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Novel Real-Time Coordinate Transformations based on N-Dimensional Geo-Registration Parameters' Matrices

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Presentation Contents

- Introduction
- Problem definition
- Problem resolving
- Proposed algorithm and processes
- Case study
- Summary

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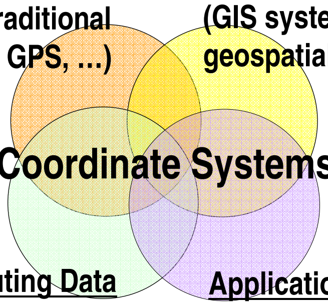
Introduction

Coordinate systems are the infrastructure to mapping, surveying, and engineering tasks and applications:

Acquiring Geospatial Data (Digitizing maps, traditional surveying, GPS, ...)

Analyzing and Processing Data (GIS systems, graphics, geospatial queries,...)



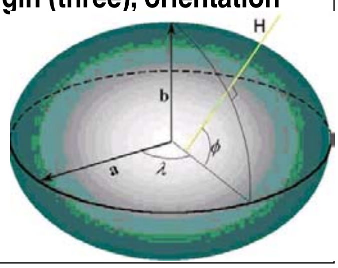
Distributing Data (GIS systems, WWW, geospatial databases, map making, decision making, ...)

Applications (Mapping and surveying, navigation, cartography, natural resource management, ...)

Introduction

Defining a location – Stage A: Geodetic Datum (Reference System):

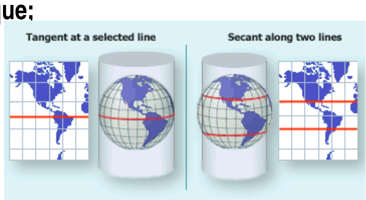
- The physical infrastructure that serves as a referent for the calculation of other parameters;
- A geodetic datum is 'a set of constants specifiyng the coordiante systems used for geodetic control, i.e., for calculating coordinate of points on the earth' (Geodetic Gloassary, 1986);
- Eight quantities are needed (at least): origin (three), orientation (three) and reference ellipsoid (two);



Introduction

Defining a location – Stage B: Map Projection:

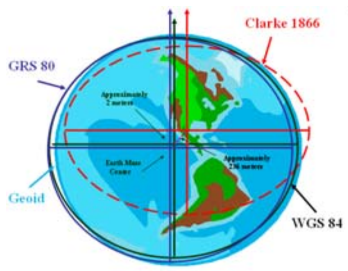
- …'A systematic representation of a round-body surface (i.e., the earth) on a plane'… (Snyder 1987);
- All transformations from 3D to 2D surfaces include distortions;
- These types of distortions can be: area, shape, scale, and direction;
- Developable surfaces used as projections: cylindar (for example: mercator), cone (lambert), and plane;
- Two main considerations:
  - Orientation: normal, transverse, and oblique;
  - Tangent or secant;



Introduction

Datum Transformation:

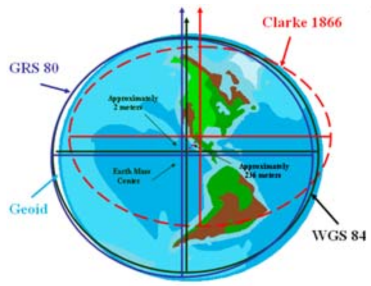
- Direct approach: utilzing formulated differential equations that relate to changes between two geodetic datums – and thus to variations affecting the geodetic coordiantes of a given point:
  - Changes in the position, semi-major axis and flattening are known;
  - Normaly, the axes of the refernce ellipsoids are assumed to be parallel (no rotation angles are involved);
  - Several approximations are incorparated to simplify the transformation formulas;



Introduction

Datum Transformation – cont.:

- Indirect approach: several transformation steps:
  - Transforming the given (reference) coordinates into Cartesian geocentric ones (X, Y, Z), according to refernece ellipsoid;
  - Applying 3D similarity transformation (compensating the change in position and the orientation of the two reference ellipsoids) to the geocentric coordiantes;
  - Transform the new target Cartesian gecentric coordinates into geodetic ones;



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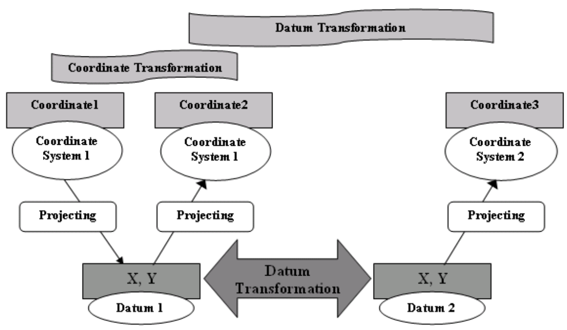
Introduction

