Navigation

SS-2004

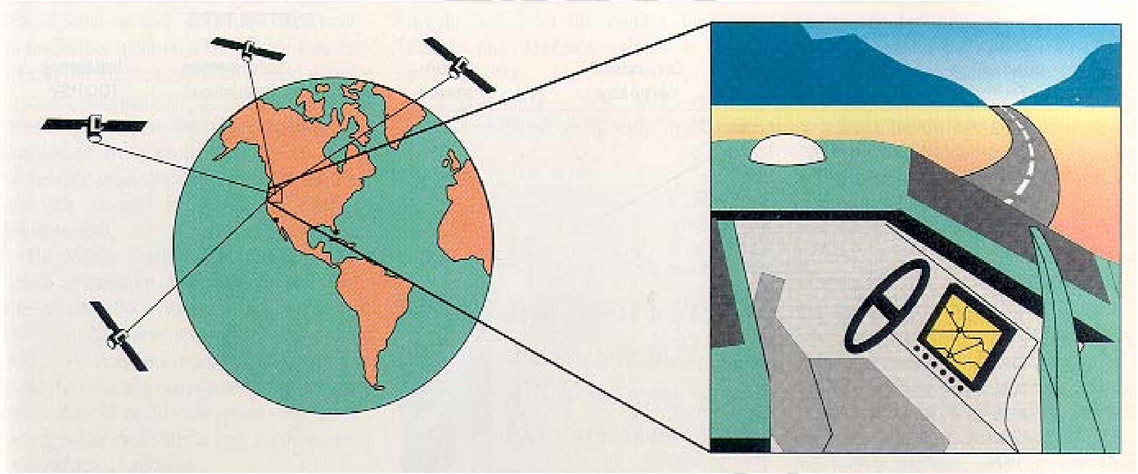
Chapter 5 – Maps

5 Maps / Contents

5 Maps (1)

5.1 Introduction

– **General remark:**
Why are maps (charts) good for navigation? ...
Since maps are planar representations of parts or all of the earth‘s surface, they serve as a navigational tool!



Furthermore, since navigation consists of positioning and guidance per definition, the use of maps seems to be the missing link!

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– Map characteristics

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Map attribute	Options
Application	Land-used, maritime, aeronautical
Contents	Topographic, thematic
Distortion	Equidistant, conformal, equivalent
Projection	Cylindrical, conical, azimuthal
Modeling	Analog, digital (raster, vector)
Scale	Large scale, small scale
Orientation	North-up, course-up

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5 Maps (3)

– **History**

3800 B.C.	Clay table map for the area from Libanon to Persia
2400 B.C.	First "world map" with Babylon in its center
2000 B.C.	First coastal and river maps are known from China
1500 B.C.	"City map" of Nippur (Iraque), engraved on a clay table
450/250 B.C.	"World maps" of Herodotos and Eratosthenes
A.D. 140	"World map" of Ptolemy from Alexandria
370	"Tabula Peutingeriana" show Roman road network together with "thematic information"
1250	Ebstorfer world map (bible based map with Jerusalem in its center and oriented towards the east)
1310	First sea maps (portolano maps) of Italy and Spain
1500	Strong progress of (sea) map production in the context of discovery tours (e.g., Columbus' map of Haiti from 1492)
1502	First complete world chart (Cantino chart)
1569	Gerhard Kremer (latinized Mercator) published his projection
1585	Mercator's world map for marine navigation
1772	Invention of Lambert's projection
1895	First automotive road map published in the USA
1909	Hermann Moedebeck produced the first aeronautical map
1968	Digital maps for the purpose of car navigation

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5.2 Types of maps

- **General remark:**
  Depending on the specific application, maps strongly differ with respect to thematic information and map symbols.

- **Maps for land application**

Object group	Examples/characteristics
Roads	Road class, road number, traffic flow, road gradient, construction status, opening period, house number, scenic value, toll road, distances, heights, etc.
Named areas	Settlement type, settlement name, etc.
Land cover	Buildings, parks, farmland, lakes, etc.
Road structures	Tunnels (maximum height), bridges (maximum weight), etc.
Traffic services	Petrol station, parking facility, rest stop, etc.
Public transport	Transport mode, holding point, route direction, etc.

5 Maps (5)

– **Maps for maritime applications:**
  Coastal maps, harbor maps, anchorage maps, etc.

Object group	Examples/characteristics
Topography	Coastline (shape, e.g., cliffs, sandy beaches, marshes), vegetation, harbors, coastal towns, etc.
Conspicuous objects	Topographic details, towers or monuments, bridges, offshore platforms (oil rig), etc.
Soundings	Contour lines, pointwise depths, underwater dangers or obstacles (bank, rock, reef, seaweed, fish trap, wreck), etc.
Navigation aids	Lighthouse, radio beacon, buoy (lighted, unlighted), acoustic (fog) signal, etc.
Tidal data	High water, low water, mean tide level, tidal stream, range of tide, etc.
Special areas	Restricted area, anchorage, fishing ground, etc.

