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School of Engineering

DEPARTMENT OF
GEOMATICS
ENGINEERING

Online Map Service Providers

Mapping the Globe using Tiled Maps

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Online Map Service Providers

- Available for ~15 years
- Well established (difficult to remember how life was without them)



mapquest

Bing  esri



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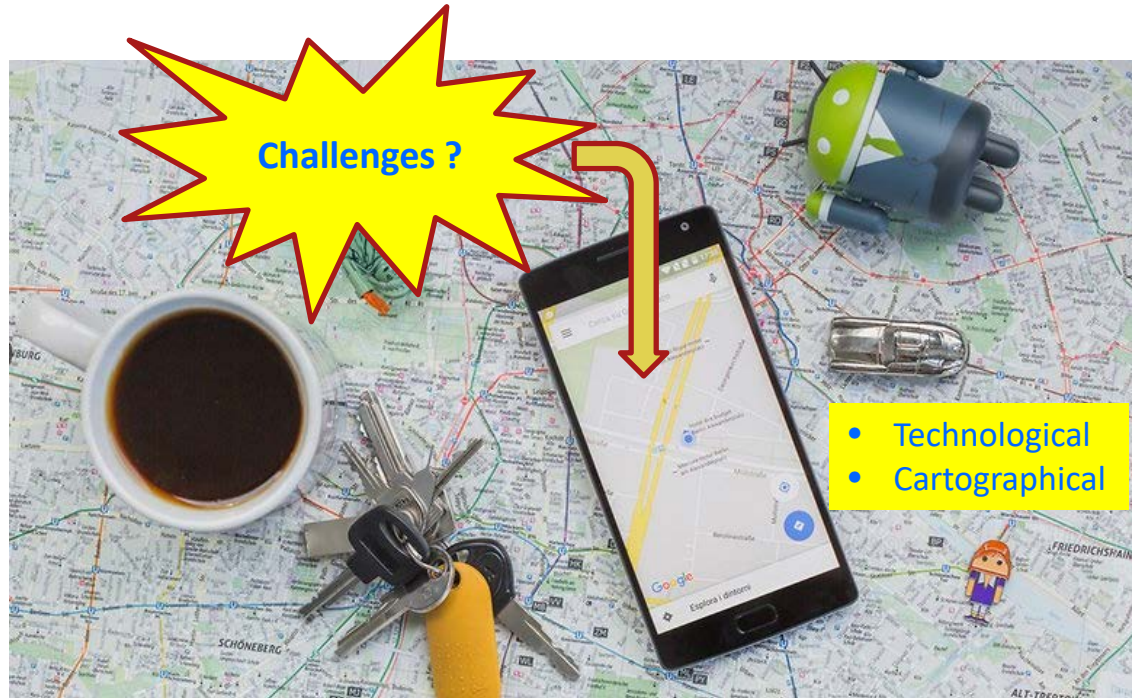
VS





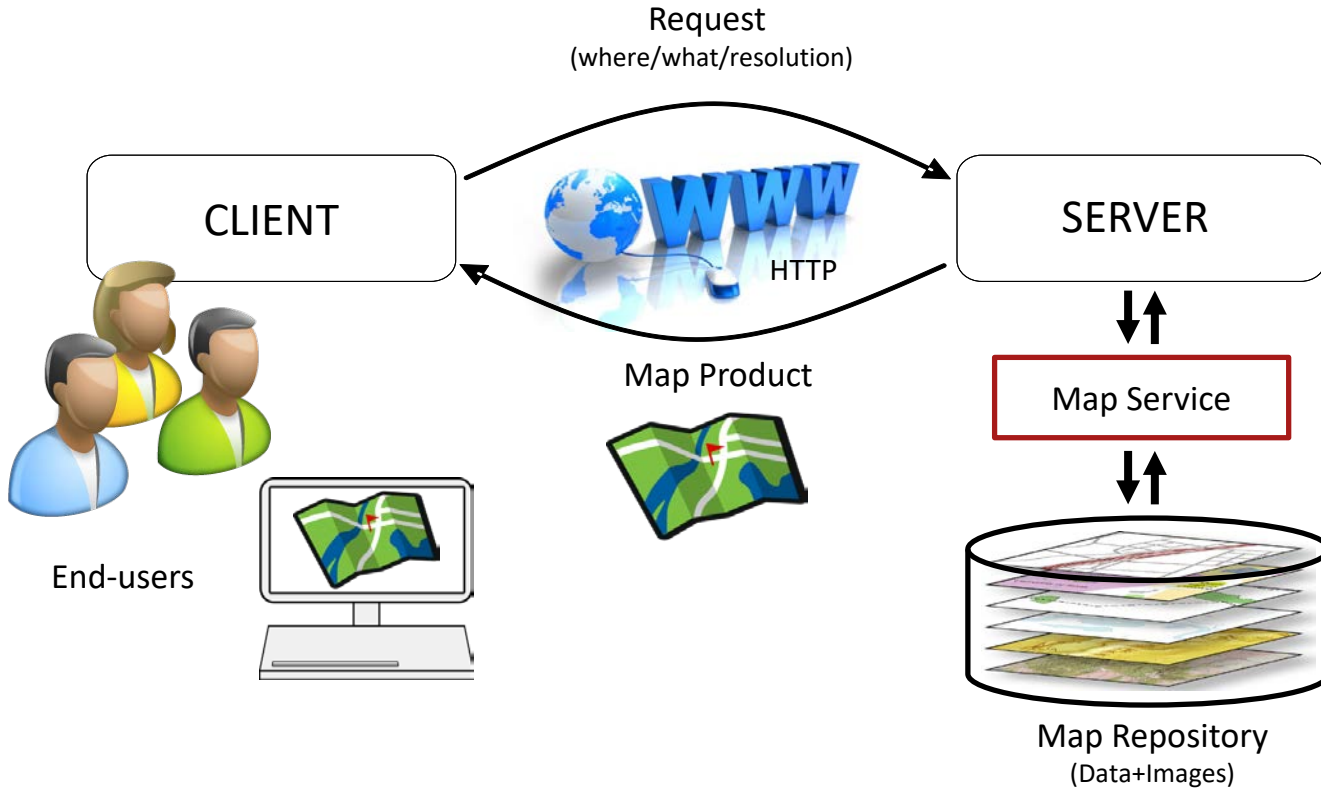
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Online Map Service Providers Framework



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



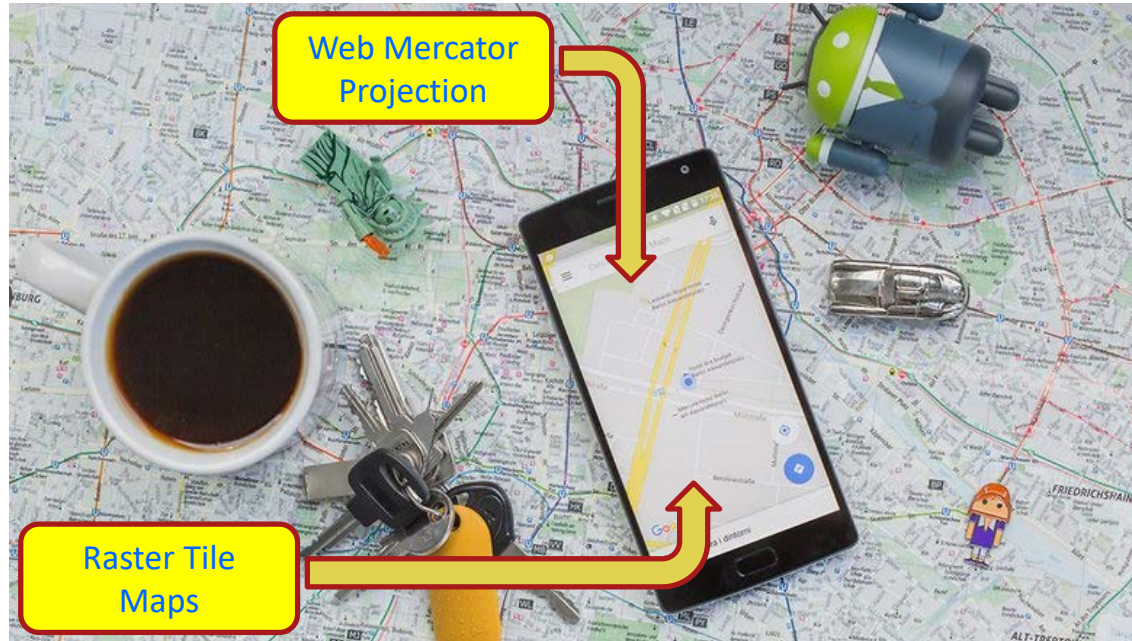


- Visualize the map on Web browser
 - flat/rectangular monitor
- Multi-resolution representation
 - various zoom levels
- Multi-theme mapping
 - various themes (layers)
- Multi-language mapping
 - various languages



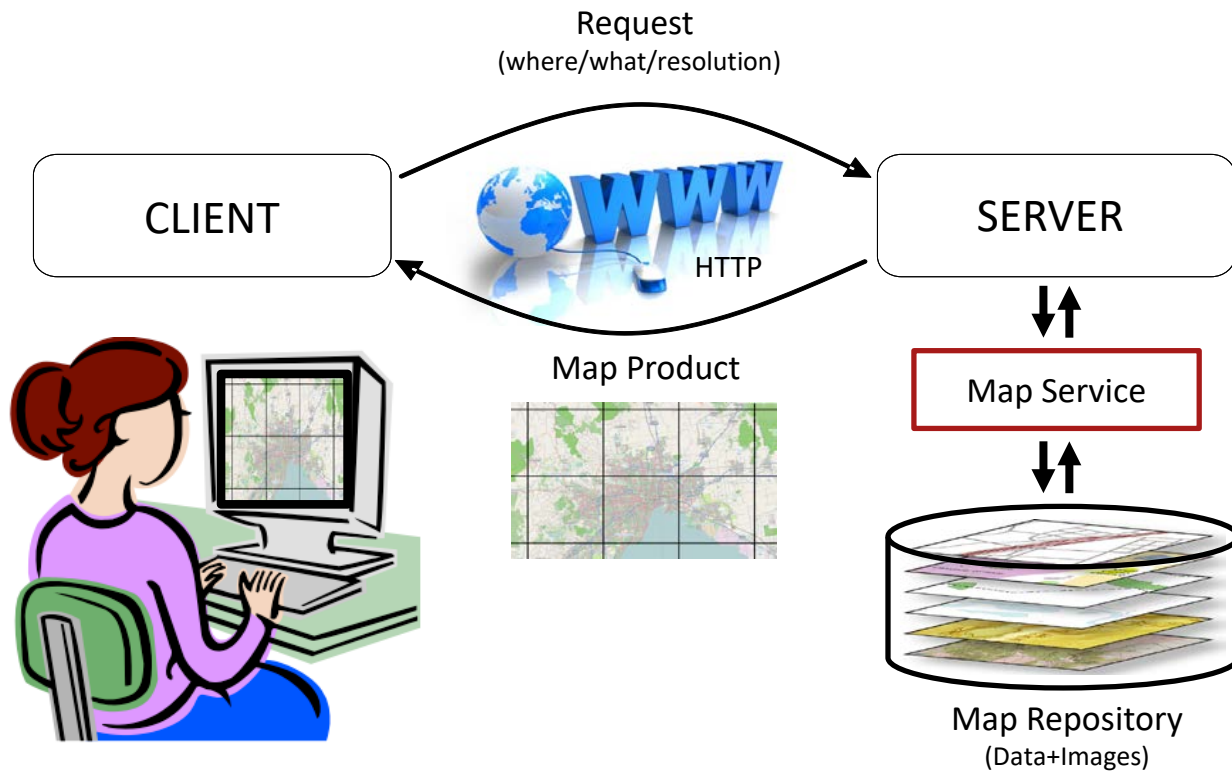
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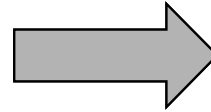
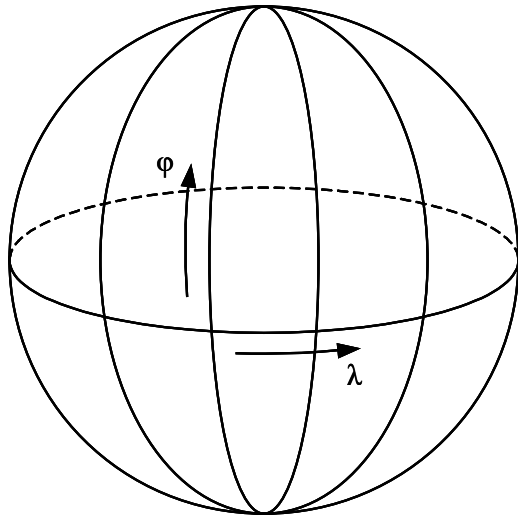




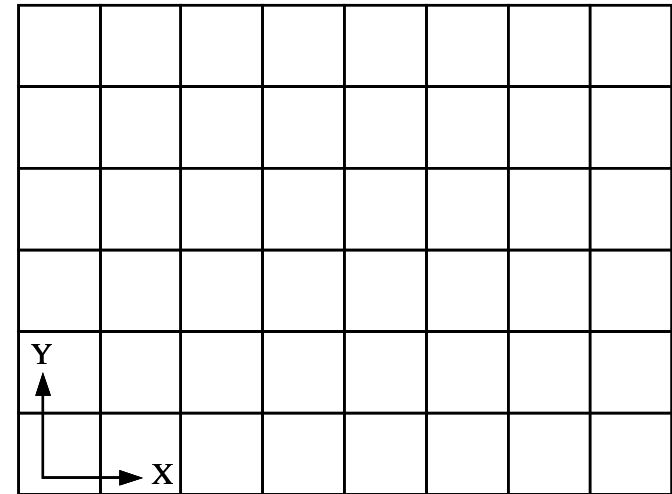
Map Product → Flat Screen



- A function f ...

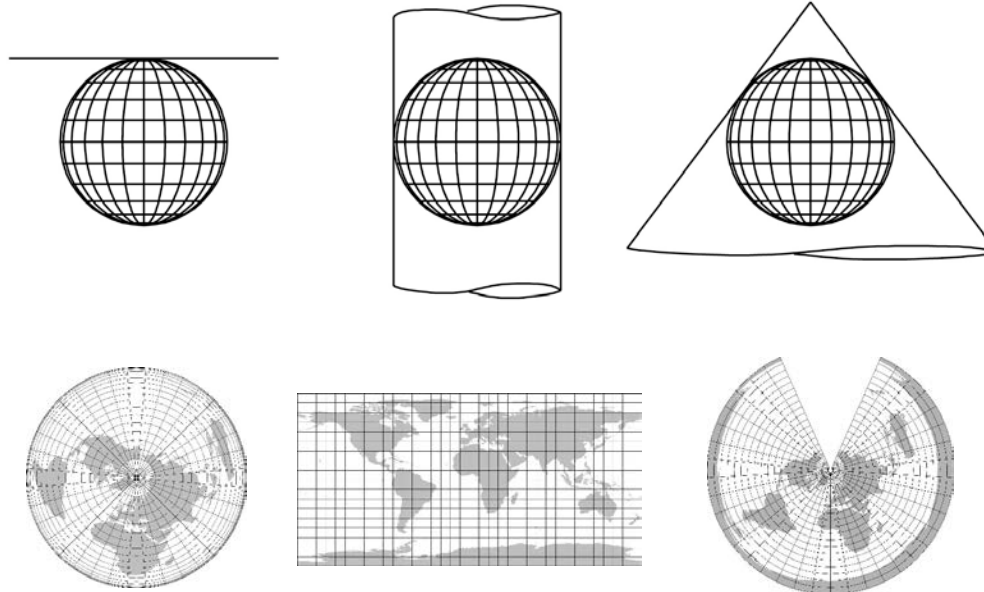


$$(X, Y) \leftarrow f(\varphi, \lambda)$$



From the Sphere to the Plane

- Use an intermediate surface (**projective surface**)...



