Web Mercator Projection & Raster Tile Maps

Two cornerstones of Online Map Service Providers

Emmanuel Stefanakis
Dept. of Geodesy & Geomatics Engineering
University of New Brunswick
estef@unb.ca
Online Map Service Providers

- Available for ~12 years
- Well established (difficult to remember how life was without them)
Online Map Service Providers
Online Map Service Providers

Challenges?

- Technological
- Cartographical
Online Map Service Providers Framework

CLIENT

Request
(where/what/resolution)

HTTP

SERVER

Map Product

Map Repository
(Data+Images)

End-users

Map Service
Technological Challenges

- High and steadily increasing demand
- Voluminous data (vectors and images)
- Bandwidth limitations
- Concurrent access
- Security issues
- Data protection
Cartographical Challenges

- Visualize the map on Web browser
  - flat/rectangular monitor
- Multi-resolution representation
  - various zoom levels
- Multi-theme mapping
  - various themes (layers)
- Multi-language mapping
  - various languages
Online Map Service Providers

- Web Mercator Projection
- Raster Tile Maps
Map Product ➔ Flat Monitor

Request
(where/what/resolution)

CLIENT

WWW

HTTP

SERVER

Map Service

Map Repository
(Data+Images)
Map Projection

A function $f \ldots$

$(X,Y) \leftarrow f(\varphi, \lambda)$
Choose a Map Projection

Cylindric

Pseudocylindric

Conic

Planar
Choose a Cylindrical

- Best fit
- Rectangular grid
Conical Projection
Conical Projection ?
Cylindrical Projection ?
Cylindrical Projection

Simulation of a cylindrical projection
Cylindrical Projection

- Simulation of a cylindrical projection
Which Cylindrical?

Plate Carree

Miller’s

Mercator ✔
Mercator Projection

- Most popular
- Conformal
- Easy math (low complexity)
  - ...to serve high demand
Mercator Projection

- Conformal
- Support navigation in Seas

\[ 2nR \cos(\phi) < 2nR \]
Mercator Projection
Mercator Projection

Scale factor on **horizontal** (along parallels at \( \varphi \)):

\[
2\pi R \cos(\varphi) \rightarrow 2\pi R
\]

**Mercator’s goal** \( \rightarrow \) **preserve shapes/directions**
Mercator Projection

Scale factor on horizontal (along parallels at $\varphi$):

$$2\pi R \cos(\varphi) \rightarrow 2\pi R$$

*Mercator applied...*

Scale factor on vertical (along meridians at $\varphi$):

$$2\pi R \cos(\varphi) \rightarrow 2\pi R$$
Mercator Projection

All parallels have the same length = equator \((2\pi R)\)

At latitude \(\phi\) the \textbf{scale factor} on the \textit{parallel} is equal to:

\[
\frac{2\pi \cdot R}{2\pi \cdot R \cos \phi} = \sec \phi
\]
Mercator applied the same factor on the parallels...

The actual distance between two parallels at latitude $\phi$ is equal to:

$$dN = R \, d\phi$$

He made it equal to:

$$dN = R \, \sec \phi \, d\phi$$
Mercator Projection

By integrating the last formula we get: (sphere)

\[
N = \int_{0}^{\varphi} R \cdot \sec \varphi \cdot d\varphi = R \int \tan \left(45^\circ + \frac{\varphi}{2}\right)
\]
Mercator Projection

- Spherical Formulas

\[ E = R(\lambda - \lambda_0) \]
\[ N = R \ln \tan(\pi / 4 + \phi / 2) \]
Mercator Projection

Ellipsoidal Formulas

Easting

\[ E = a(\lambda - \lambda_0) \]

Northing

\[ N = a \ln \left( \tan \left( \frac{\pi}{4} + \frac{\phi}{2} \right) \frac{1 - e \sin \phi}{1 + e \sin \phi} \right)^{e/2} \]

P(\varphi_e, \lambda_e) → WGS’84

P(E_e, N_e) → Ellipsoidal Formulas
Mercator Projection

- Spherical Formulas

  Easting: 
  
  \[ E = R(\lambda - \lambda_0) \]