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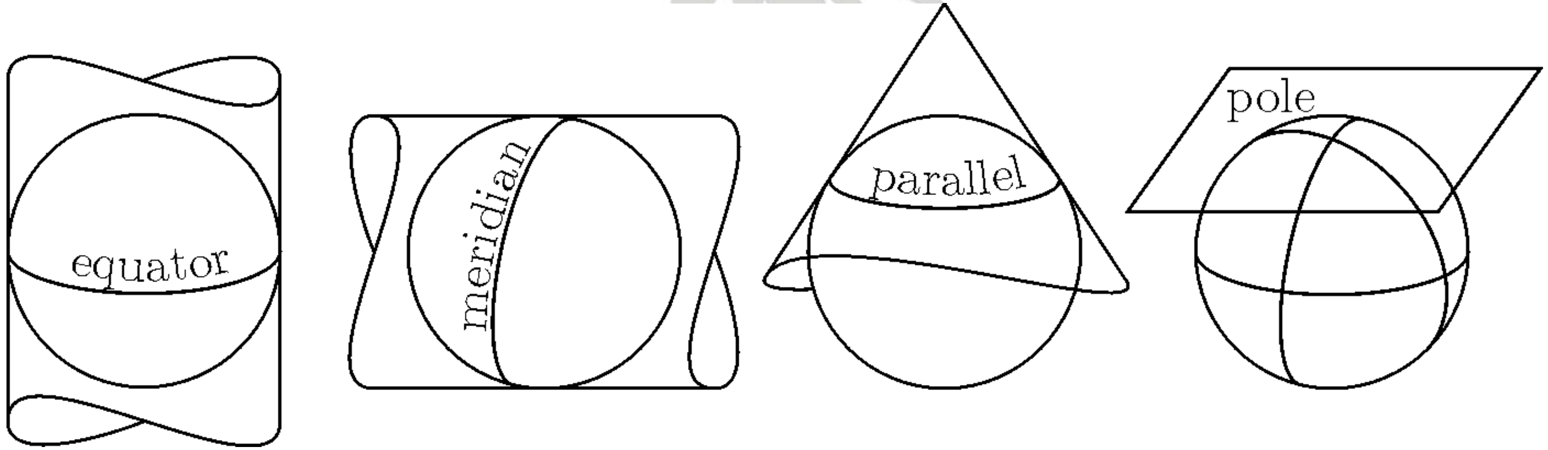
– **Maps for aeronautical applications:**
En route, area, approach, landing, and aerodrome maps.

Object group	Examples/characteristics
Structures on land	Settlements (e.g., cities, towns, villages), transportation network (e.g., highways, roads, railway tracks and stations, bridges, tunnels), etc.
Topography details	Spot elevation, highest elevation, mountain pass, glacier, cliff, dune, lake, river, etc.
Landmarks	Tower, church, castle, monument, factory, lighthouse, dam, oil field, pipeline, etc.
Aerodromes	Airport (international, civil, military), airfield (longest runway), heliport, (hang) glider site, parachute jumping site, free balloon site, etc.
Radio navigation aids	VHF omnidirectional radio range (VOR), nondirectional radio beacon (NDB), marker beacon, basic radio facility, radio frequencies, etc.
Restricted airspace	Danger area, temporary reserved airspace, low level flight protection zone, bird reserve, etc.
Air traffic management	Control area, terminal control area, flight information region, airport traffic zone, etc.
Obstacles	Obstacle (lighted, unlighted), funicular, etc.

5.3 Map projections

– General remarks

- Spherical approximation makes projections more convenient.
- Some projections can only be defined analytically.
- Projections aim at the mapping of parallels and meridians.
- A sphere cannot be mapped without distortion of distances.
- Conformal projections (no distortion of angles) are preferred.
- Projections are performed directly or via a cylinder or cone.



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– Cylindrical projection

- The cylinder is tangent to the sphere either at the equator or at a selected meridian (transverse mode).
- Conformal **Mercator** projection:

isometric grid ... $ds^2 = R^2 \cos^2\varphi \, (dq^2 + d\lambda^2)$ $\qquad dq = \dfrac{1}{\cos\,\varphi}\, d\varphi$

Mercator integral ... $q(\varphi) = \displaystyle\int_0^{\varphi} \frac{1}{\cos\varphi}\, d\varphi = \ln\tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right)$

Cartesian coordinates ... $x = R\, q(\varphi) \quad \text{and} \quad y = R\,\lambda$

- Transverse projections:
Gauss-Krüger projection (tangent meridians every 3°);
Universal transverse Mercator (**UTM**) projection (tangent meridian every 6°, scale factor of 0.9996)

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– Conical projection

- The cone is tangent to the sphere at a selected parallel or is penetrating the sphere at two selected parallels.
- Meridians are mapped to straight lines through the apex and parallels become concentric circular arcs around it.
- An example is the conformal **Lambert projection**, mostly used for aeronautical charts.

– Azimuthal projection

- The projection uses a plane tangent to the sphere at a specific surface point (pole).
- Meridians are mapped to straight lines through the pole and parallels become concentric circles around it.
- An example is the **stereographic projection** which can geometrically be interpreted.

5.4 Digital maps

5.4.1 Definitions

- **General remarks**
  - Navigation systems require digital maps.
  - Vector (not raster) maps are used.
  - Vector maps rely on node-edge structures.
  - Node-edge structures are treated by graph theory.
  - Digital maps for navigation are called navigable maps.
  - Digital maps model the traffic infrastructure.
  - Modeling applies concepts used for GIS.
  - Modeling involves geometry and semantics.
  - Geometry consists of metrics and topology.

