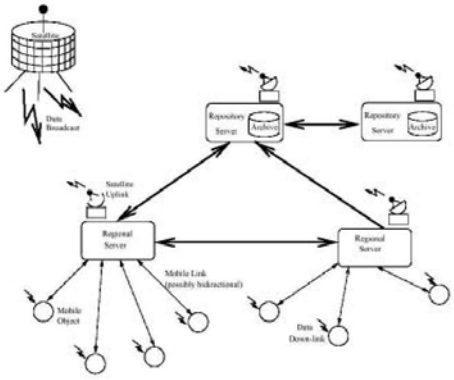
```
SELECT
  COUNT(ID)
FROM
  MovingObjects
INSIDE
  Region R
```



source: (Mokbel et al. 2004)

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Trajectory mining (1/3)

- Trajectory mining: find patterns (common, rare, etc. behaviors) in a collection of trajectories
- e.g. motion pattern – a 5-tuple of the form
  (position, heading, direction, distance, duration)

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source: (Schlieder et al. 2001)

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Trajectory mining (2/3)

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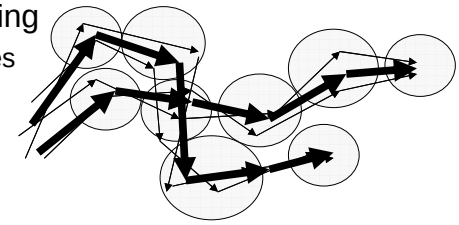
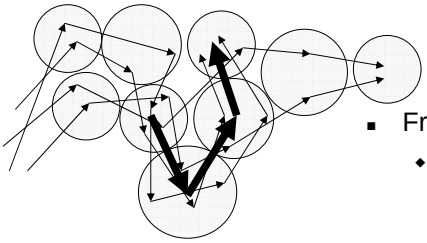
- Trajectory clustering
  - Cluster trajectories
  - For each cluster, find the 'mean' trajectory





- Frequent pattern mining
  - Discover frequent routes, etc.

Trajectory mining (3/3)

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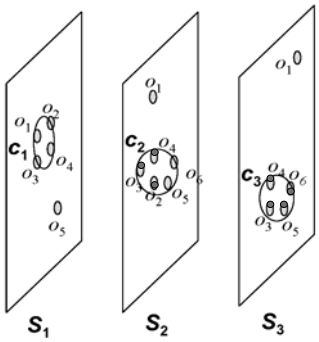
- Extracting moving clusters
  - Dense clusters of objects that move similarly for a long time period (convoy of cars, etc.)
  - Not necessarily the same objects during the lifetime of the cluster

Example …



source: (Kalnis et al. 2005)

Anonymity & Privacy issues

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- Privacy is "the claim of individuals, groups and institutions to determine for themselves, when, how and to what extent information about them is communicated to others"
  Alan Westin

- EU - enforced LBS privacy principles
  - obtain the subscriber's explicit consent
  - provide complete information about the use and storage of data
  - erase personal data after use or make it anonymous
  - give the user the possibility to restrict or prevent transmission of personal data
  - do not transfer the data to a third party without the user's consent

Privacy-aware knowledge extraction

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- From moving objects databases (MOD) to …
  a "filtered" (for sake of privacy) knowledge extraction and delivery
- Is 'privacy-aware' extraction from LBS an oxymoron?
  No…
- The GeoPKDD project (Nov. 2005 – Oct. 2008)
  - FP6-IST FET Programme
  - Coordinator: KDD Lab@ ISTI-CNR & U. Pisa (IT)
  - Partners: Hasselt U. (B), EPFL (CH), FAIS (D), WUR (NL), CTI & U. Piraeus (GR), Sabanci U. (TK), WIND (IT)