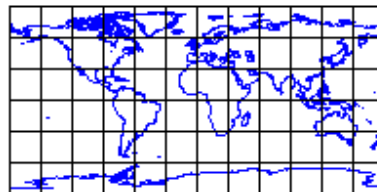


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Choose a Map Projection



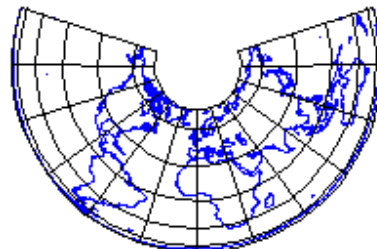
Cylindric



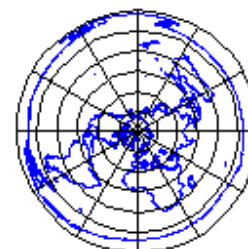
Pseudocylindric



Conic



Planar





Choose a Cylindrical

Cylindrical

Pseudocylindrical

Conic

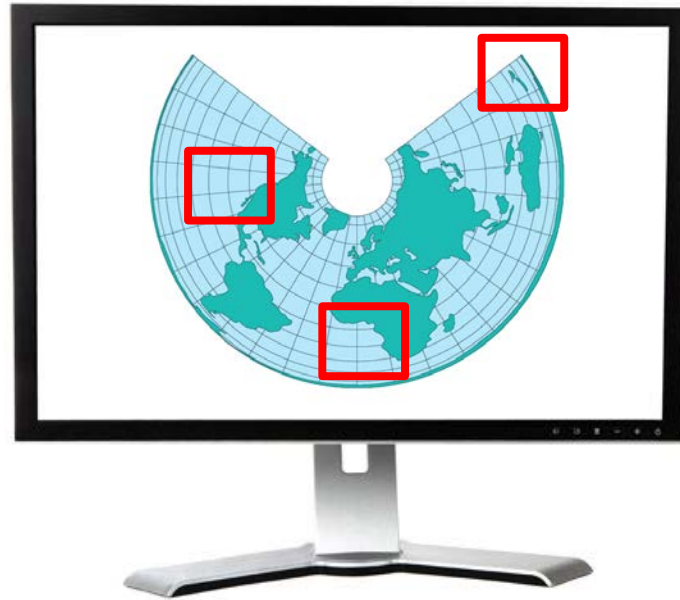
Planar

- Best fit
- Rectangular grid

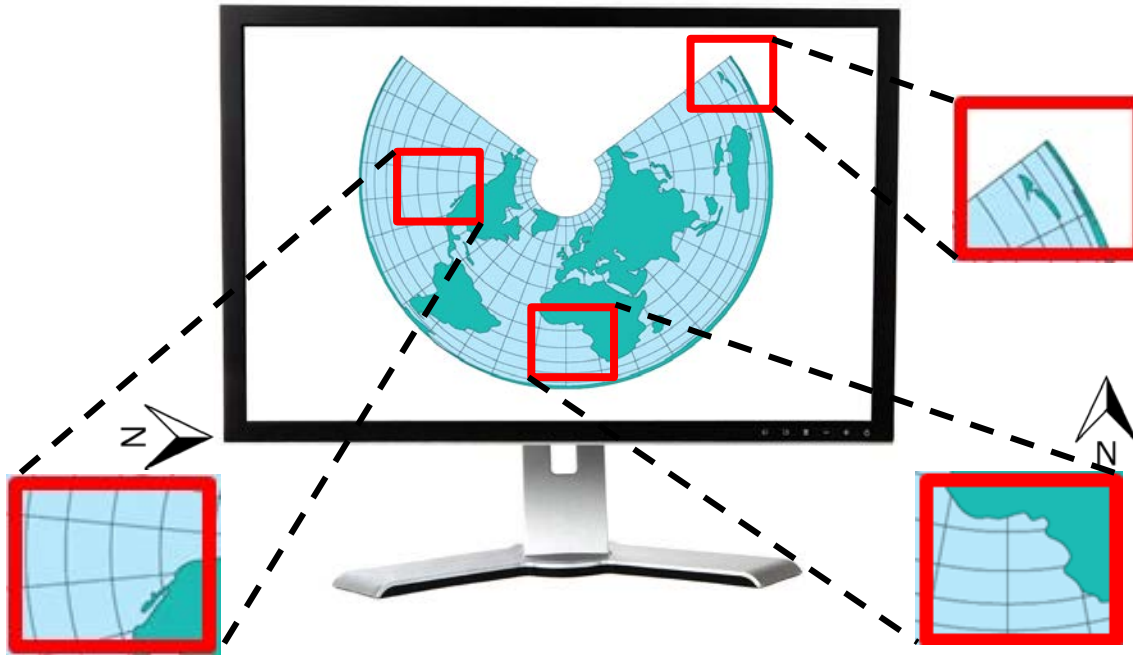


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Conical Projection ?



Conical Projection ?



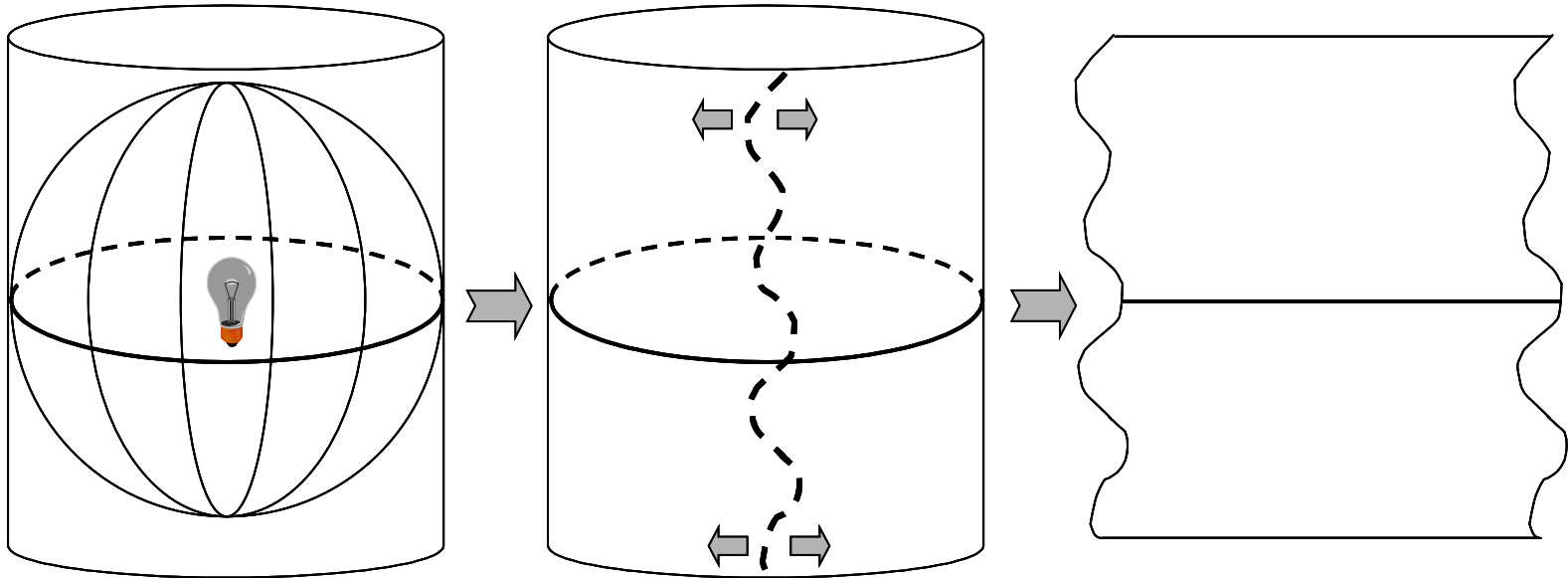


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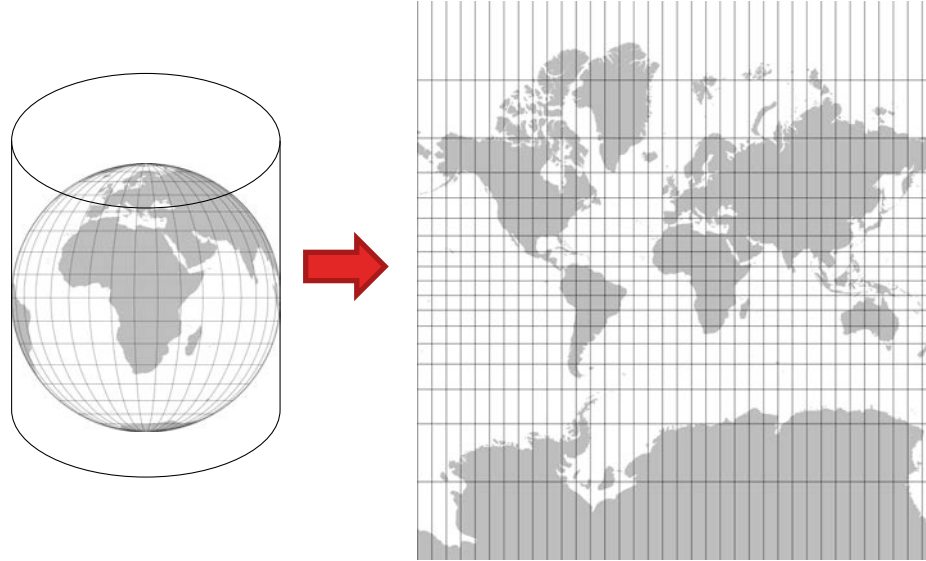
Cylindrical Projection ?



- Simulation of a cylindrical projection



- Simulation of a cylindrical projection





Which Cylindrical?

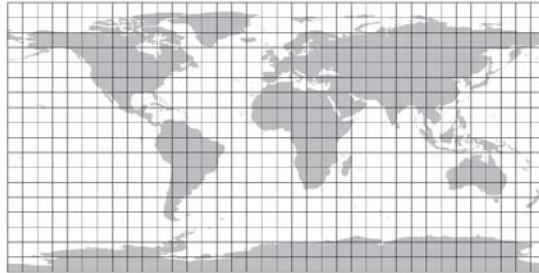
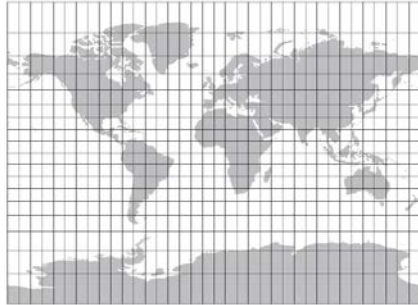
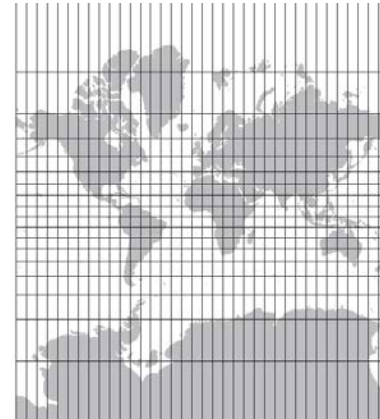


Plate Carree



Miller's



Mercator

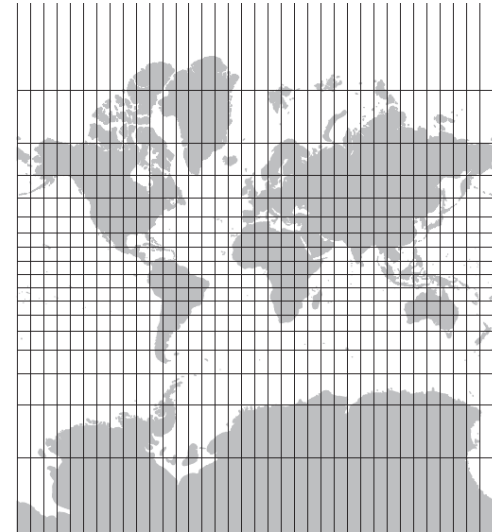




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Mercator Projection

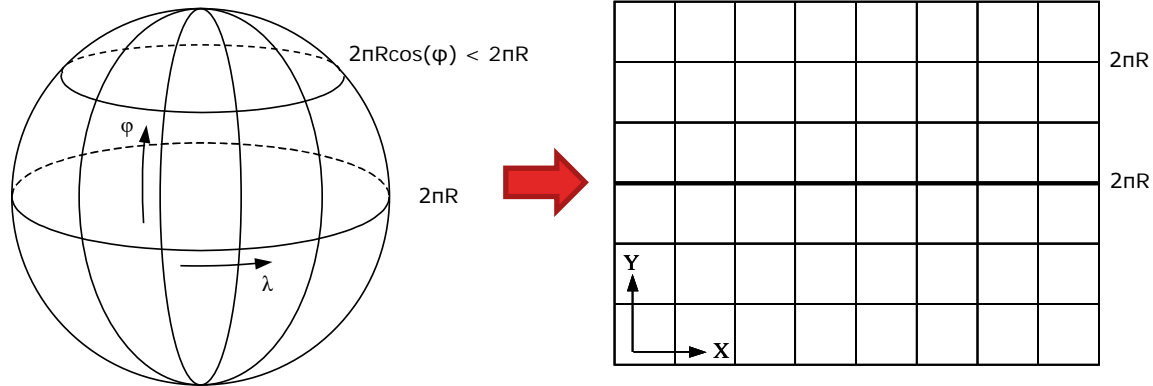
- Most popular
- Conformal
- Easy math (low complexity)
 - ...to serve high demand



- Conformal
- Support navigation in Seas



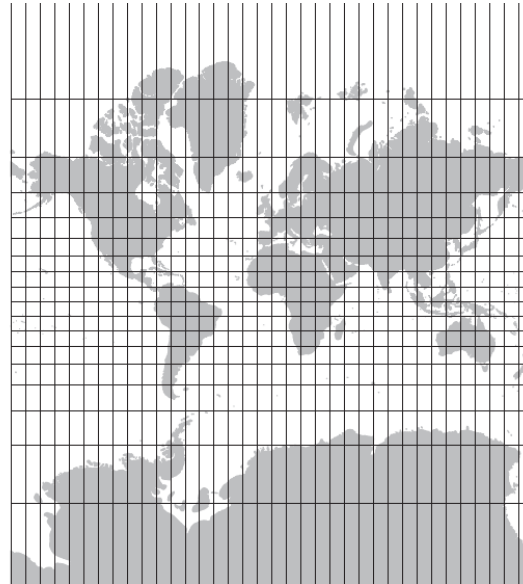
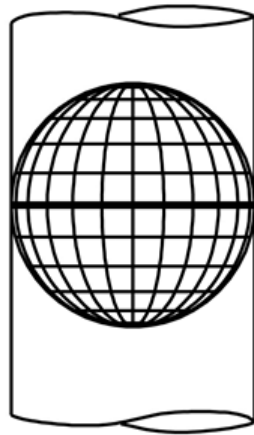
1512-1594





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Mercator Projection



$2\pi R$

$2\pi R$



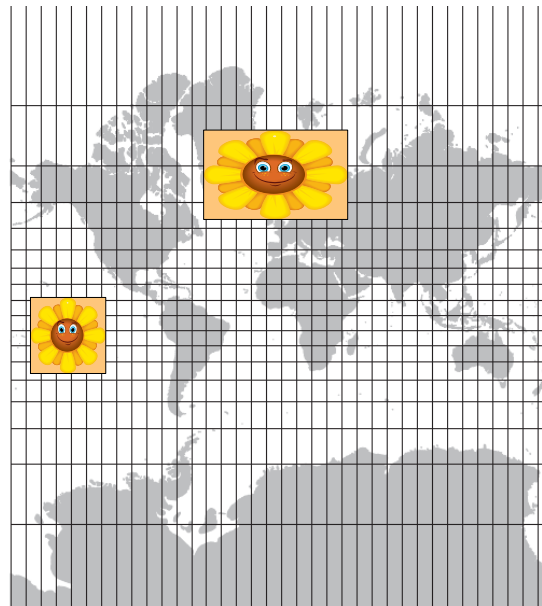
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Mercator Projection

Scale factor on **horizontal**
(along parallels at φ):

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

Mercator's goal \rightarrow *preserve
shapes/directions*





Mercator Projection

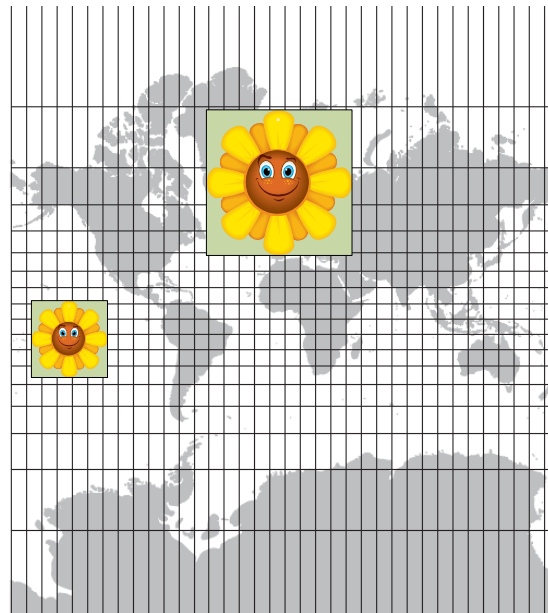
Scale factor on
horizontal (along
parallels at φ):

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

Mercator applied...