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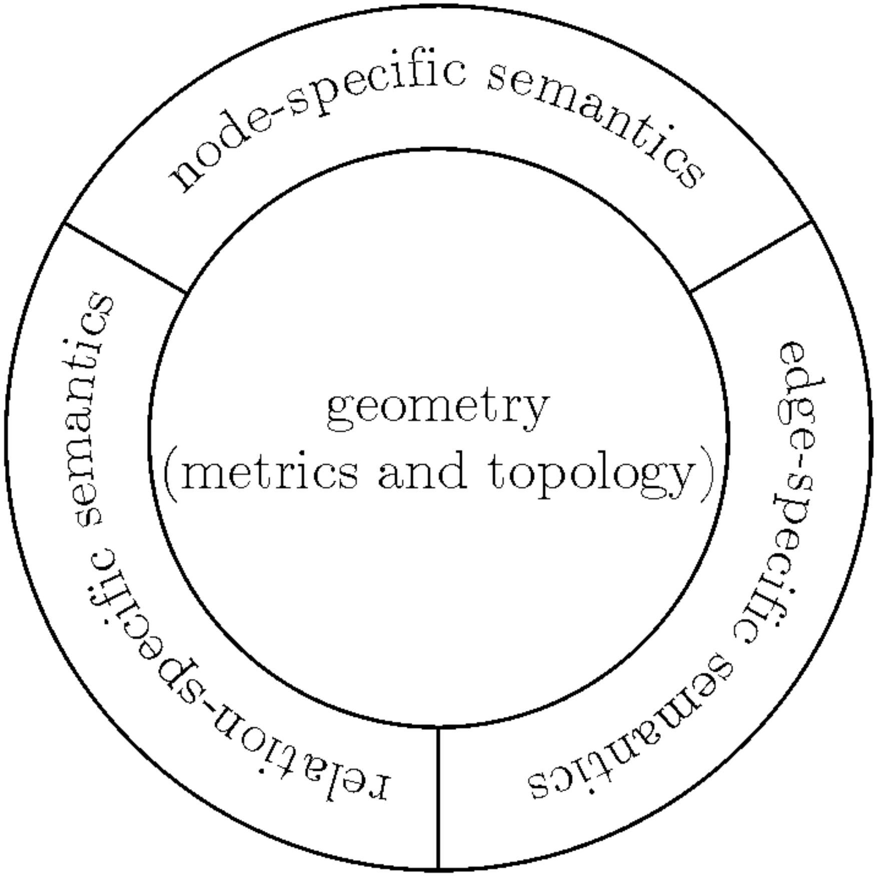
– **GIS modeling:**
„The real world of objects with their characteristics and behavior is mapped into the virtual world of features with their attributes and constraints“.

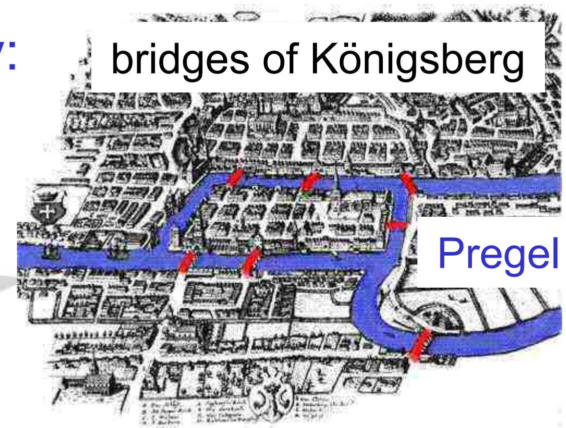


5.4.2 Modeling and graph theory

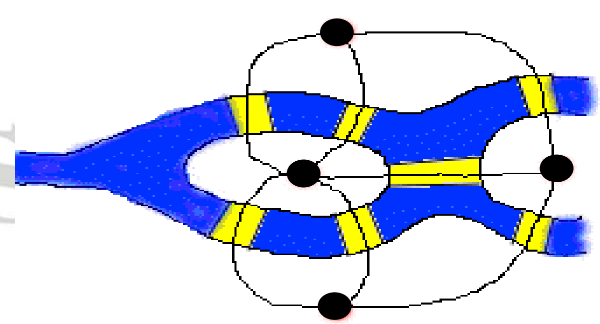
– General remarks

- Graph theory contains:
  - Graph definition
  - Graph properties
  - Graph algorithms

- History:



L. Euler (1736)



- Basic definition of a graph:

G = G(V,E)
V ... set of nodes / vertices
E ... set of edges

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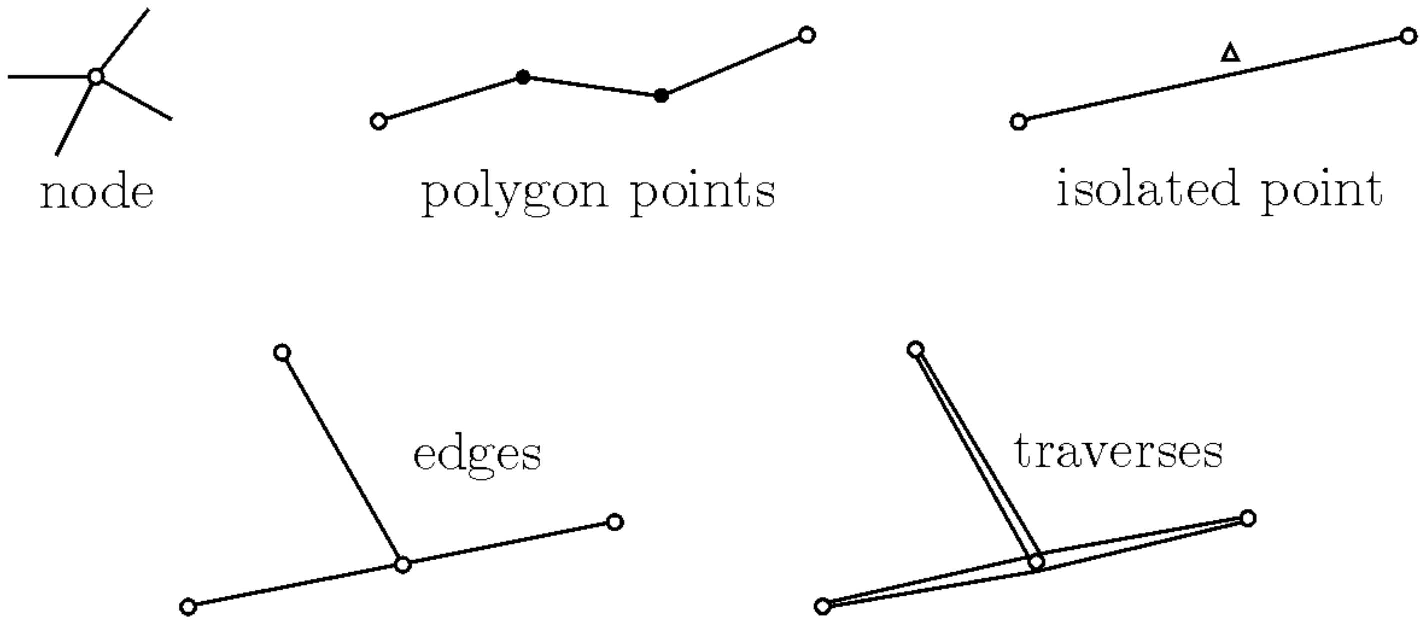
– Graph elements