GeoPKDD project

- The overall concept

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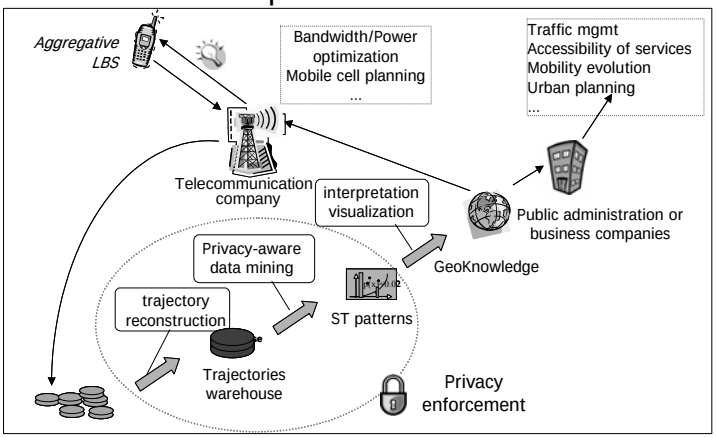

source: (Giannotti et al. 2005)

Hermes MLS prototype (1/8)

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- Research project @ Information Systems Lab., Univ. Piraeus
- Data model: absolute vs. relative location coordinates
  - Current location as a function in time over the starting location
  - Const, linear, arc movement functions
- Trajectory management
  - Insert / Update / Delete a moving object or a segment of its trajectory (at real-time)
  - Search functions over trajectories or sets of trajectories
  - Supported indices: R-tree (for stationary data), TB-tree (for objects moving in unrestricted space), FNR-tree (for objects moving on a network)

(cont.)

Hermes MLS prototype (2/8)

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- Data Analysis (OLAP) and Data Mining
  - over moving object trajectories
- Data Visualization
  - User interface customized for user's device (desktop PC, PDA, mobile, …)

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Hermes MLS prototype (3/8)

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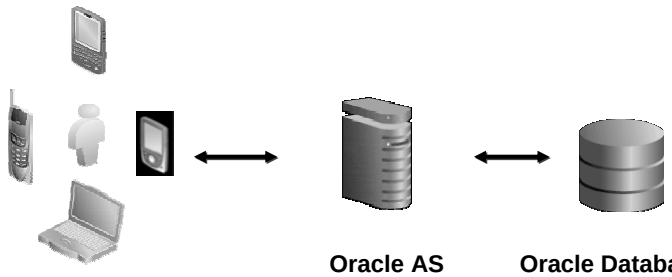
- Hermes architecture



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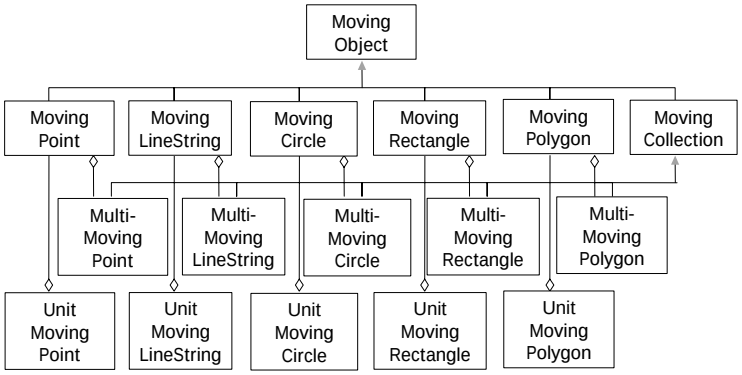
Hermes MLS prototype (4/8)

- Oracle data model extension: Hermes Moving Data Cartridge (MDC)



source: (Pelekis et al. 2005)