Scale factor on **vertical**
(along meridians at φ):

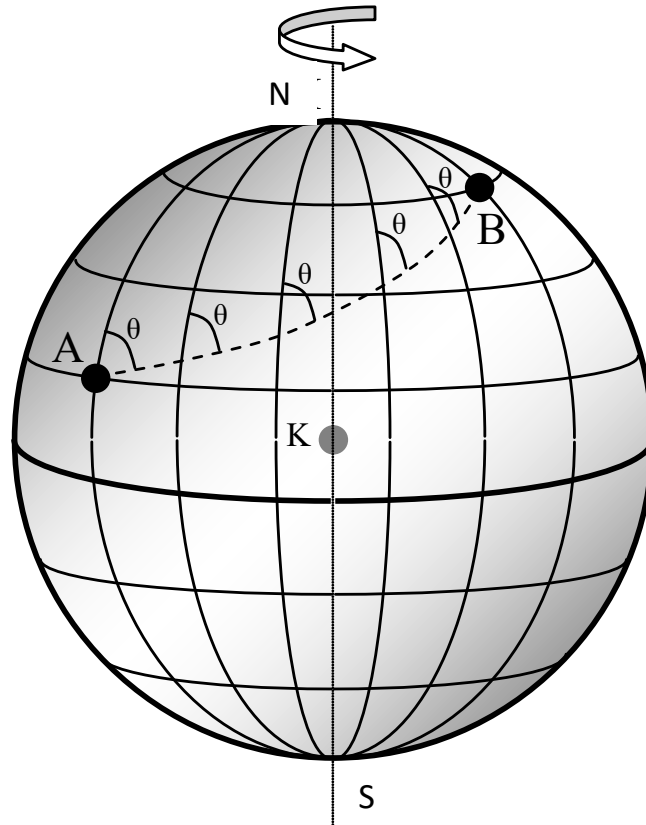
$$2\pi R \cos(\varphi) \rightarrow 2\pi R$$





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Loxodrome



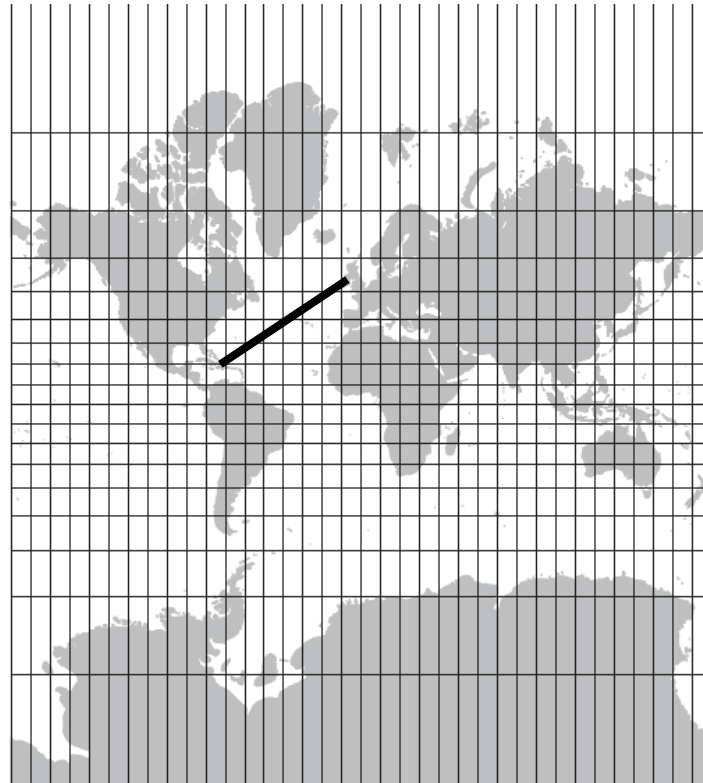
equator





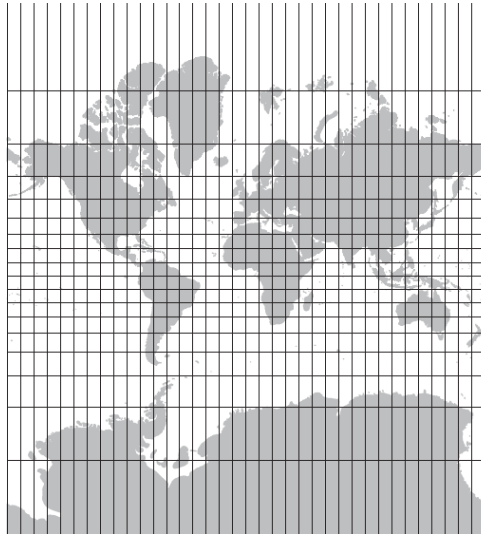
Mercator Projection

- Pros:
 - The loxodromes are straight lines(!)
- Cons:
 - Huge distortions in areas, distances
 - Africa = 14 x Greenland





Mercator Projection



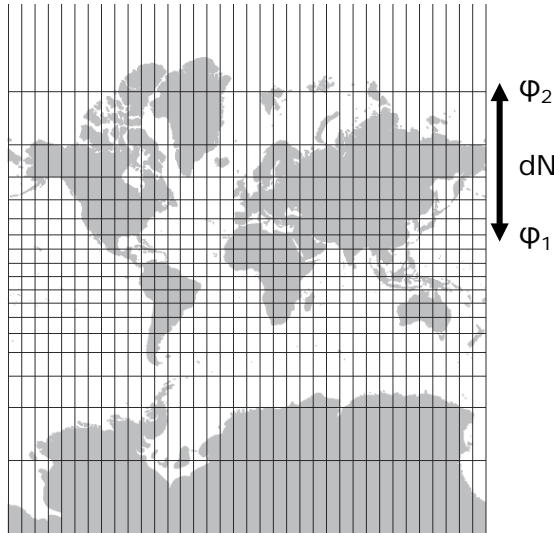
φ

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

At latitude φ the **scale factor** on the **parallel** is equal to:

$$\frac{2\pi \cdot R}{2\pi \cdot R \cos \varphi} = \sec \varphi$$

Mercator Projection



Mercator applied the **same factor** on the **parallels**...

The actual distance between two parallels at latitude ϕ is equal to:

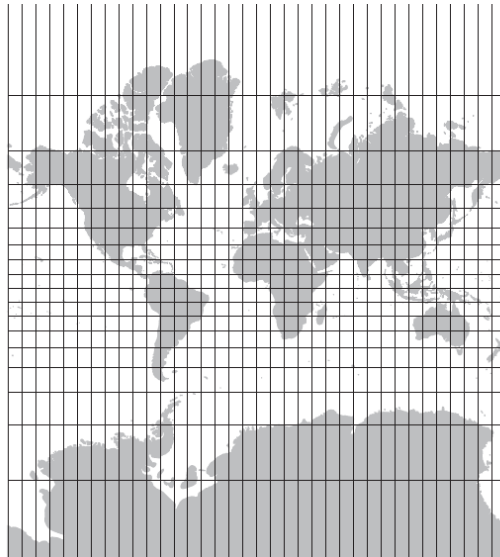
$$dN = R d\phi$$

He made it equal to:

$$dN = R \sec\phi d\phi$$

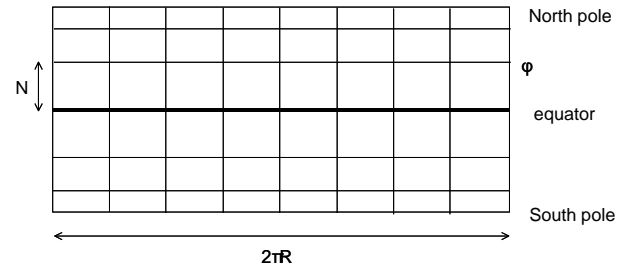


Mercator Projection



By integrating the last formula we get: **(sphere)**

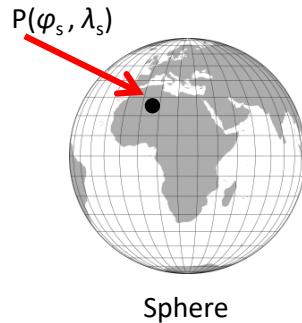
$$N = \int_0^{\varphi} R \cdot \sec\varphi \cdot d\varphi = R \ln \tan \left(45^\circ + \frac{\varphi}{2} \right)$$



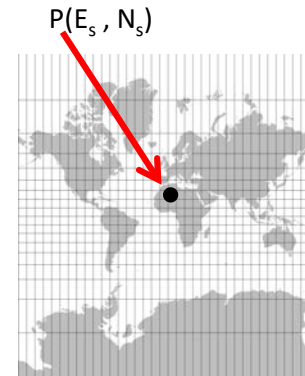
■ Spherical Formulas

Easting $E = R(\lambda - \lambda_0)$

Northing $N = R \ln \tan(\pi/4 + \phi/2)$



Spherical Formulas

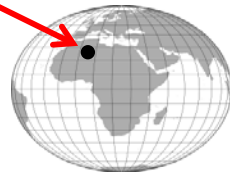


■ Ellipsoidal Formulas

Easting $E = a(\lambda - \lambda_0)$

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

$P(\phi_e, \lambda_e)$



WGS'84

Ellipsoidal Formulas

$P(E_e, N_e)$





■ Spherical Formulas

$$\text{Easting} \quad E = R(\lambda - \lambda_0)$$

$$\text{Northing} \quad N = R \ln \tan(\pi/4 + \phi/2)$$



■ Ellipsoidal Formulas

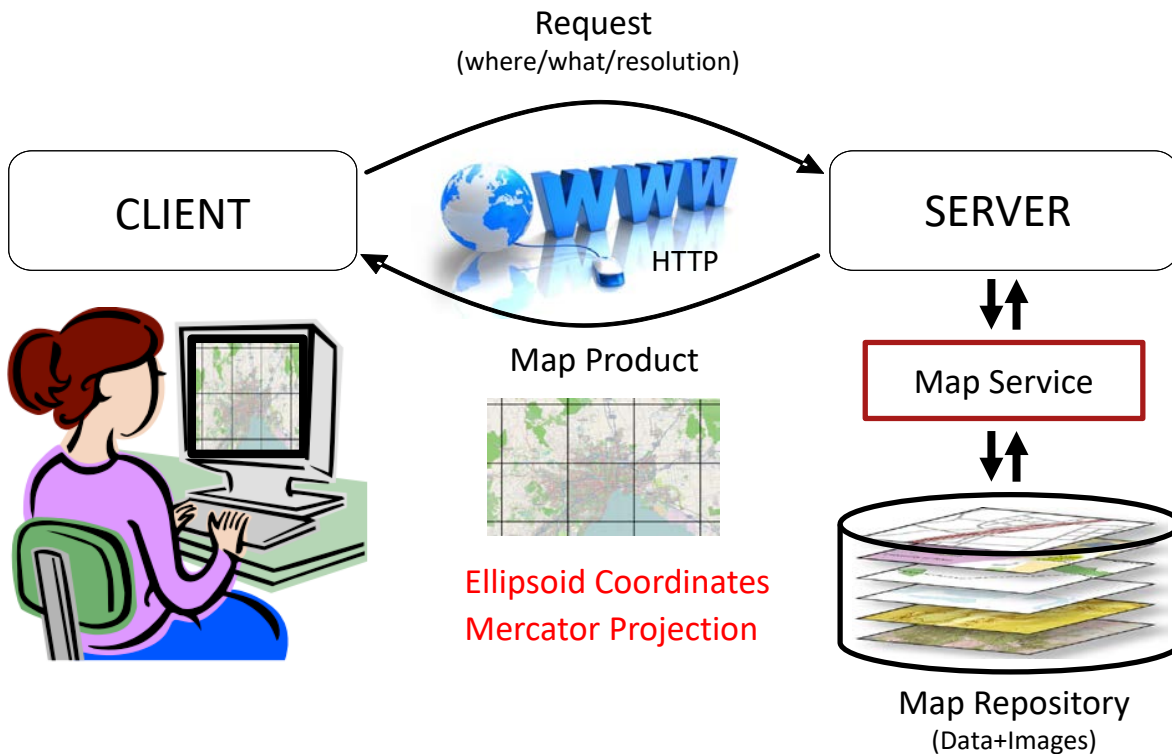
$$\text{Easting} \quad E = a(\lambda - \lambda_0)$$

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

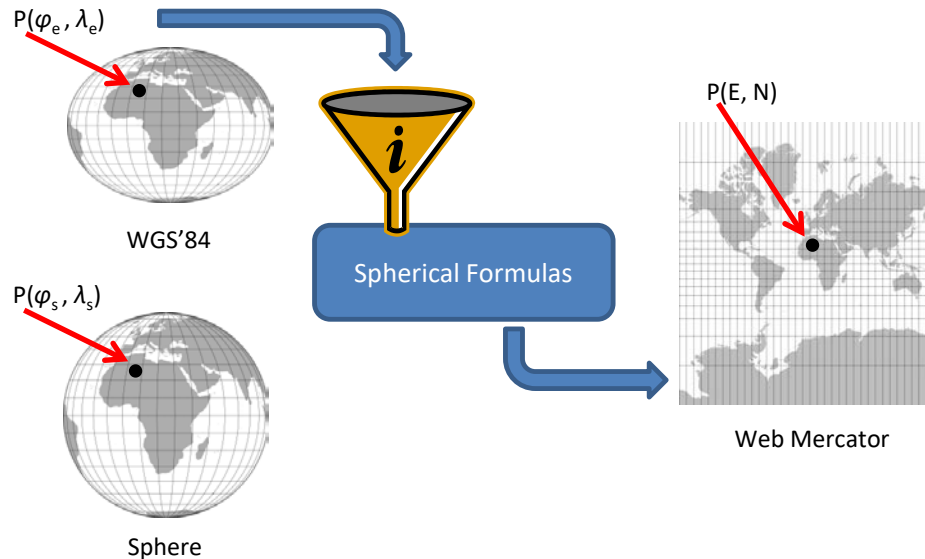




Adopt Mercator Projection



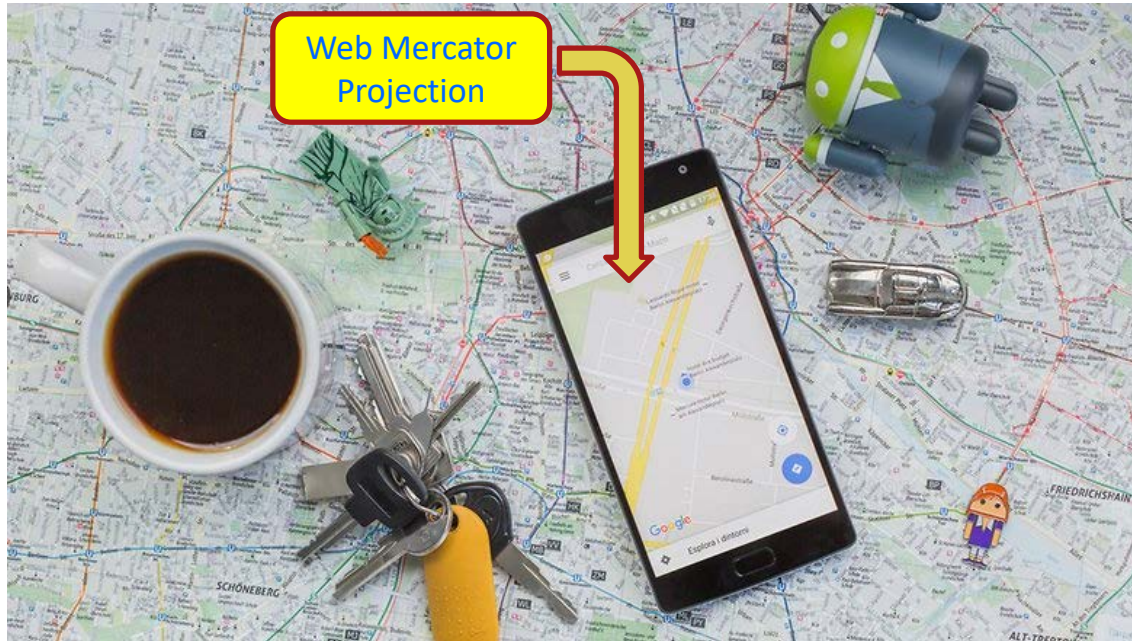
- Make it even less computationally expensive
 - Ellipsoid Coordinates – Spherical Formulas