- Single graph elements:
  node, edge, point (polygon points and isolated points), arc (directed edge), traverse (edge-to-edge or triple-node relation).



Two nodes joined by an edge are called **adjacent**, whereas the edge is said to be **incident** with the nodes.

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- Complex graph elements:

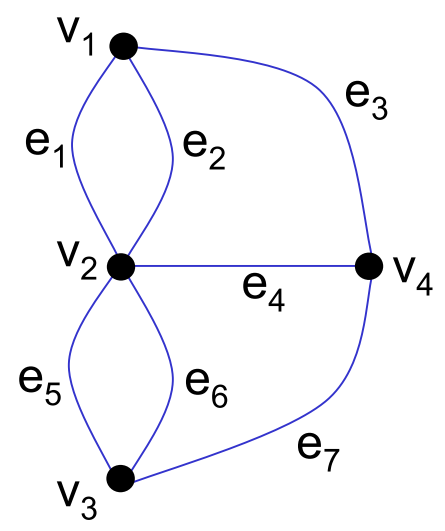
  An **edge (arc) sequence** consists of adjacent edges (arcs), not necessarily distinct from each other, e.g., e_1 - e_5 - e_7 - e_4 - e_5 - e_6 .

  A **chain** is an edge sequence with diverse edges, e.g., e_1 - e_5 - e_7 - e_4 - e_6 . A **path** is an arc sequence with diverse arcs.

  A chain (path) with distinct nodes is called a **simple chain (path)**, e.g., e_1 - e_5 - e_7 .

  A closed chain is called a **circuit**, e.g., e_1 - e_5 - e_7 - e_4 - e_2 . A closed path is a **cycle**.

  A circuit (cycle) with distinct nodes is called a **simple circuit (cycle)**, e.g., e_1 - e_5 - e_7 - e_3 .



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– **Graph properties**
  - A finite graph has a finite number of nodes and edges; opposite: infinite.
  - A simple graph has no loops (edges incident with one node) and no parallel edges (edges incident with the same two nodes); opposite: nonsimple.
  - In a regular graph all nodes have the same degree (number of edges incident with a node); opposite: irregular.
  - In a complete graph, every pair of nodes is joined by an edge; opposite: incomplete.
  - In a connected graph every pair of nodes is joined by at least one chain. In a strongly connected graph every pair of nodes (A,B) is joined by at least one path from A to B and from B to A.
  - A directed graph (digraph) contains arcs instead of edges.
  - A cyclic graph has at least one cycle; opposite: acyclic.

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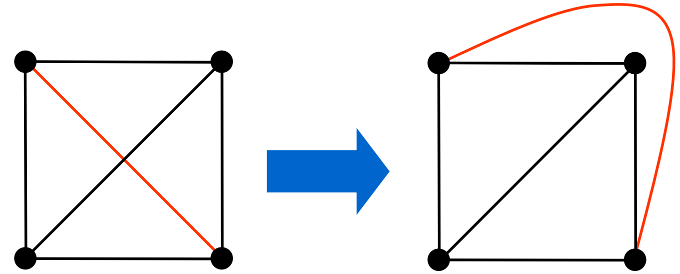
- Planar graph



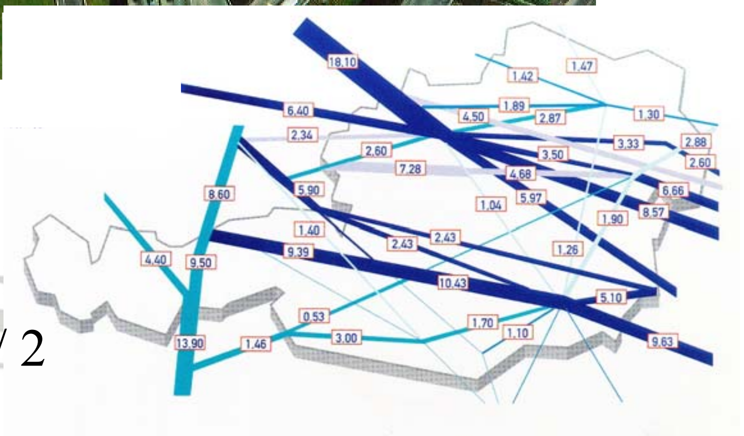
Definition:

Embedding the graph into a plane, edges only intersect at nodes.