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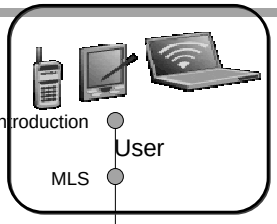
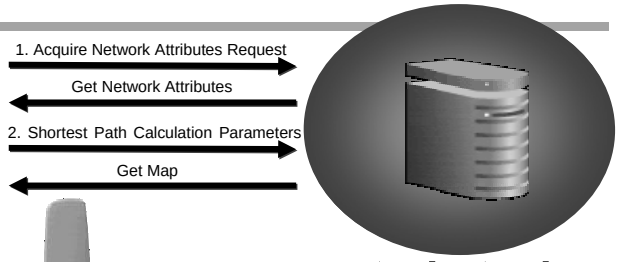
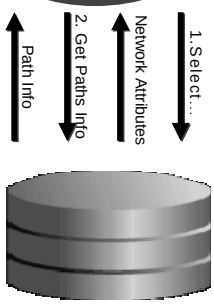
Hermes MLS prototype (5/8)







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Hermes MLS prototype (6/8)

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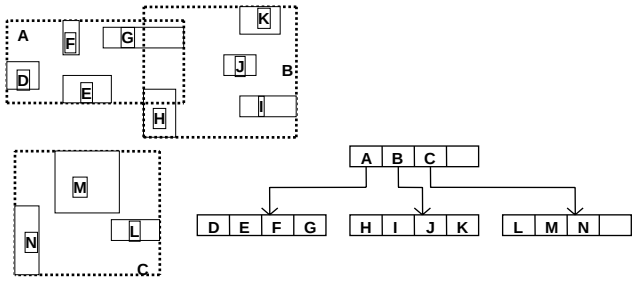
- R-tree (Guttman, 1984; Beckmann et al. 1990; Manolopoulos et al. 2005)
  - A multi-dimensional index for points and rectangles
  - Implemented in Oracle Spatial extension



Hermes MLS prototype (7/8)

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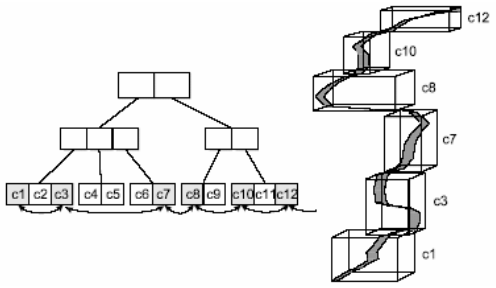
- TB-tree (Pfoser et al. 2000) - maintains the 'trajectory' concept
  - Each node consists of segments of a single trajectory; nodes corresponding to the same trajectory are linked together in a chain
  - Supported operations: topological (enter, …) and unary (speed, …)



Hermes MLS prototype (8/8)

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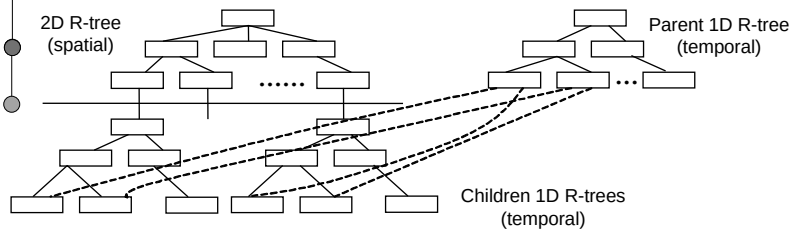
- TB-tree (Frentzos, 2003) - a forest of 1D R-trees on top of a 2D R-tree
  - one 2D R-tree stores spatial information about the network
  - each 2D R-tree leaf node corresponds to a 1D R-tree storing time interval information about objects moved on those line segments
  - an additional 1D R-tree (parent) indexes time intervals of all leaf nodes of all 1D R-trees (for temporal-only queries)



Summary

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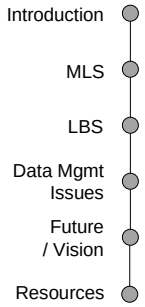
- Location-based services are (or soon will be) ubiquitous
- However, to be effective and efficient they require robust systems and tools for
  - trajectory and motion pattern management
    - modeling; physical representation; indexing; query processing and optimization
  - trajectory and motion pattern analysis / mining
    - co-location patterns; outlier analysis; …