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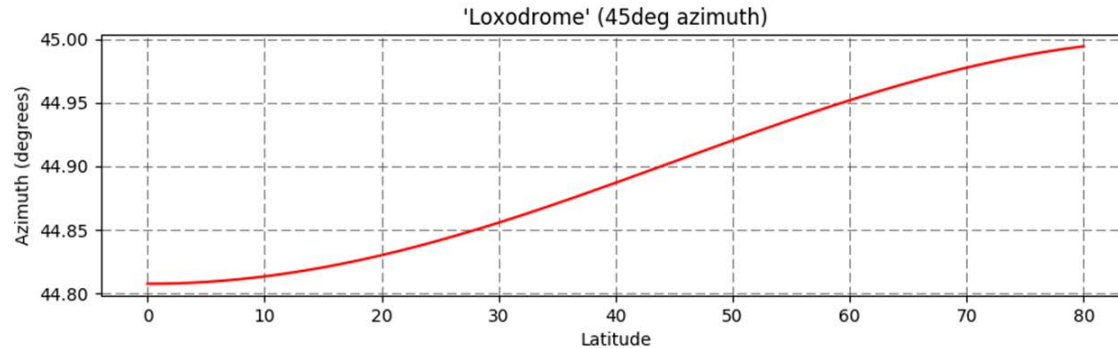
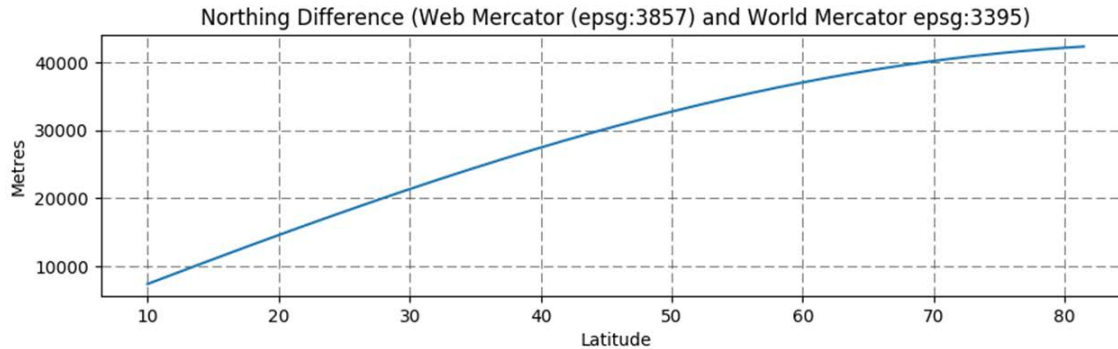




Web Mercator (vs) Mercator

- Mercator basic properties are lost
 - Non-Conformal
 - Loxodromes → Not straight lines
- Rationale (Google)
 - Simpler calculations
 - Map to be projected on a computer monitor or phone
 - No body can notice the differences

Web Mercator (vs) Mercator





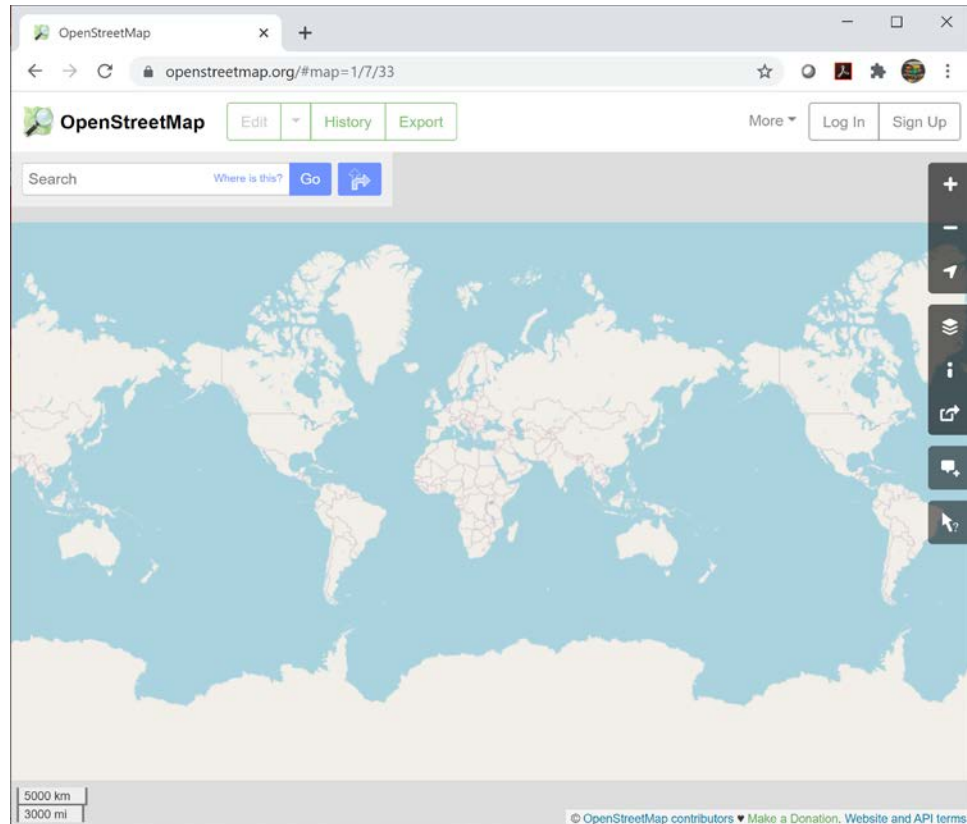
- Geodesy Subcommittee of the Oil and Gas Producers (aka EPSG) rejected it in 2008 as *“technically flawed”* & *“an inappropriate geodesy and cartography”*
- National Geospatial-Intelligence Agency of the US Department of Defense declared it as *“unacceptable for any official use, because a general lack of understanding of its properties has caused considerable confusion and misuse”*

- An unofficial code “**900913**” (GOOGLE spelled with numbers) was initially assigned
- Later, EPSG introduced an official identifier:
EPSG:3857 -- WGS84 Web Mercator (Auxiliary Sphere)



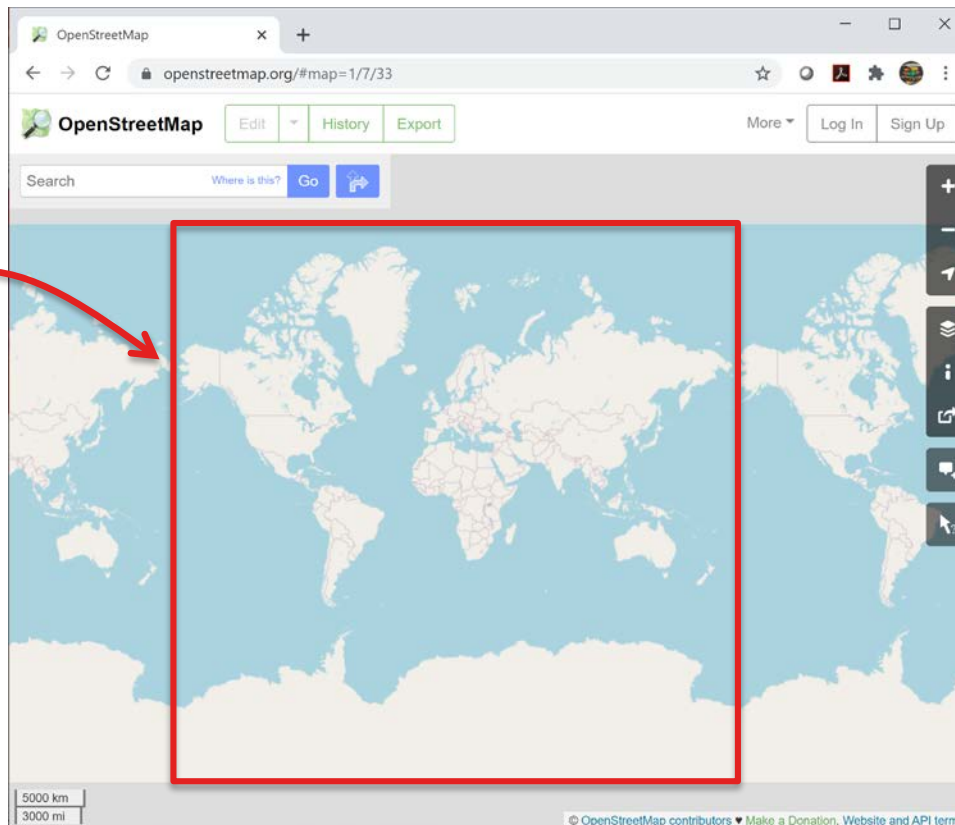
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Web Mercator Map of the World





Web Mercator Map of the World



- Absolute square...



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Web Mercator Map of the World

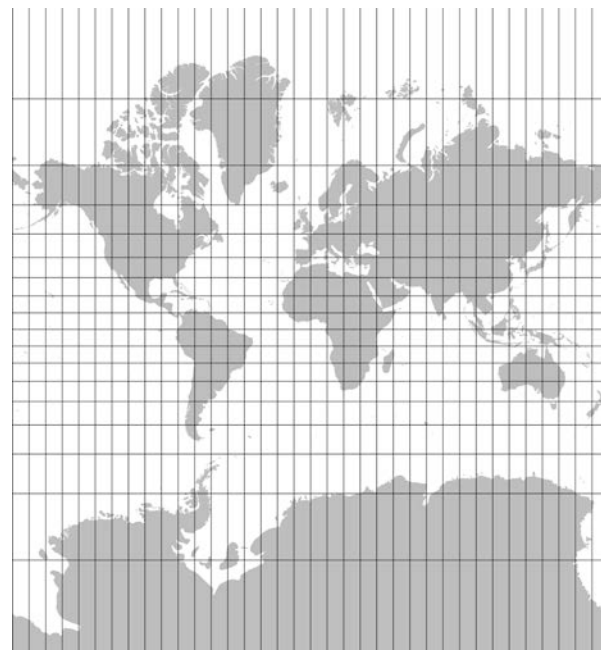
- Absolute **square**...
- Very convenient for panning, tiling, and indexing

85.051129 North →

40,075,017.25

85.051129 South →

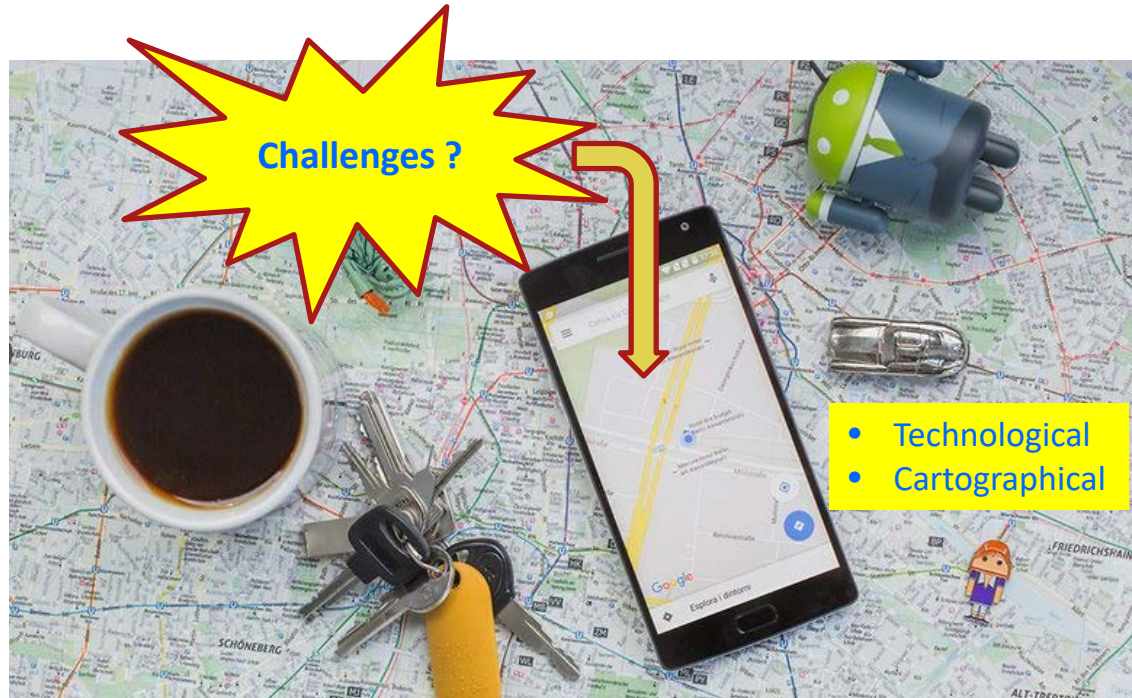
40,075,017.25





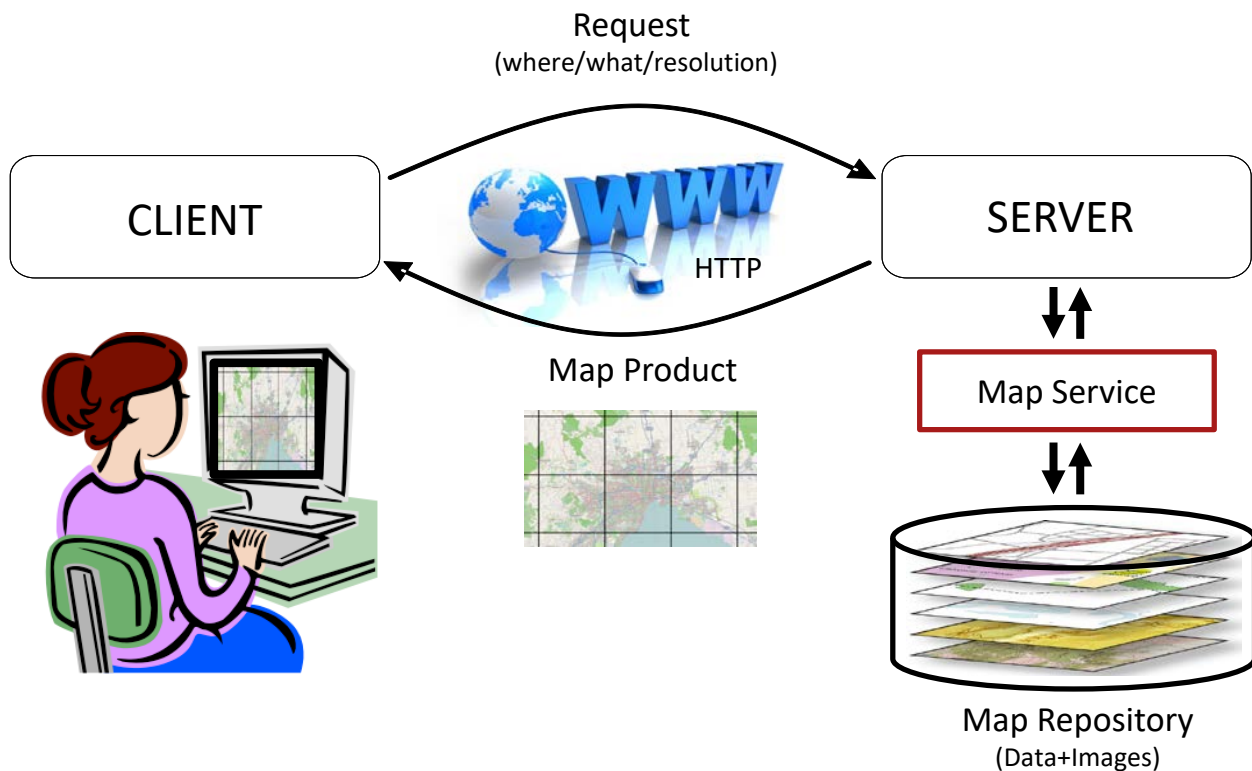
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How to deliver the map product?

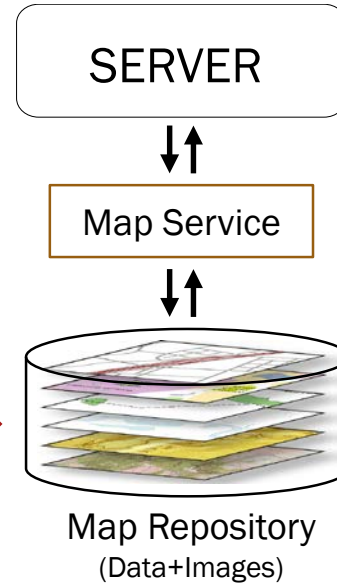


How to deliver the map product?

One map?



Web Mercator





How to deliver the map product?

One map?