  Northing: 
  
  \[ N = R \ln \tan(\pi/4 + \phi/2) \]

- Ellipsoidal Formulas

  Easting: 
  
  \[ E = a(\lambda - \lambda_0) \]

  Northing: 
  
  \[ N = a \ln \left[ \tan(\pi/4 + \phi/2) \left( \frac{1 - e \sin \phi}{1 + e \sin \phi} \right)^{e/2} \right] \]
Adopt Mercator Projection

Request (where/what/resolution)

CLIENT

HTTP

SERVER

Map Product

O Ellipsoid Coordinates
O Mercator Projection

Map Repository (Data+Images)
Web Mercator

- Make it even less computational expensive
  - Ellipsoid Coordinates – Spherical Formulas

\[ P(\varphi_e, \lambda_e) \]

\[ P(\varphi_s, \lambda_s) \]

\[ WGS'84 \]

\[ Sphere \]

\[ Web Mercator \]

\[ Spherical Formulas \]

\[ P(E, N) \]
Online Map Service Providers

Web Mercator Projection
Web Mercator (vs) Mercator

- Mercator basic properties are lost
  - Non-Conformal
  - Loxodromes $\rightarrow$ Not straight lines

- Rationale (Google)
  - Simpler calculations
  - Map to be projected on a computer monitor
  - No body can notice the differences
Criticism

- Geodesy Subcommittee of the Oil and Gas Producers (aka EPSG) rejected it in 2008 as "technically flawed" & "an inappropriate geodesy and cartography"

- National Geospatial-Intelligence Agency of the US Department of Defense declared it as "unacceptable for any official use, because a general lack of understanding of its properties has caused considerable confusion and misuse"
A Code for Web Mercator

- An unofficial code “900913” (GOOGLE spelled with numbers) was initially assigned.

- Later, EPSG introduced an official identifier: EPSG:3857 – WGS84 Web Mercator (Auxiliary Sphere)
Web Mercator Map of the World

- Absolute **square**...

- Very convenient in panning, tiling, and indexing
Online Map Service Providers

Challenges?

- Technological
- Cartographical
How to deliver the map product?

CLIENT

HTTP Request
(where/what/resolution)

SERVER

Map Repository
(Data+Images)

Map Service

Map Product

WWW

↑↓
How to deliver the map product?

One map?

SERVER

↓↑

Map Service

↓↑

Map Repository
(Data+Images)

Web Mercator
How to deliver the map product?

One map?

Map product:
Various areas

Web Mercator

SERVER

Map Service

Map Repository
(Data+Images)
How to deliver the map product?

One map?

Map product:
Various resolution
How to deliver the map product?

One map?

SERVER

↓↑

Map Service

↓↑

Map Repository
(Data+Images)

Map product:
Various theme
Various language
One map?

Multiple themes
Multiple Languages

On-the-fly rendering?

SERVER

Map Service

Map Repository
(Data+Images)
On-the-fly generalization?
Use of Map Tiles

Request (where/what/resolution)

CLIENT

HTTP

SERVER

Map Product

Map Service

Map Repository (Data+Images)

Preprocessing → generation of map tiles

One map → not an option
Online Map Service Providers

Raster Tile Maps
Use of Map Tiles

Request
(where/what/resolution)

CLIENT

HTTP

SERVER

Map Product

Preprocessing → generation of tiles

Map Repository
(Data+Images)
Tiled maps

- A series of precompiled maps...
  - for... various areas
  - in... various resolutions

Map Repository
(Data+Images)
Tiled maps – An old practice

- Old practice...
- Sheet Division and Organization of Topographic maps

Map Repository
(Data+Images)
Sheet Division & Organization

- Topographic Maps
Sheet Division & Organization

- NRCan: National Topographic Map Index
Web Mapping → Tiled Maps

- Web mapping
  - rapid growth of map data availability
  - rapid growth of demand