Example: complete square

Real networks:

maritime applications ... planar
land appl. ... planar / non-planar
aeronautical appl. ... non-planar



Euler formula: $m \le 3n-6 \ll n(n-1)/2$

$\rightarrow$ sparseness!

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- Valuated graph (network)

Definition of a network:

G(V,A,c) with c: $c_{ij} = c(a_{ij})$

Cost number c_{ij}:

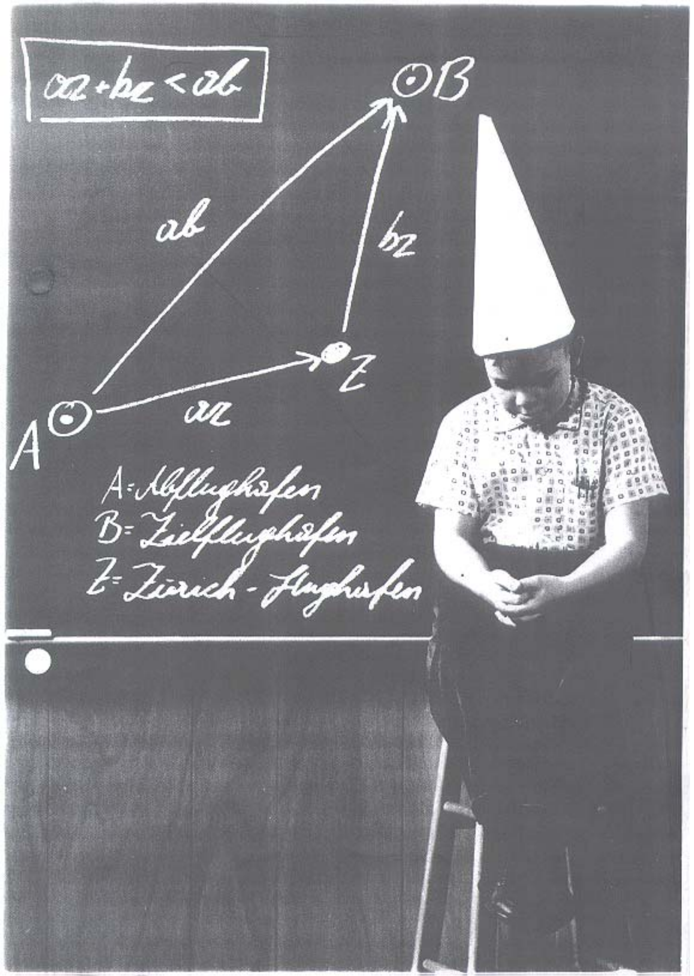
geometric length (L2-norm)

$\left.\begin{array}{l}\text{monetary cost}\\\text{transfer time}\end{array}\right\}$ no norm!

Weight number p_{ij}:

probability (random walk)

$c_{ij} = -\log p_{ij}$



Valuation is required also for traverses and paths!

A valuation is static or dynamic, deterministic or stochastic.

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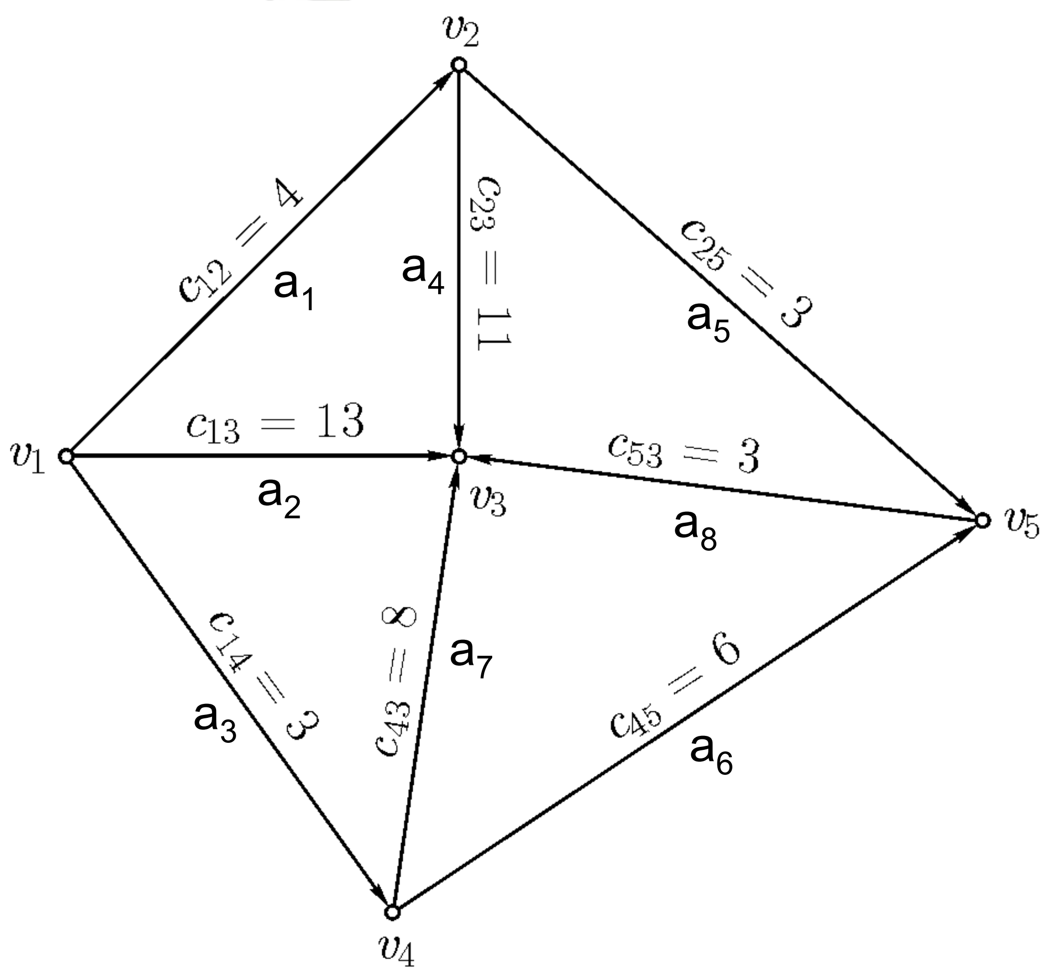
– Graph storage