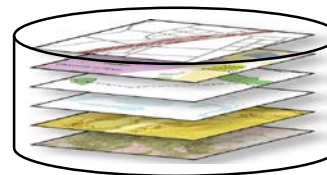


Web Mercator

SERVER



Map Service

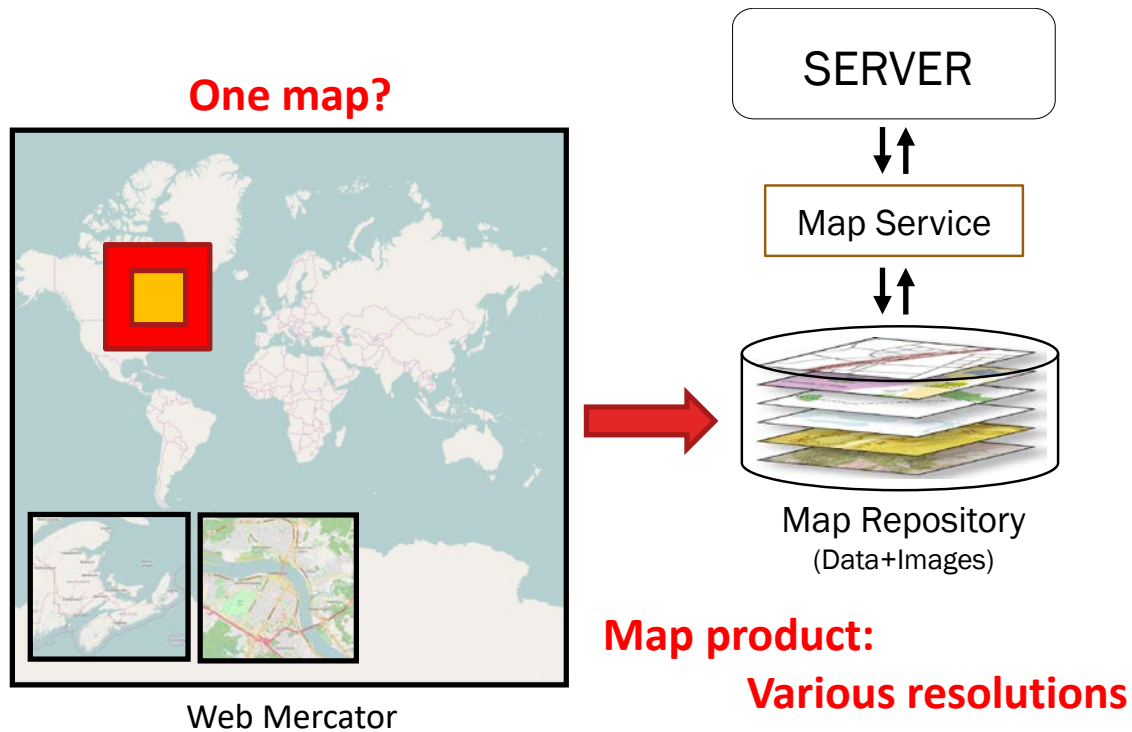


Map Repository
(Data+Images)

**Map product:
Various areas**

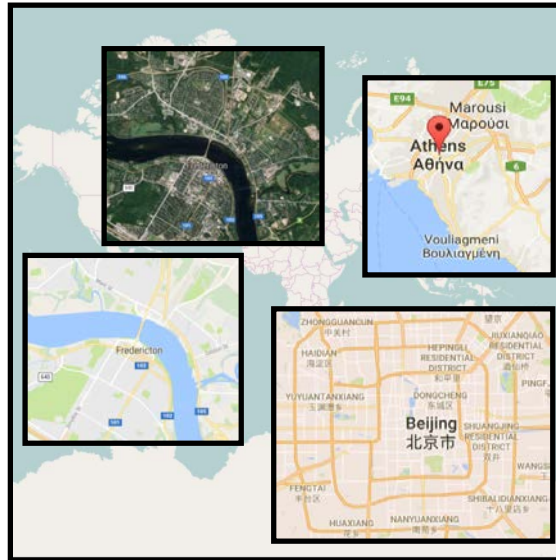


How to deliver the map product?

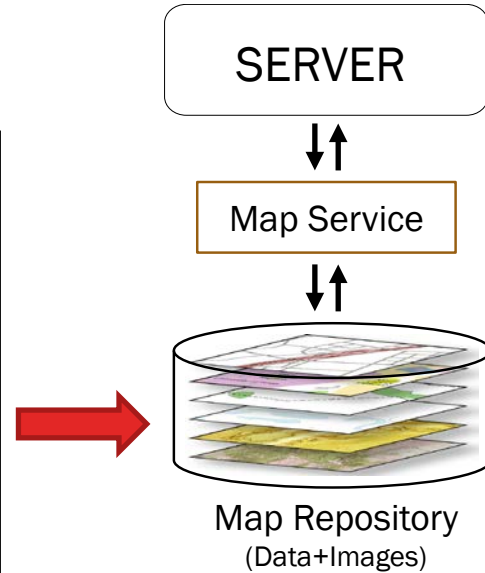


How to deliver the map product?

One map?



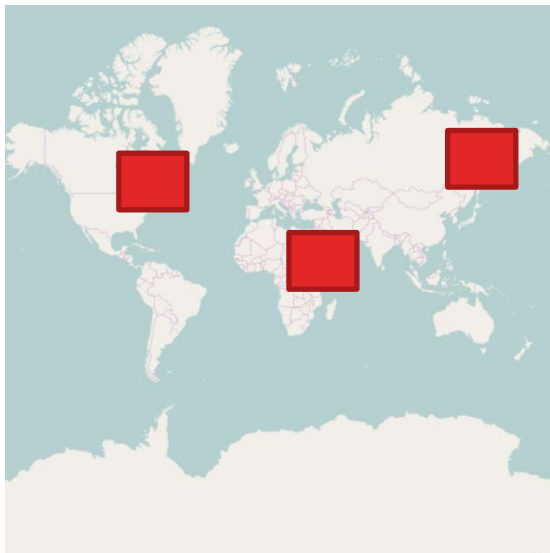
Web Mercator



Map product:
Various themes
Various languages



How to deliver the map product?

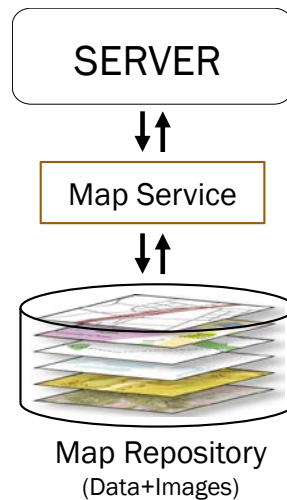


On-the-fly rendering ?



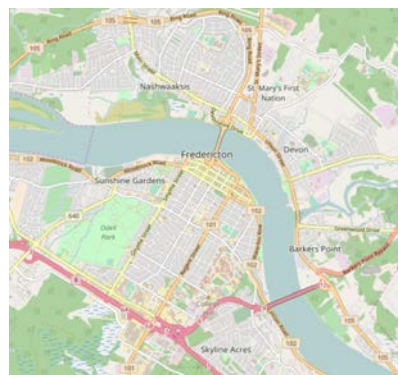
One map ?

Multiple themes
Multiple Languages



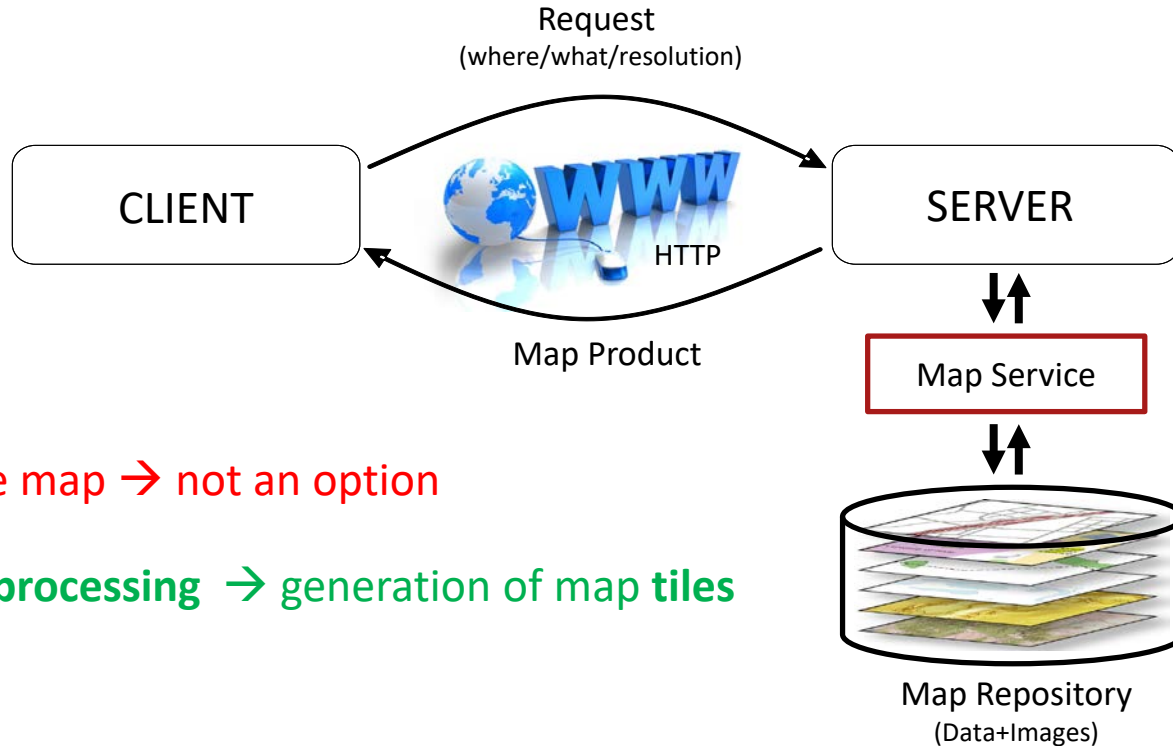


How to deliver the map product?



On-the-fly generalization ?

No!



One map → not an option

Preprocessing → generation of map tiles



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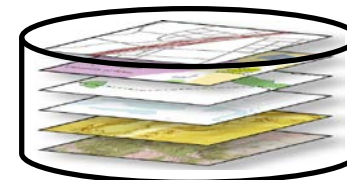
Online Map Service Providers



Raster Tile
Maps



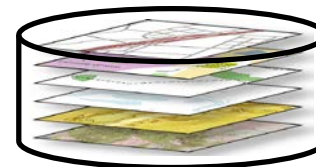
Preprocessing → generation of tiles



Map Repository
(Data+Images)

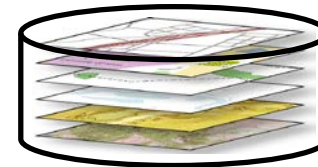


- A series of precompiled maps...
 - for... various areas
 - at... various resolutions (scales)



Map Repository
(Data+Images)

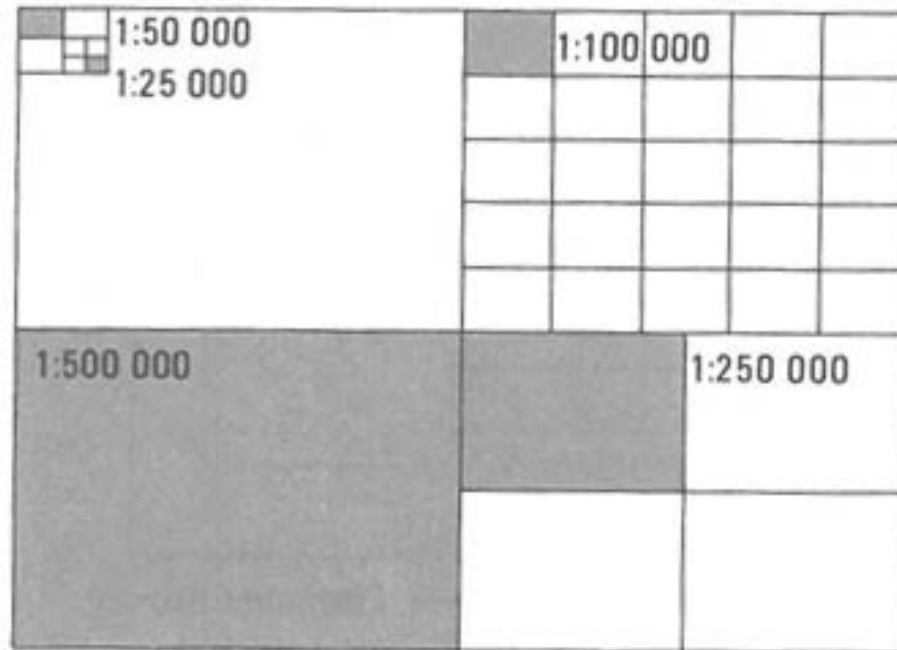
- Old practice...
 - Sheet Division and Organization of Topographic maps



Map Repository
(Data+Images)



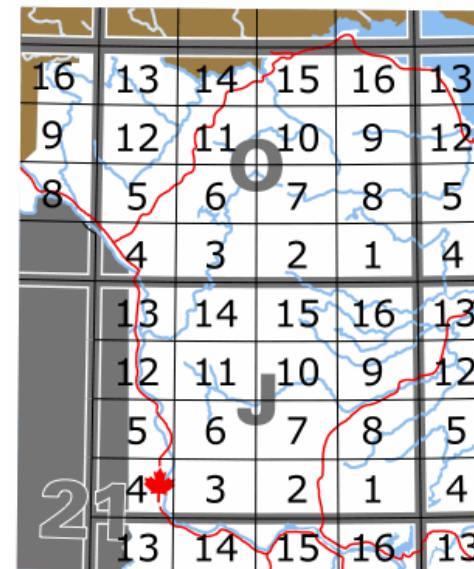
- Topographic Maps





Sheet Division & Organization

- NRCan: National Topographic Map Index





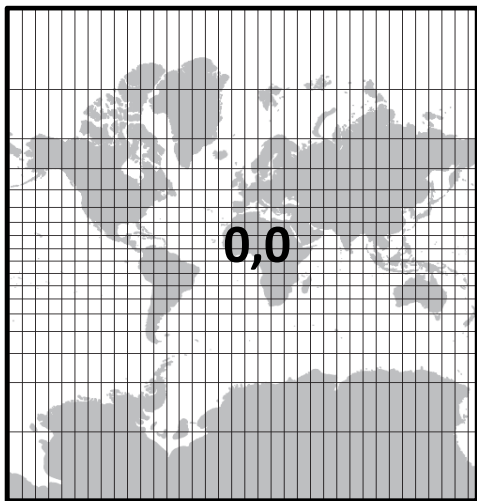
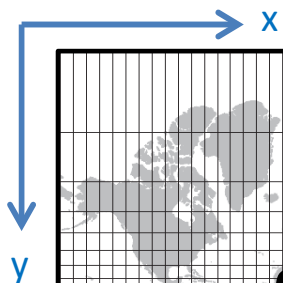
Web Mapping → Tiled Maps

- 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

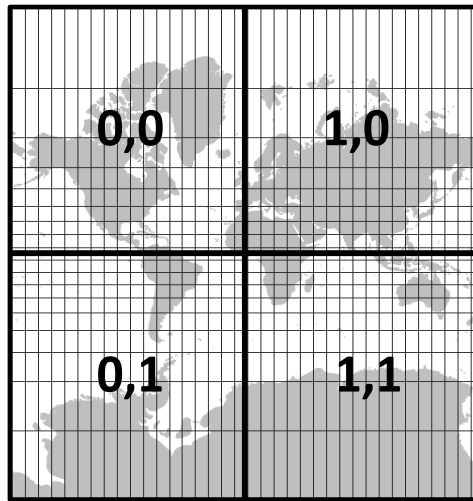


- Google...
 - was the first major mapping provider to adopt the tiled web maps
- Others followed...
 - Bing and OpenStreetMap, Esri and Oracle
 - provide functionality for map tiling and caching of vector layers and/or raster images

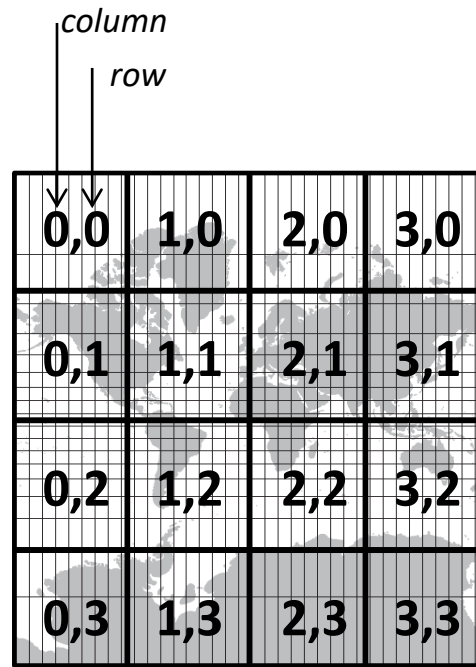
- Conventions...
 - All map tiles
 - Square-shaped and equal-sized
 - **256x256 pixels**
 - World rendered in a single tile at the outer most zoom level: 0
 - Projection: Web Mercator
 - latitude values [-85.0511, +85.0511] degrees