Map Projected Coordinate Transformation:

- In addition to the datum-to-datum transformation, adding the different unique mapping formulae (and unique parameters) that must be known precisely to the datum to datum transformation;
- These procedures are mostly time consuming and involve mass mathematical formulae and a-priori considerations;
- … Ambiguity exists;



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Problem Definition

Map(s) positioning:

- There exist a large number of datums and projections presenting locations given in numerous coordinate systems, while demanding simultaneous use in real-time geo-oriented systems;
- Transforming location-based data between two given coordinate-systems may be time consuming and might involve data uncertainty;
- Data-transformation is becoming more complicated – involving dozens of sets of transformations – due to an increasing number of datums, adjustments, and coordinate systems being continuously updated;

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Problem Resolving

Suggesting....

- Simplification of coordinate systems transformation, while enabling a faster process with no accuracy loss;
- A process that is not solely derived from the 'known' transformation model;
- Enabling to utilize higher degree of transformation model;
- Utilizing feature-based identification to extract transformation model (future research).

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Proposed algorithm and processes

- Utilizing an N-dimensional geo-registration matrices:
  - Phase I – pre-processing: establishing the geo-registration matrices
    - Dividing the entire area covered by both coordinate systems into a matrix composed of cells;
    - Executing an indirect transformation on all matrix-nodes;
    - Calculating the source-to-target coordinates differences stored as geo-registration matrices.
  - Phase II – the transformation
    - Locating grid-cell bounding the desired source coordinate needed for transformation;
    - Implementing designated interpolation concepts on the values stored in the geo-registration matrices;
    - Calculating the precise coordinate corrections (source-to-target).

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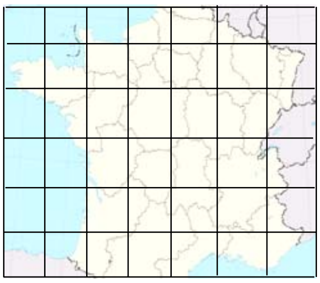
Proposed algorithm and processes

Phase I – pre-processing:

- Dividing the entire area covered by both coordinate systems into a matrix composed of cells;



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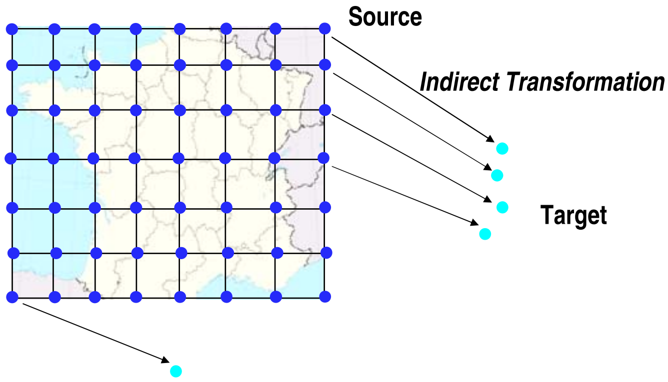
Proposed algorithm and processes

Phase I – pre-processing:

- **Executing an indirect transformation on all matrix-nodes;**



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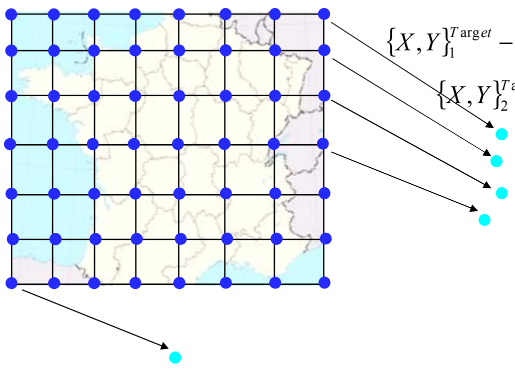
Proposed algorithm and processes

Phase I – pre-processing:

- **Calculating the source-to-target coordinates differences stored as geo-registration matrices;**



$$\{X,Y\}_1^{Target} - \{X,Y\}_1^{Source} = \{dX, dY\}_1$$

$$\{X,Y\}_2^{Target} - \{X,Y\}_2^{Source} = \{dX, dY\}_2$$

$$\{X,Y\}_n^{Target} - \{X,Y\}_n^{Source} = \{dX, dY\}_n$$

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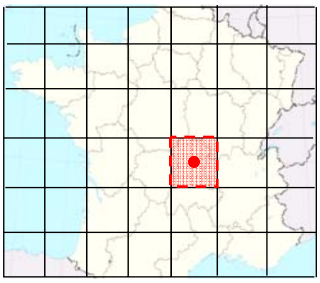
Proposed algorithm and processes