- Example of a digraph:



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- Adjacency matrix **A**:

$$A_{ij} = \begin{cases} 1 & \text{if an edge } e_{ij} \text{ or an arc } a_{ij} \text{ exists} \\ 0 & \text{otherwise} \end{cases}$$

- Incidence matrix **B**:

$$B_{pq} = \begin{cases} 1 & \text{if } v_p \text{ is start node of } a_q \\ -1 & \text{if } v_p \text{ is end node of } a_q \\ 0 & \text{if } a_q \text{ is not incident with } v_p \end{cases}$$

- Adjacency list:
  Each record describes an arc by its adjacent nodes and at least one attribute.

- Indexed adjacency list:

node no.	1	2	…	v_j			…	n
index				•				
arc no.	1	2	…		a_{jk}		…	m_a
successor					v_k			
attribute					c_{jk}			
index					•			
traverse no.	1	2	…			t_{ijk}	…	m_t
predecessor						v_i		
attribute						b_{ijk}		

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5.4.3 Navigable maps and requirements

– **General remark:**
  The term navigable implies that the digital map is not a visualization tool only, but has to play an active part during the different phases of navigation.

– **Questions asked during a navigational procedure**

	pre-trip	on-trip	after-trip
planning	where am I? where to go? how to go?	where to go next?	
action		where am I? what to do next?	where have I been? what was my course?

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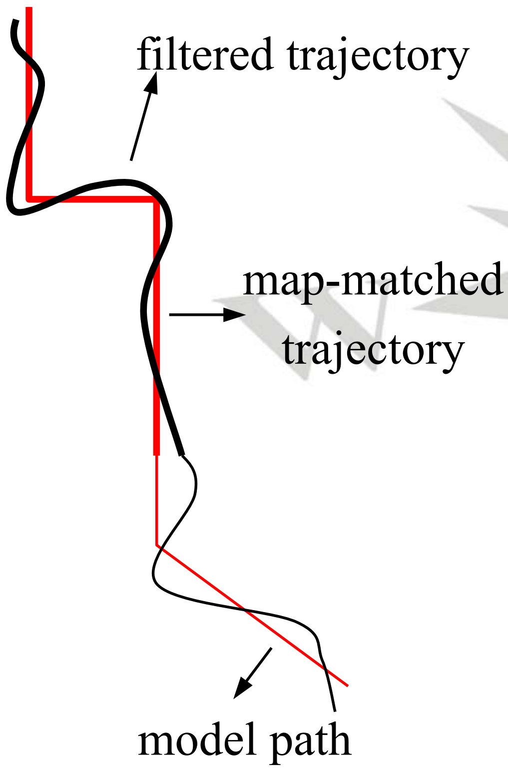
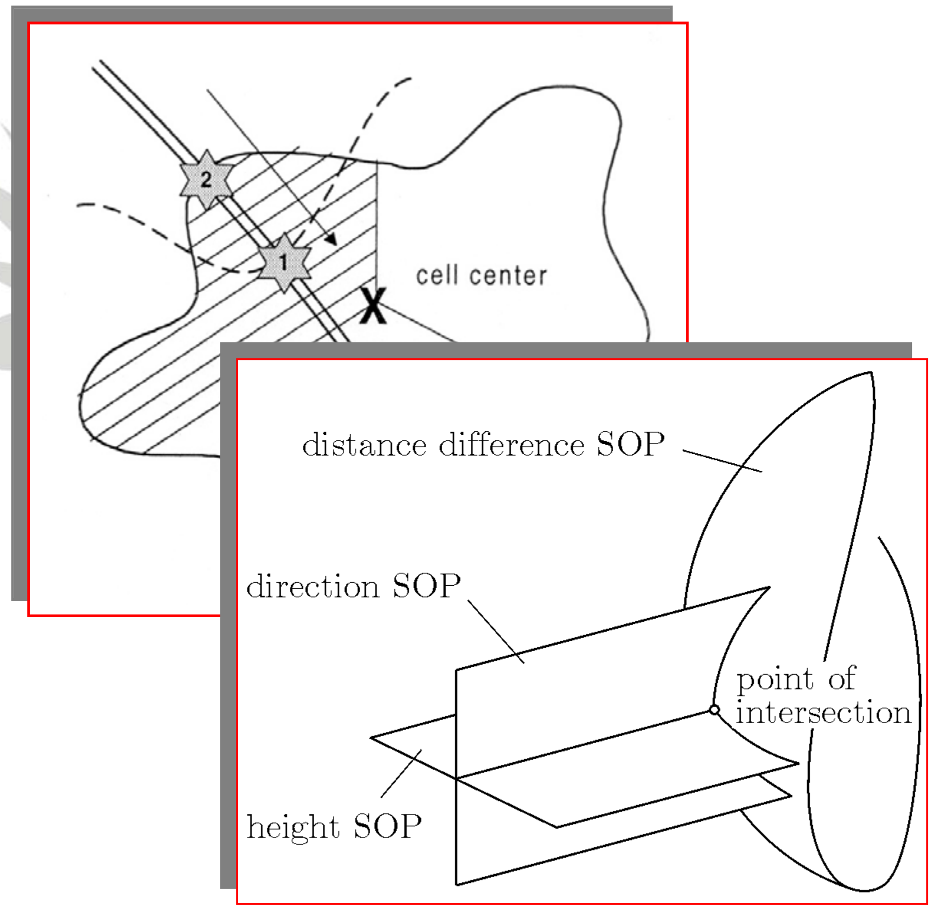
– **Map-related navigational tasks**