Zoom Level: 0
Number of Tiles: 1



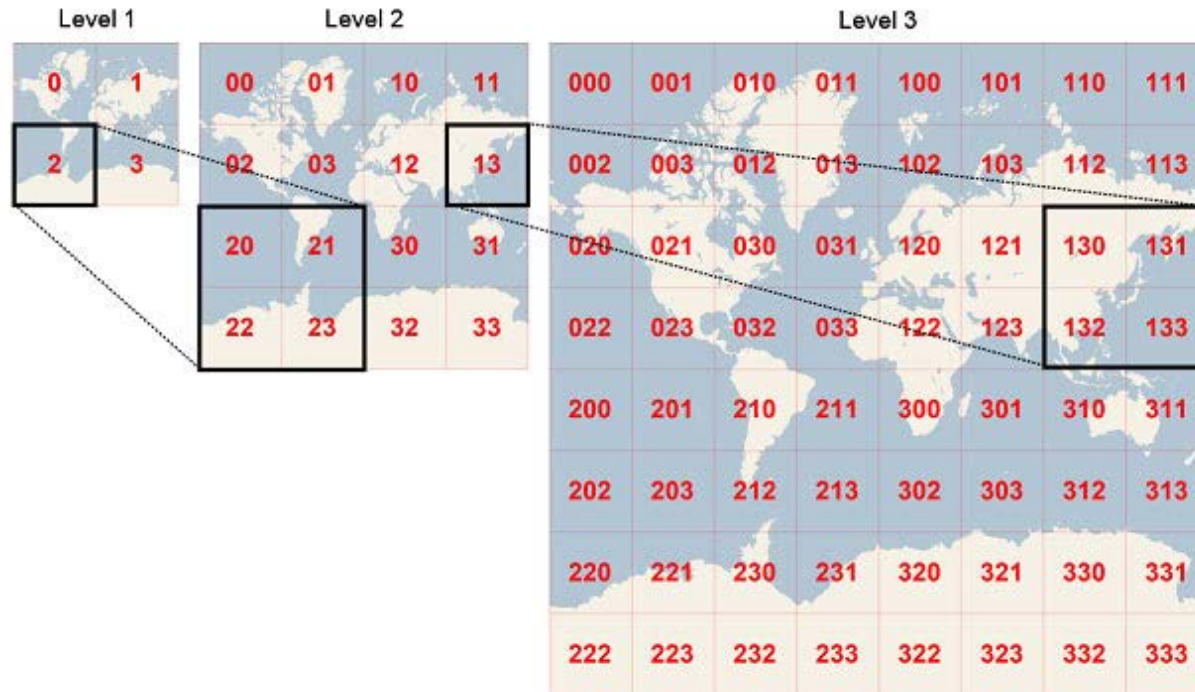
Zoom Level: 1
Number of Tiles: 4



Zoom Level: 2
Number of Tiles: 16

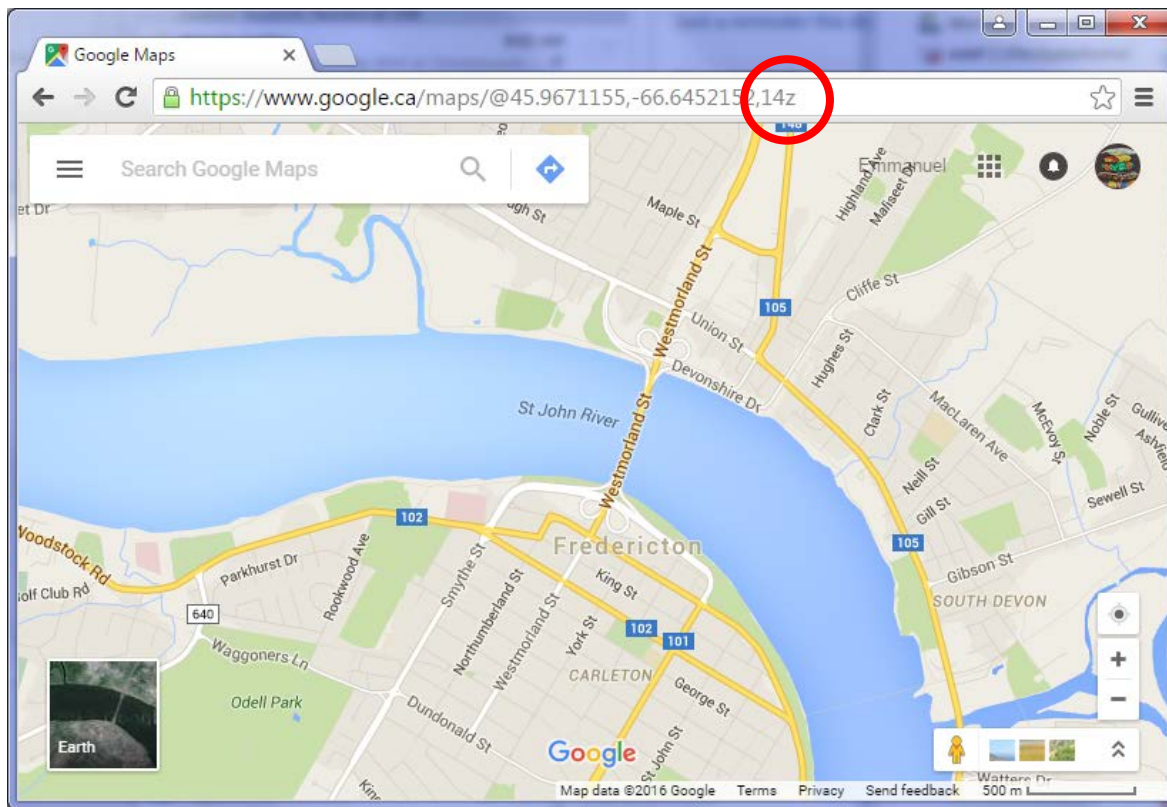


■ Quadtree encoding: Quadkeys

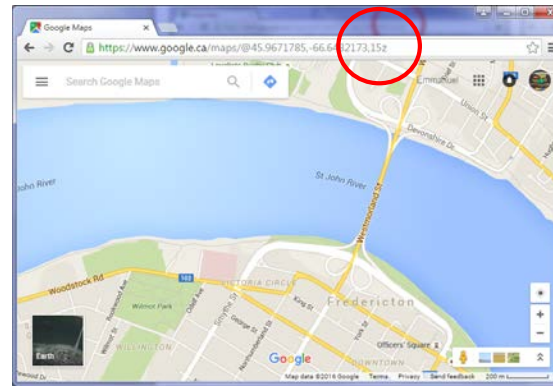
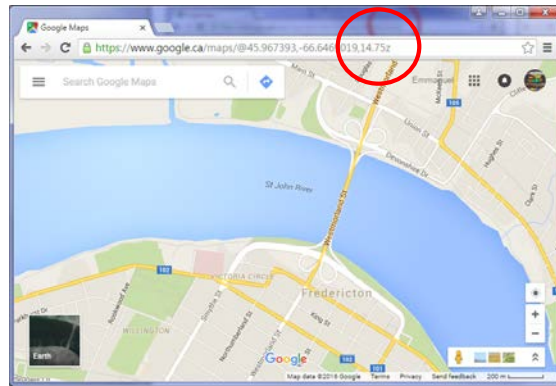
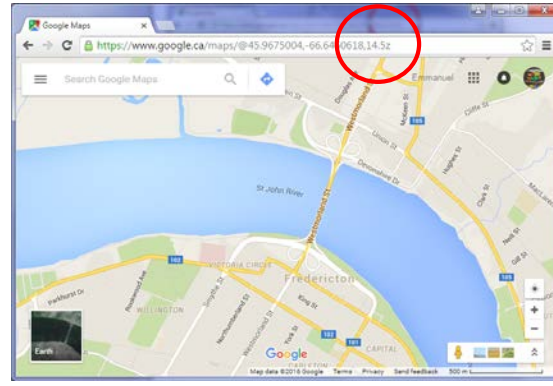
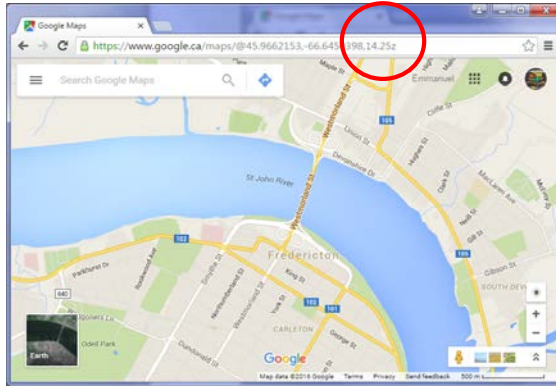




Google Maps – Zoom Level [0-24]