Phase II – exact transformation calculation:

- **Locating grid-cell bounding the desired source coordinate needed for transformation;**



$$\{X, Y\}_{SOURCE}$$

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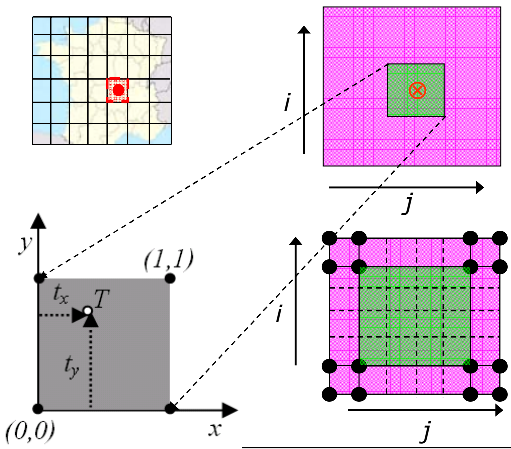
Proposed algorithm and processes

Phase II – exact transformation calculation:

- **Implementing designated interpolation concepts on the values stored in the geo-registration matrices;**

$$F_1(t) = -0.5 \cdot t + 1.0 \cdot t^2 - 0.5 \cdot t^3$$
$$F_2(t) = +1.0 - 2.5 \cdot t^2 + 1.5 \cdot t^3$$
$$F_3(t) = +0.5 \cdot t + 2.0 \cdot t^2 - 1.5 \cdot t^3$$
$$F_4(t) = -0.5 \cdot t^2 + 0.5 \cdot t^3$$
$$Z_P = \sum_{i=1}^{4} \sum_{j=1}^{4} F_j(x) \cdot F_i(y) \cdot H(i, j)$$



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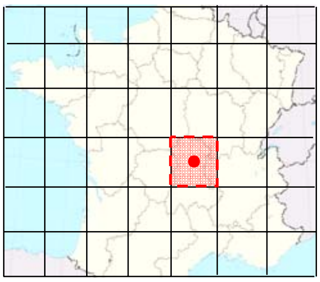
Proposed algorithm and processes

Phase II – exact transformation calculation:

- **Calculating the precise coordinate corrections (source-to-target);**



$$F_1(t) = -0.5 \cdot t + 1.0 \cdot t^2 - 0.5 \cdot t^3$$
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$$F_4(t) = -0.5 \cdot t^2 + 0.5 \cdot t^3$$
$$Z_P = \sum_{i=1}^{4} \sum_{j=1}^{4} F_j(x) \cdot F_i(y) \cdot H(i,j)$$
$$\downarrow$$
$$\{dX, dY\}_{CALC}$$
$$\downarrow$$
$$\{X, Y\}_{TARGET} = \{X, Y\}_{SOURCE} + \{dX, dY\}_{CALC}$$

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Case Study

- **Lambert Conformal conic and Transverse Mercator;**
- **Varying scale but retain the correct shape of the mapped surface;**
- **Scale variation is greatest in north-south directions for Lambert, and the east-west directions for transverse Mercator;**
- **France was chosen for evaluating the proposed concept (UTM zones 31-33**);
- **France's Lambert datum is defined by Clarke 1880 ellipsoid, where the UTM datum is defined by WGS84 ellipsoid.**

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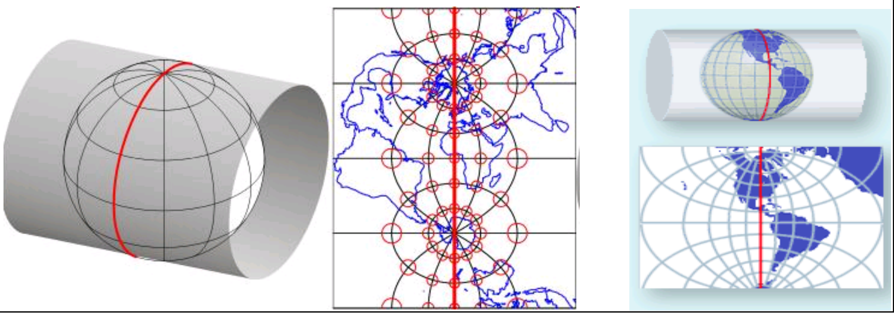
Case Study