- Where am I ?: **positioning** together with **map matching** (position→ location), **address matching** or **map aiding**





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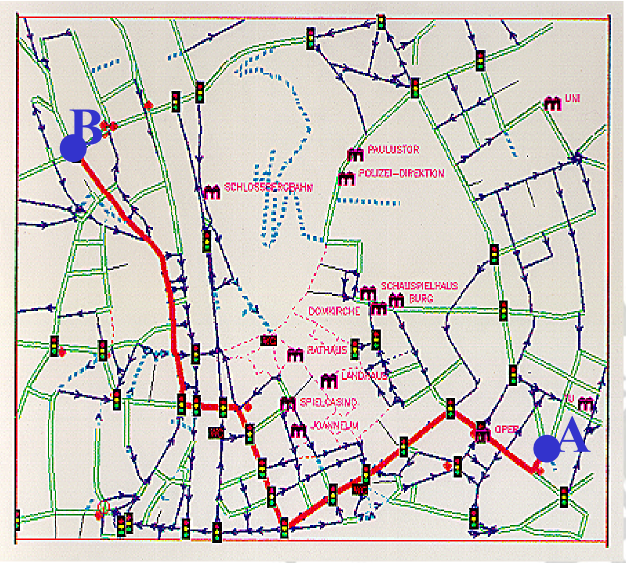
- How to go?, where to go?, where to go next?: **routing**



- What to do next?: **guidance**

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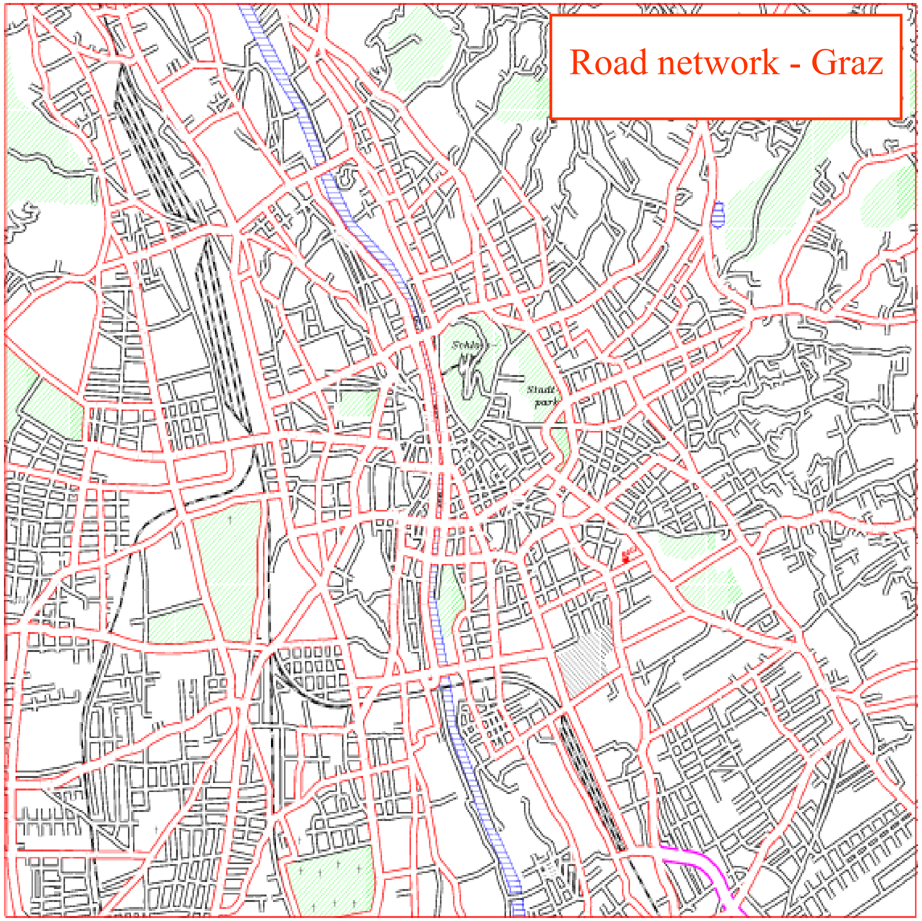
– Requirements

- Geometrically accurate (for map matching and map aiding)
- Topologically consistent (for route planning)
- Thematically correct, complete, and up-to-date (for route guidance)
- Efficient storage!
- Standardized products!