Google Maps – Each Level 4 subdivisions





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Map Tiler App



<http://www.maptiler.org/google-maps-coordinates-tile-bounds-projection/>

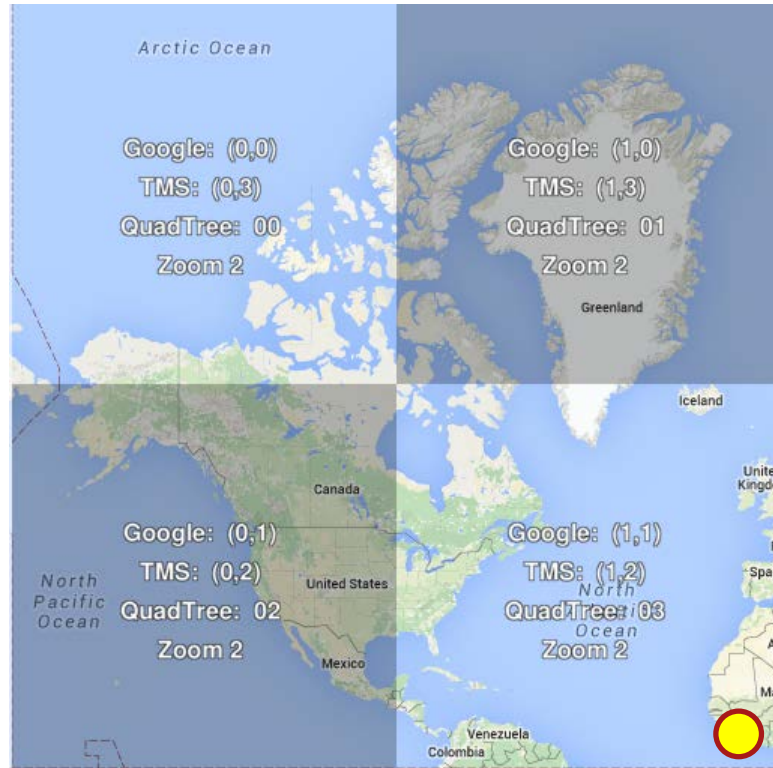


Map Tiler App



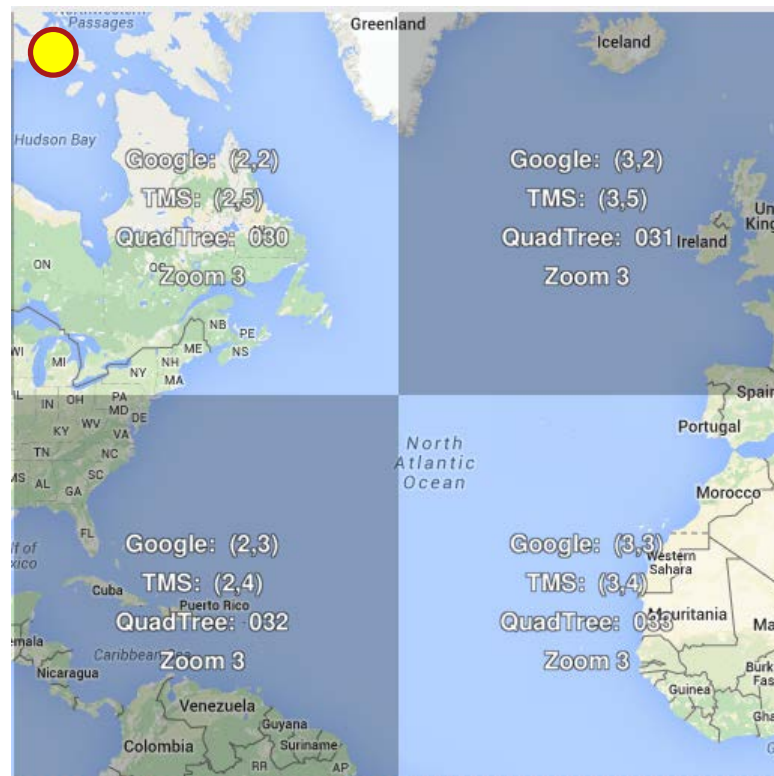


Map Tiler App



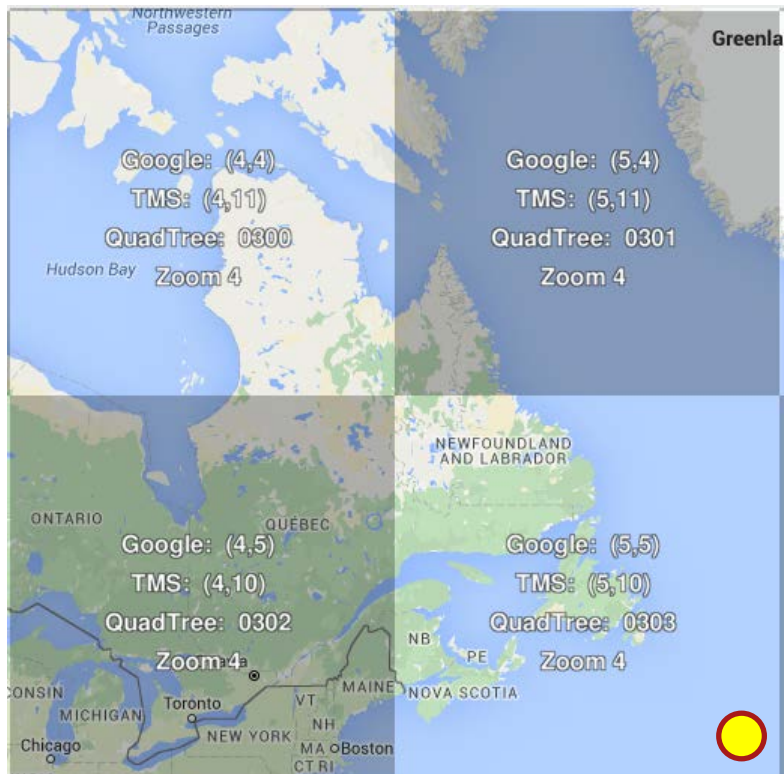


Map Tiler App



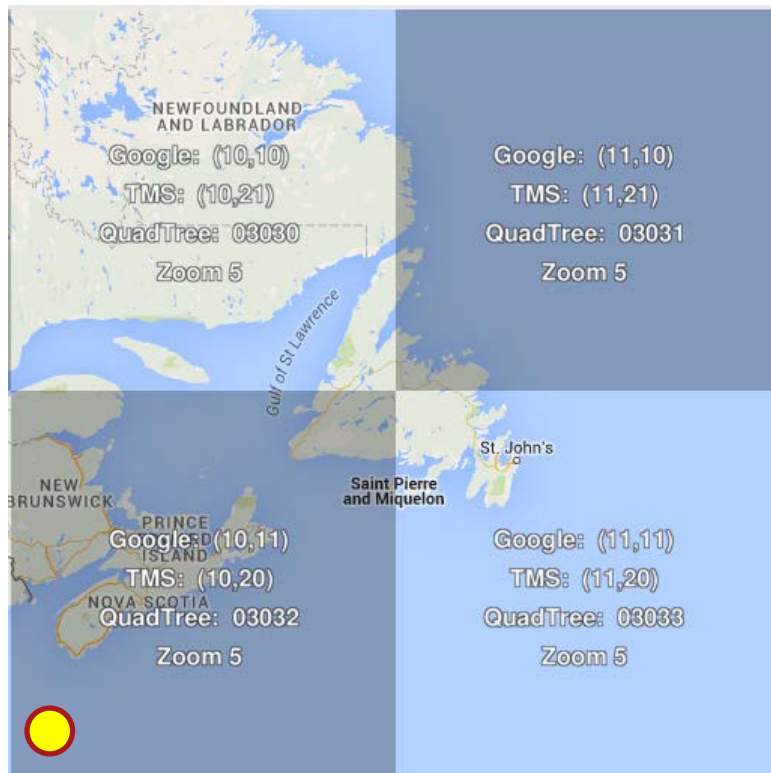


Map Tiler App



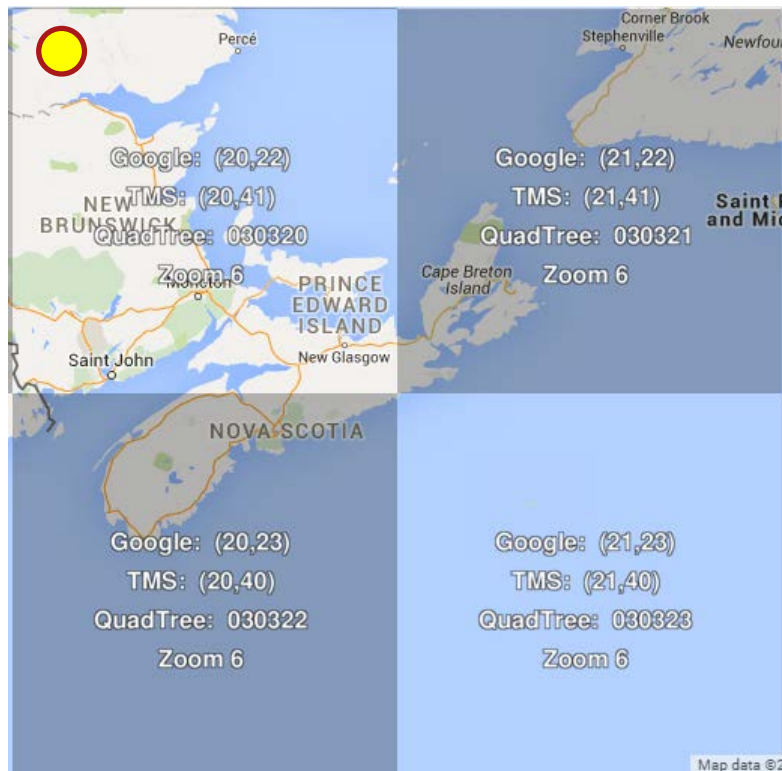


Map Tiler App



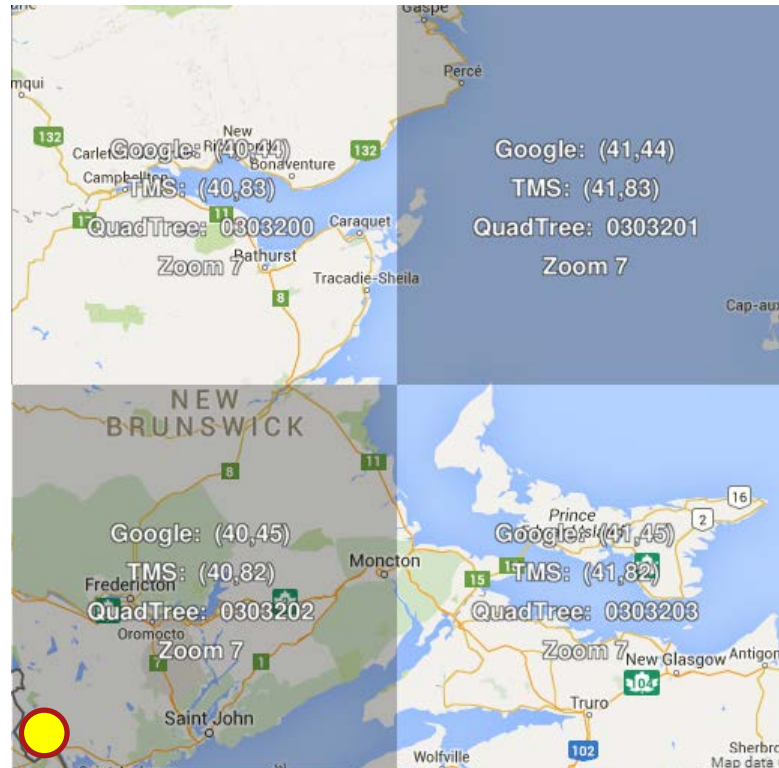


Map Tiler App



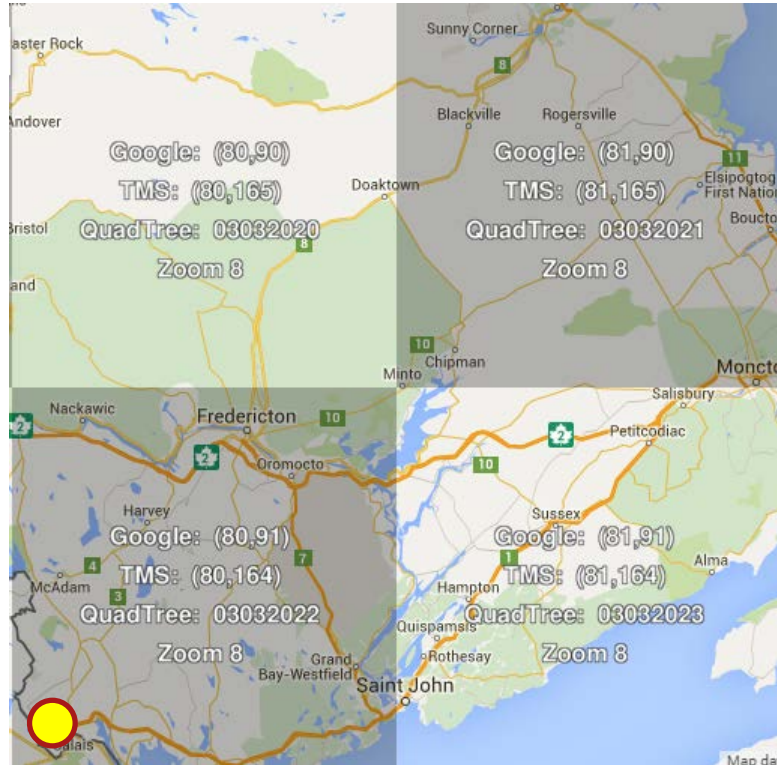


Map Tiler App



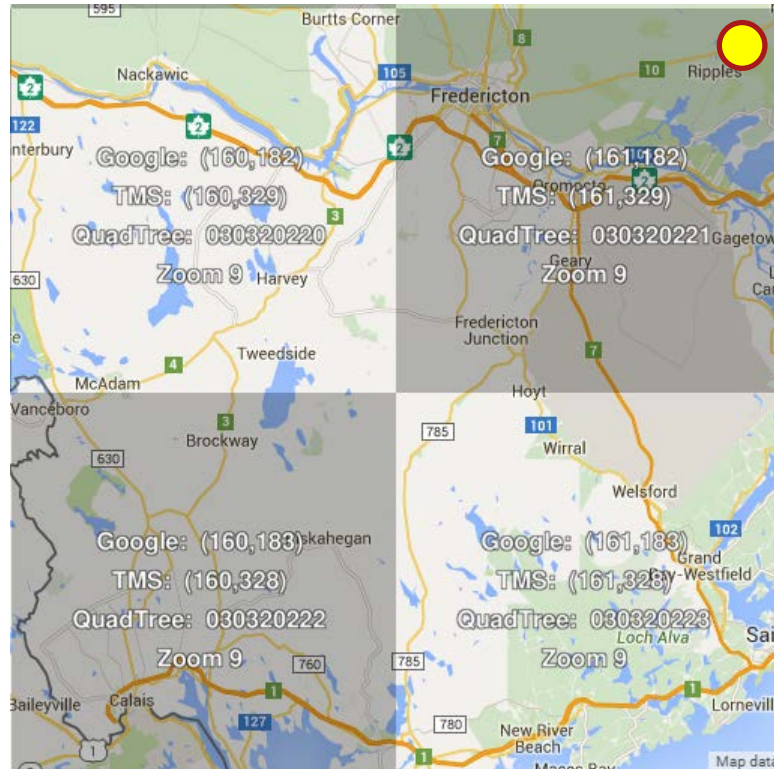


Map Tiler App



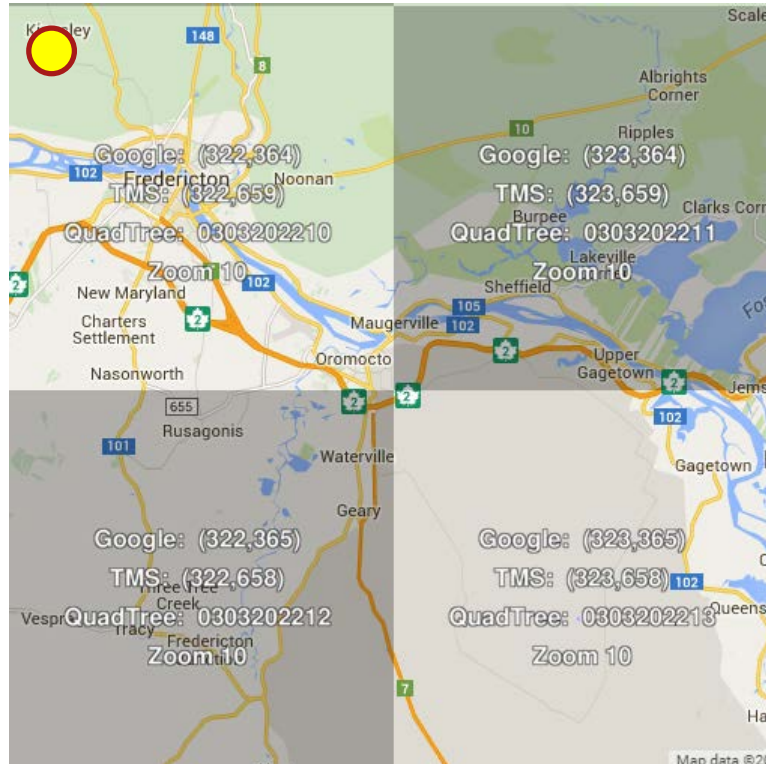


Map Tiler App



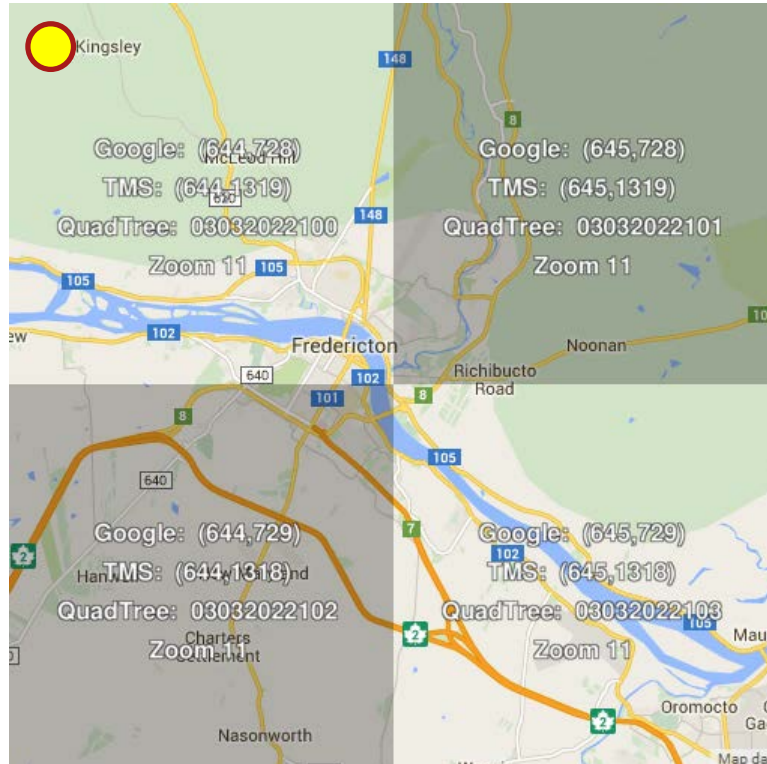


Map Tiler App



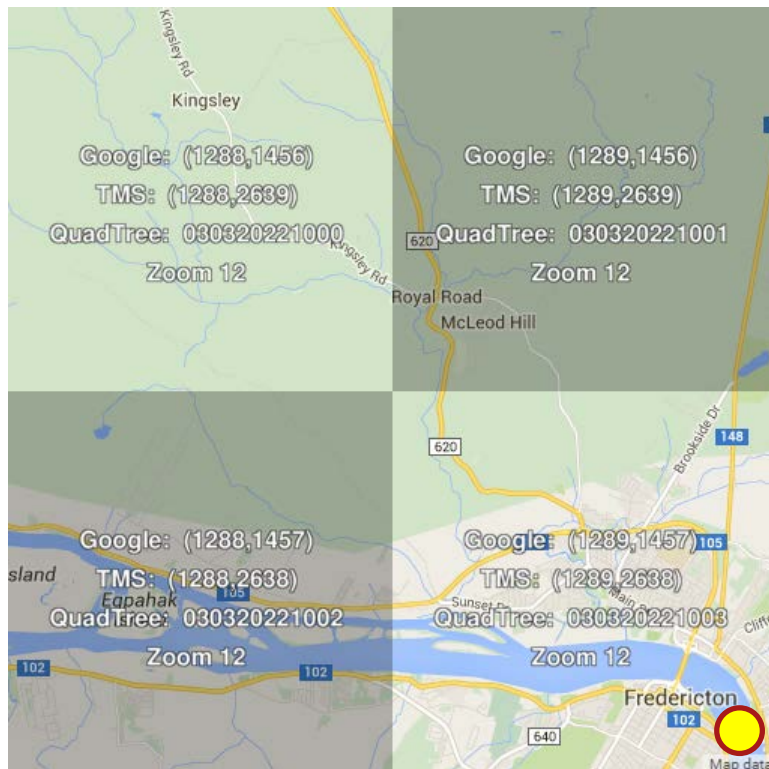


Map Tiler App



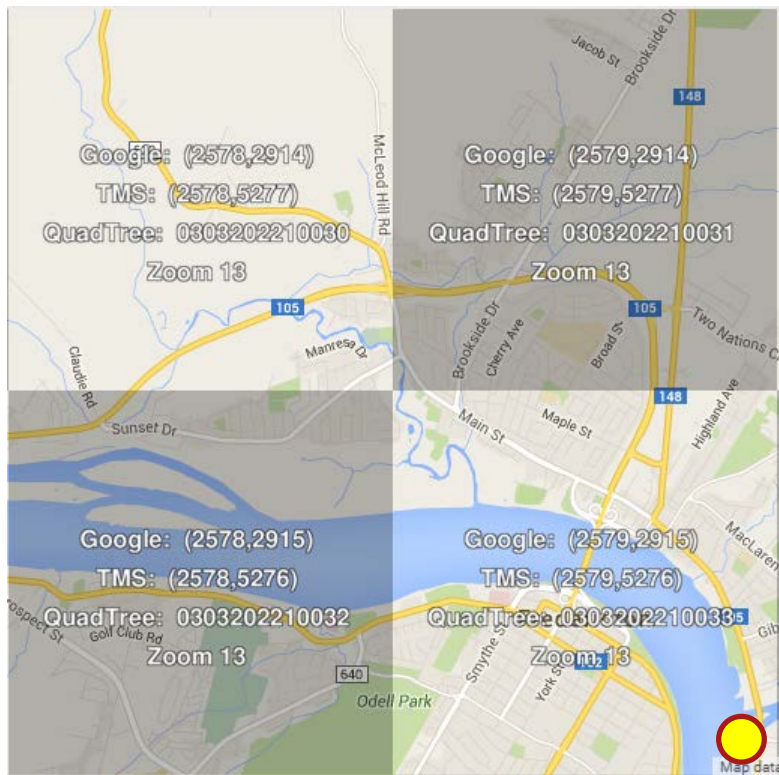


Map Tiler App



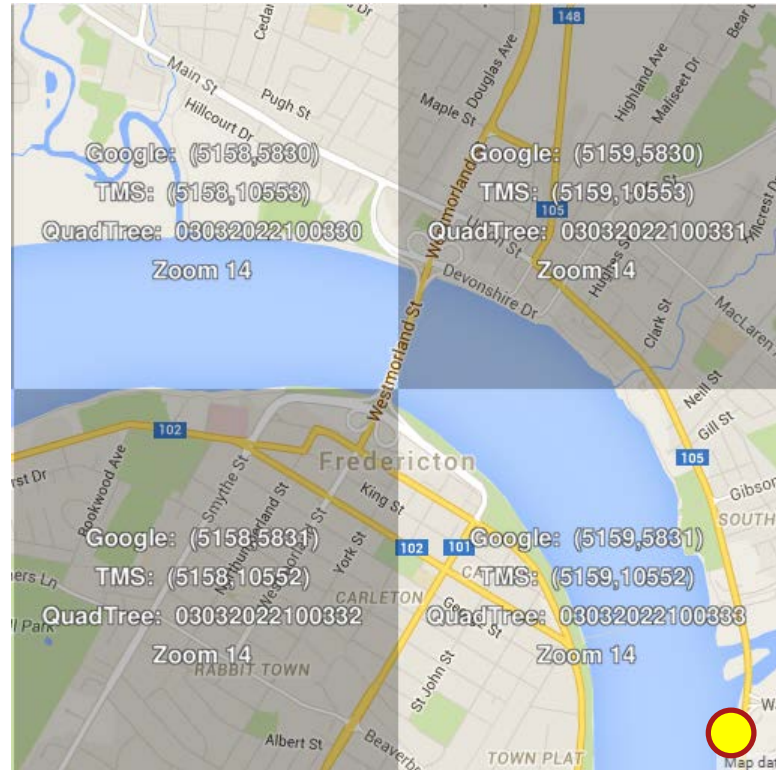


Map Tiler App



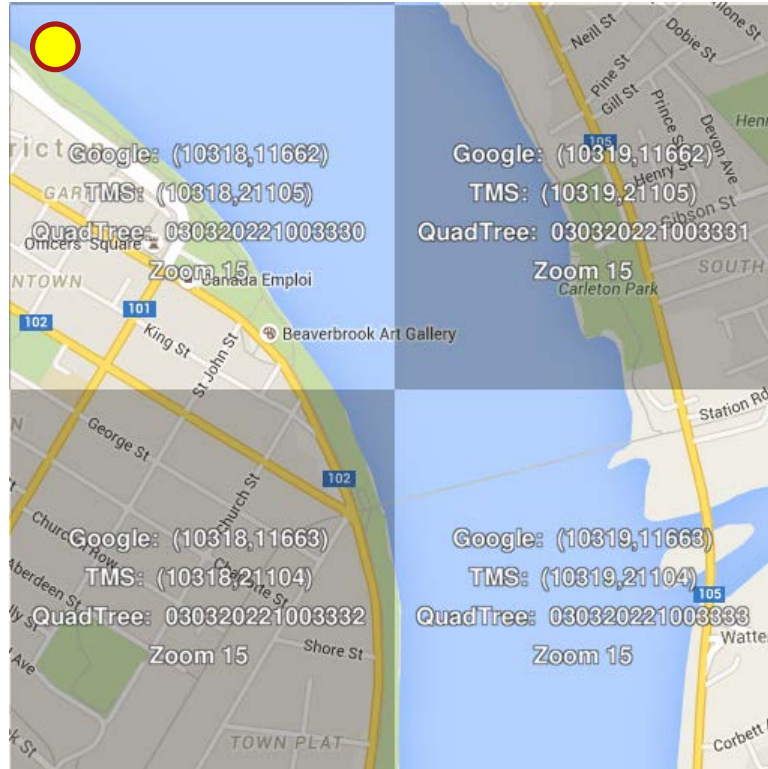


Map Tiler App



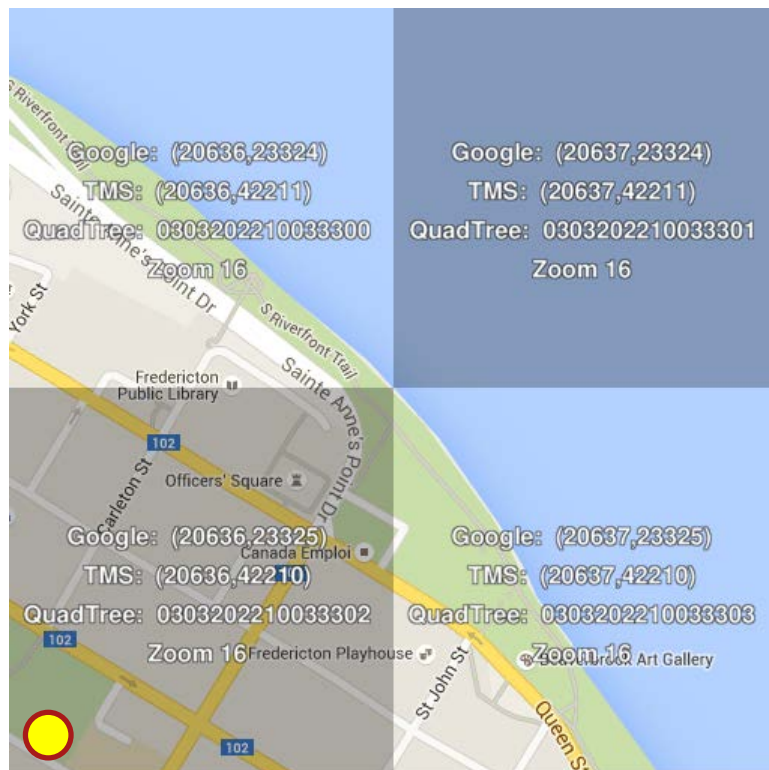


Map Tiler App



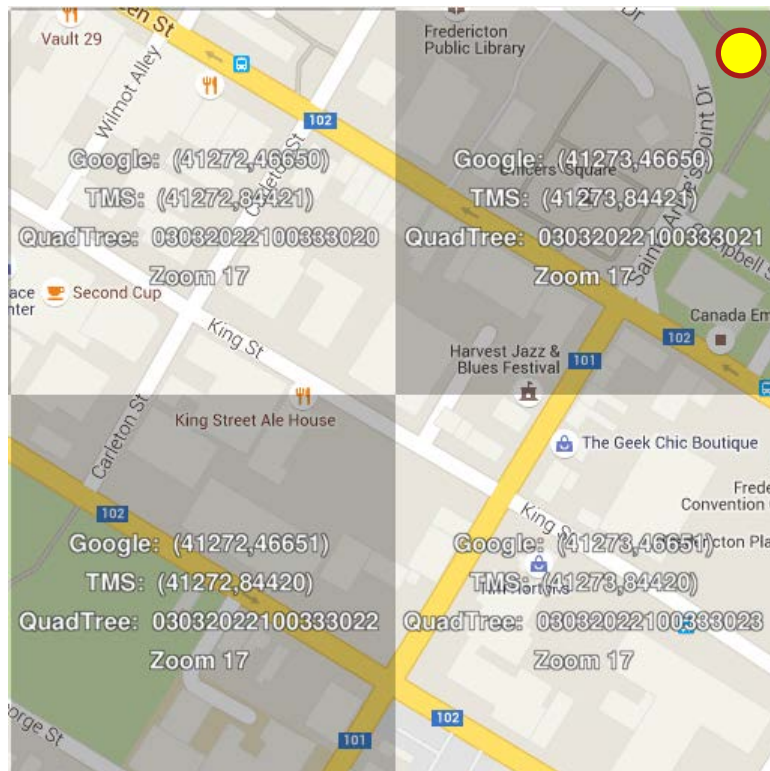


Map Tiler App