- **Transverse Mercator:**
  - Cylincrical (transverse) projection;
  - Conformal projection;
  - Tangent and opposite (180^0) meridians, and equator appear as straight lines;
  - Other meridians and parallels will appear as complex curves;
  - Utilized for quadrangle maps at scales from 1:24,000 to 1:250,000;



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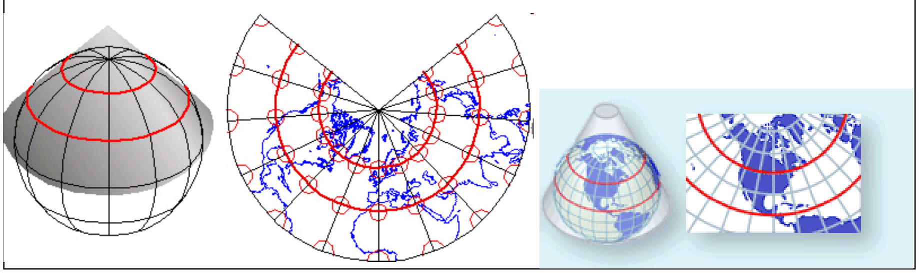
Case Study

- **Lambert:**
  - Conic projection;
  - Conformal projection;
  - Parallels are unequally spaced arcs of concentric circles; Meridians are equally spaced radii of the same circles;
  - Parallels will cut the meridians at the right angle;
  - Scale is true along the standrad parallels;
  - Utilized for regions and countries with predominant east-west extent;



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Case Study

- GUI programmed in VB.NET;
- Input:
  - User-defined grid resolution value (X and Y directions);
  - Source coordinate for transformation;
- Output:
  - Translation values, i.e., dX and dY, via two processes;
  - Translation values difference;
  - Clock time of two processes;

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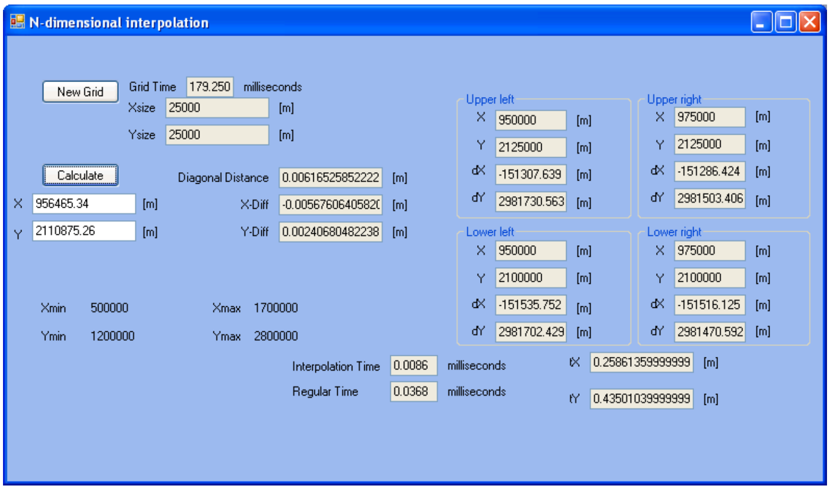
Case Study

GUI developed:



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Case Study

Accuracy as function of grid resolution.

Resolution value (grid spacing) [m]	Diagonal difference [m]
500	5.65E-08
1,000	3.37E-07
5,000	5.58E-05
10,000	0.0005
25,000	0.006
50,000	0.0645
100,000	0.3846

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Case Study

Main conclusions:

- From a precision viewpoint:
  - For most geodetic purposes accuracy of less than 1 cm is sufficient - accepted while utilizing a 25,000 m resolution.
  - For graphic purposes a resolution of 100,000 m is adequate.
- Usually, a small number of matrix cells is required in the pre-processing phase, i.e., a short process and small database storage is required – essential for hand-held devices;
- Though large variations exist in the geo-registration matrices cells, the interpolation concept was accurate enough and reliable to predict local trends exist;
- Approx. 5 times faster than the indirect process – significant when real-time (web-based) decision-making application is considered.

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Summary

What has been achieved:

- Fully automatic process for calculating – and modelling – transformation parameters for a required location;
- A solution that is generic for any given sets of coordinate systems, datums and projections;
- An adaptive solution when other types of transformation model is implemented (other than translation only);
- No algorithmic and calculation complexities.

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Summary

- **Future research:**
  - Adding rotation parameters stored in the matrices and utilized in the transformation model;
  - When no transformaion model (formulae) is known - identifying counterpart unique entities that exist in both given maps, hence replacing the "known" indirect transformation model;
  - Establishing a non-gridded (matrix) geo-registration model.

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I can't find my GPS!
Oh, the sweet, sweet irony.
Thank You