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– Application examples

Vehicle Navigation Systems (VNS) and Intelligent Transportation Systems (ITS)

Electronic Chart Display and Information System (ECDIS) and Vessel Traffic Services (VTS)

Flight Management Systems (FMS) and Air Traffic Management (ATM)

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5.4.4 Standardization and products

– Digital maps for land applications

- General remark:

  In the case of **Digital Road Maps** (DRM), the most promising standard is the **Geographic Data File** (GDF).

- GDF-historical background:

  GDF development started in the mid 1980s in the frame of the EUREKA-project DEMETER (Digital Electronic Mapping of European TERritory);
  GDF was designed in equivalence to the British National Transfer Format (NTF) and under consideration of the U.S. Spatial Data Transfer Standard (SDTS);
  GDF focuses on road map data from the very beginning;
  GDF was extended considering Road Transport Informatics (RTI) and Advanced Transport Telematics (ATT) in connection with the European initiative DRIVE (Dedicated Road Infrastructure for Vehicle use and safety in Europe);
  GDF started with GDF 1.0 in Oct. 1988 and is currently at GDF 4.0.

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- GDF Structure:

  GDF structure is based on three levels ... level 0 (geometry incl. topology), level 1 (semantics for simple objects, e.g., road elements), level 2 (semantics for complex objects, e.g., roads).

GDF module	Explanation
Feature catalogue	List of objects of the real world
Attribute catalogue	List of characteristics of objects
Relationship catalogue	Inter-object relations
Feature representation	Conceptual data model
Quality description specifications	Data quality and quality checking
Global Data Catalogue	Self-description of data
GDF logical data structure	Data content specifications
Media record specifications	Data format specifications

  GDF interprets a vehicle to be either an automobile, a train, or a special sort of vessel (e.g., ferry boat).

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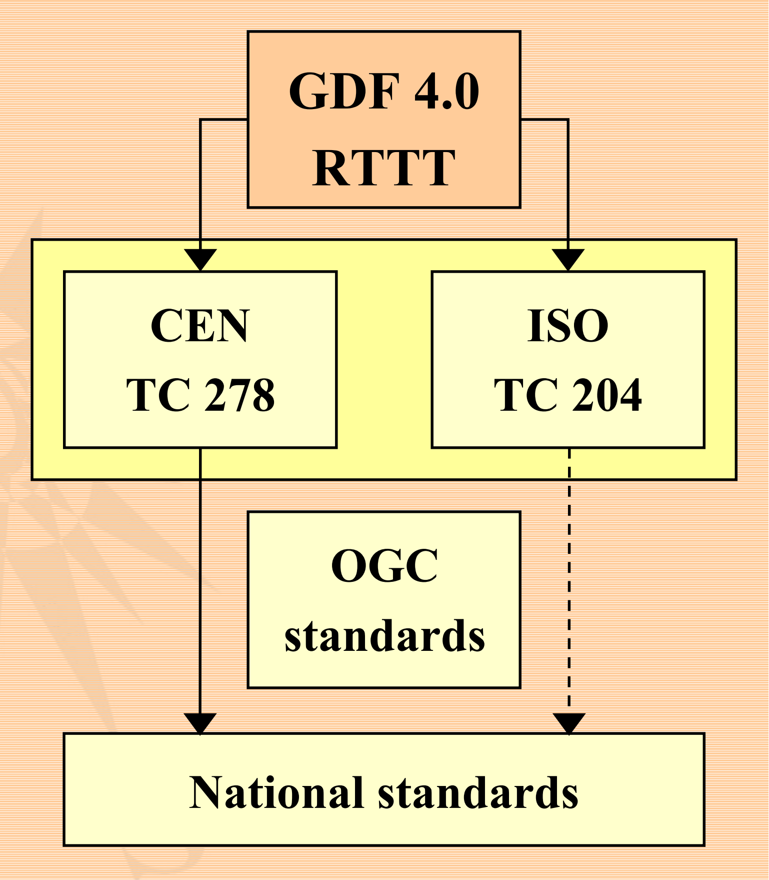
- GDF in CEN and ISO:

  RTTT ... Road Transport and Traffic Telematics

  CEN ... Comite Européen de Normalisation

  ISO ... International Organization for Standardization

  OGC ... Open GIS Consortium



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- Worldwide DRM products:

  Etak Inc. started production of DRMs in 1983 for the USA; in Europe, Etak entered a joint venture with **Bosch** (Germany) and **Tele Atlas** (Belgium) named European Digital Road Map Association (**EDRA**); nowadays, Tele Atlas Europe and Tele Atlas North America distribute their GDF-based MultiNet database for 15 European countries and the complete USA.

  Navigation Technologies (**NavTech**), founded in 1985, generates navigable DRMs for the USA mainly based on maps of the American Automobile Association (AAA). NavTech Europe was formerly called European Geographic Technologies (**EGT**).

  The Japan Digital Road Map Association (**JDRMA**), founded in 1988, produces DRMs covering all of Japan in the meantime.

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– Digital sea charts

- **Electronic Navigational Charts (ENC):**
  digital version of nautical paper charts; vector-formatted;
  basis for ECDIS; officially authorized due to IMO (International Maritime Organization) performance standards; fulfill transfer standards and symbol specifications issued by the IHO (International Hydrographic Organization).

- **System Electronic Navigational Chart (SENC):**
  equals ENC plus vessel position, way points, course lines, etc.; direct input to ECDIS.

- **Raster Navigational Chart (RNC):**
  not fully applicable to ECDIS; produced and updated by the Admiralty Raster Chart Service (ARCS); based on traditional paper charts of the British Admiralty; mainly used in areas where no ENCs are available.

References

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Attachments

- Historical maps
- Maritime chart including chart symbols
- Aeronautical chart including chart symbols