Outline of Part II



- Data management issues and challenges
  - Advanced LBS
  - DBMS operations to be supported
- Future / vision
  - Mobile location data mining
  - Privacy issues
  - Prototypes and tools
- Resources
  - Useful links
  - Bibliographical references

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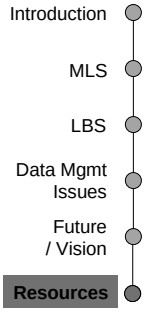
Selected literature on …



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Temporal and spatial database indexing (cont'd):

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Online Resources

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Acknowledgements

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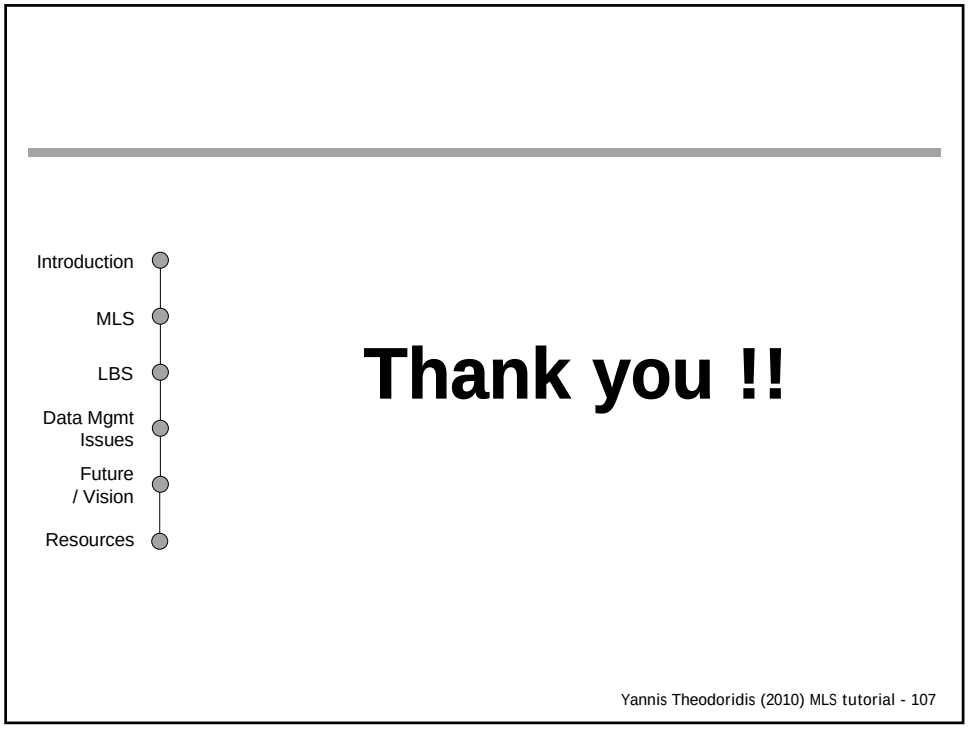
- Research on MLS/LBS funded by
  - Project GeoPKDD – Geographical Privacy-aware Knowledge Discovery and Delivery (2005-08; FP6-IST-FET Programme of the European Communities)
  - Project NGLBS – Next-Generation Location-Based Services (2004-06; EPAN Programme of the General Secretariat for Research and Technology of Greece)
  - Several grants and scholarships under the EPEAEK II Programme of the Greek Ministry of National Education
- Colleagues and students contributed (since 2003)
  - Christos Attikos, Vasilis Delis, Elias Frentzos, Nikos Giatrakos, Kostas Gratsias, Dimitris Kallergis, Gerasimos Marketos, Irene Ntoutsi, Aristides Papadakis, Nikos Pelekis, George Sikalias, Sotiris Zaharopoulos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Thank you !!
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