- Use of map tiles (slippy maps)
  - pre-computation and caching of map image tiles
  - map servers use far fewer resources than maps rendered on demand
  - delivery only limited by the bandwidth of the connection with the map server
Tiled Maps

- Google...
  - was the first major mapping provider to adopt the tiled web maps

- Others followed...
  - Bing and OpenStreetMap, Esri and Oracle
    - provide functionality for map tiling and caching of vector layers and/or raster images
Google Maps

- Conventions...
  - All map tiles
    - Square-shaped and equal-sized
    - 256x256 pixels
  - World rendered in a single tile at the outermost zoom level: 0
  - Projection: Web Mercator
    - Latitude values [-85.0511, +85.0511] degrees
Google Maps

Zoom Level: 0  
Number of Tiles: 1

Zoom Level: 1  
Number of Tiles: 4

Zoom Level: 2  
Number of Tiles: 16
Bing Maps

- Quadtree encoding: Quadkeys
Google Maps – Zoom Level [0-24]
Google: (0,0)  
TMS: (0,0)  
QuadTree:  
Zoom 0

to Zoom Level 23...

http://www.maptiler.org/google-maps-coordinates-tile-bounds-projection/
#Tiles & Pixel size / Zoom Level

Each tile: 256x256 pixels

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>TILES/LEVEL</th>
<th>Pixel Size (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>156,543.034</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>78,271.517</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>39,135.758</td>
</tr>
<tr>
<td>3</td>
<td>64</td>
<td>19,567.879</td>
</tr>
<tr>
<td>4</td>
<td>256</td>
<td>9,783.940</td>
</tr>
<tr>
<td>5</td>
<td>1,024</td>
<td>4,891.970</td>
</tr>
<tr>
<td>6</td>
<td>4,096</td>
<td>2,445.985</td>
</tr>
<tr>
<td>7</td>
<td>16,384</td>
<td>1,222.992</td>
</tr>
<tr>
<td>8</td>
<td>65,536</td>
<td>611.496</td>
</tr>
<tr>
<td>9</td>
<td>262,144</td>
<td>305.748</td>
</tr>
<tr>
<td>10</td>
<td>1,048,576</td>
<td>152.874</td>
</tr>
<tr>
<td>11</td>
<td>4,194,304</td>
<td>76.437</td>
</tr>
<tr>
<td>12</td>
<td>16,777,216</td>
<td>38.219</td>
</tr>
<tr>
<td>14</td>
<td>268,435,456</td>
<td>9.555</td>
</tr>
<tr>
<td>15</td>
<td>1,073,741,824</td>
<td>4.777</td>
</tr>
<tr>
<td>16</td>
<td>4,294,967,296</td>
<td>2.389</td>
</tr>
<tr>
<td>17</td>
<td>17,179,869,184</td>
<td>1.194</td>
</tr>
<tr>
<td>18</td>
<td>68,719,476,736</td>
<td>0.597</td>
</tr>
<tr>
<td>19</td>
<td>274,877,906,944</td>
<td>0.299</td>
</tr>
<tr>
<td>20</td>
<td>1,099,511,627,776</td>
<td>0.149</td>
</tr>
<tr>
<td>21</td>
<td>4,398,046,511,104</td>
<td>0.075</td>
</tr>
<tr>
<td>22</td>
<td>17,592,186,044,416</td>
<td>0.037</td>
</tr>
<tr>
<td>23</td>
<td>70,368,744,177,664</td>
<td>0.019</td>
</tr>
<tr>
<td>24</td>
<td>281,474,976,710,656</td>
<td>0.009</td>
</tr>
</tbody>
</table>

\[
4^\text{LEVEL} \cdot \frac{2\pi R}{(256 \cdot 2^\text{LEVEL})}
\]

GRS80 (eq) 6,378,137.00 m
Circumference (2\pi R) 40,075,016.69 m
Map Tile Management

Interoperability across multiple Map Providers

http://docs.opengeospatial.org/wp/16-019r4/16-019r4.html
Online Map Service Providers

Web Mercator Projection

Raster Tile Maps
References