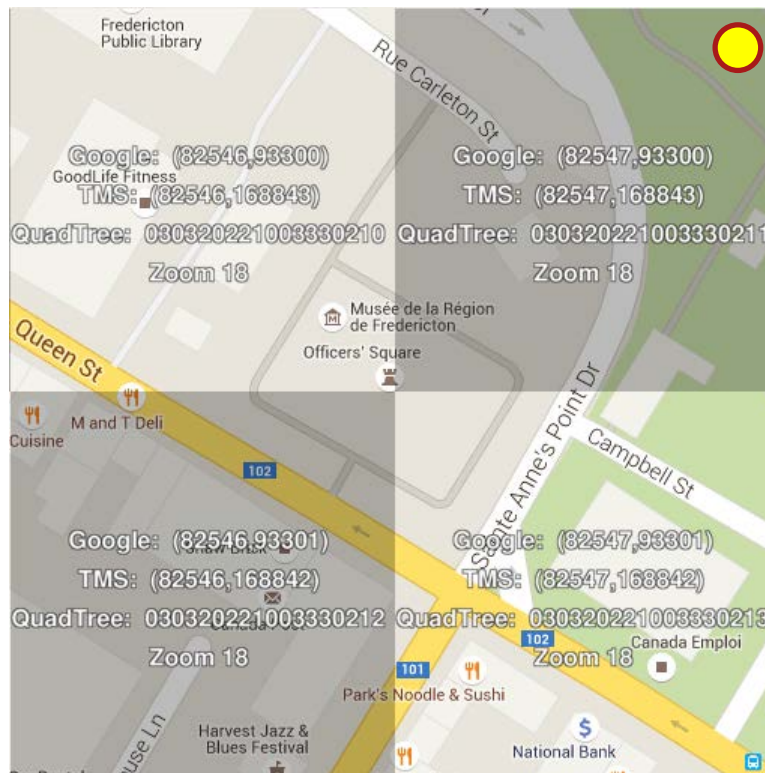


Map Tiler App



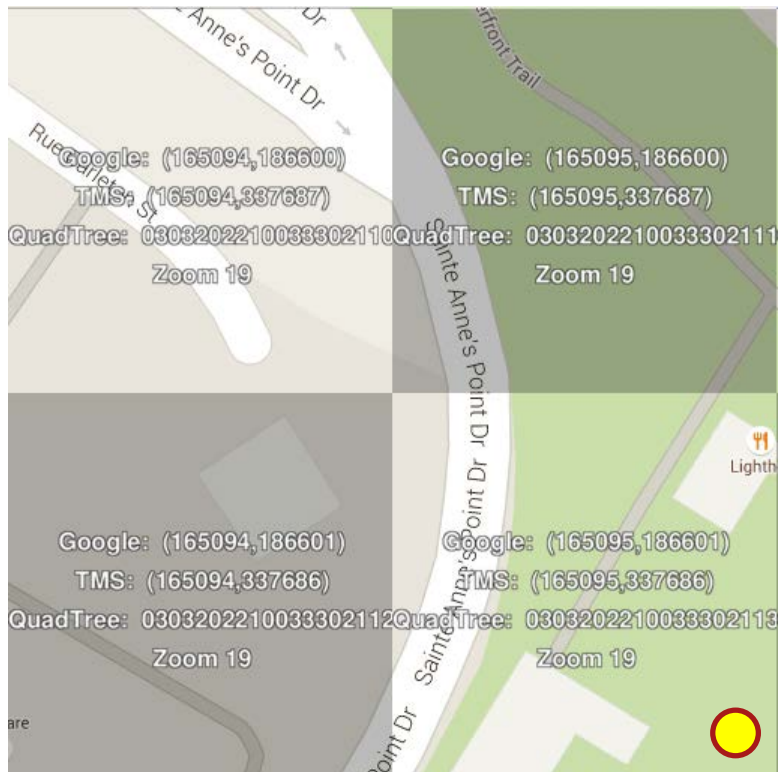


Map Tiler App



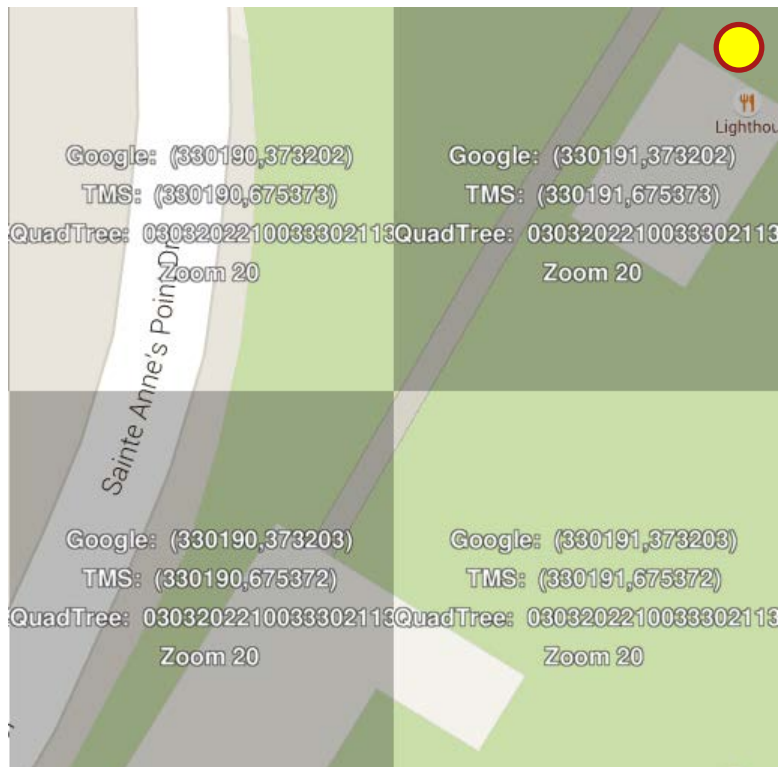


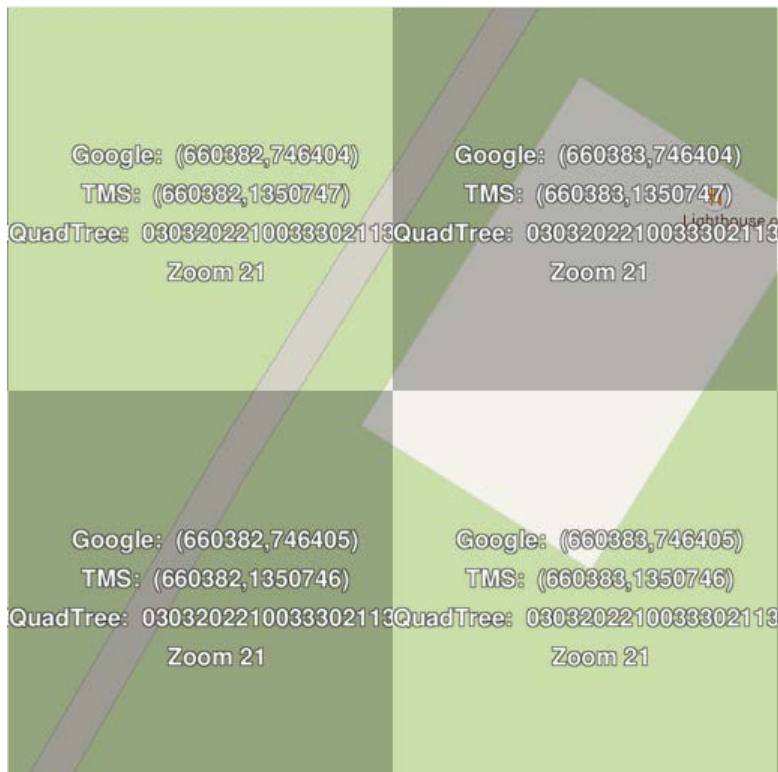
Map Tiler App





Map Tiler App

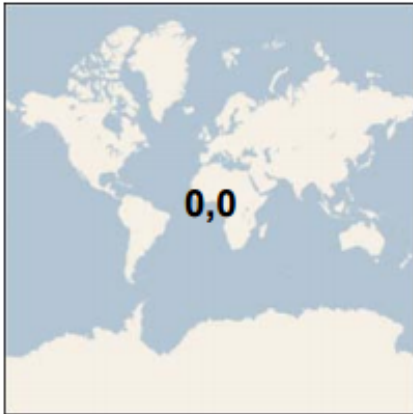




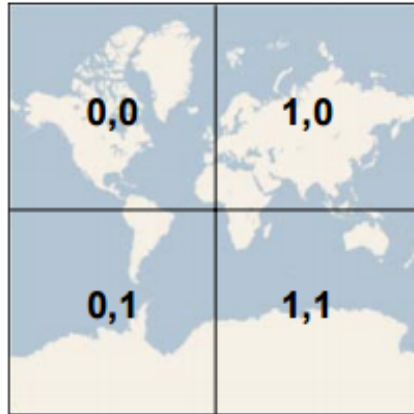


#Tiles & Pixel size / Zoom Level

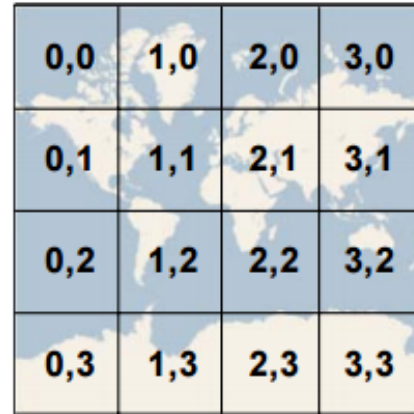
Zoom Level 0: 1 tile



Zoom Level 1: 4 tiles



Zoom Level 2: 16 tiles



Each tile: 256x256 pixels

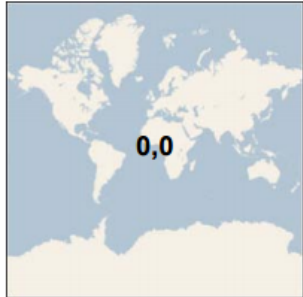
<http://www.microimages.com/documentation/TechGuides/78googleMapsStruc.pdf>

Google Zoom Level	Pixel Size at Equator
0	157 km
1	78 km
2	39 km
3	19.6 km
4	9.8 km
5	4.9 km
6	2.4 km
7	1.2 km
8	611 m
9	306 m
10	153 m
11	76 m
12	39 m
13	19 m
14	10 m
15	5 m
16	2.4 m
17	1.2 m
18	60 cm
19	30 cm
20	15 cm
21	7.5 cm
22	3.7 cm
23	1.9 cm
24	9.3 mm

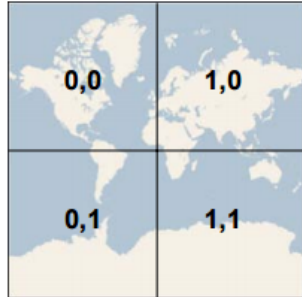


#Tiles & Pixel size / Zoom Level

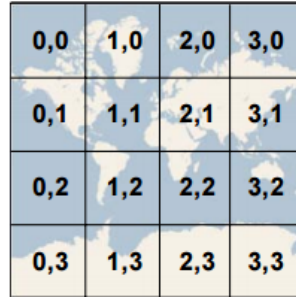
Zoom Level 0: 1 tile



Zoom Level 1: 4 tiles



Zoom Level 2: 16 tiles



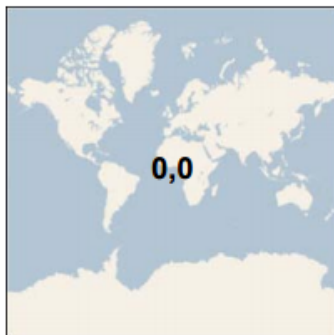
Each tile: 256x256 pixels

LEVEL	TILES/LEVEL	Pixel Size (m)
0	1	156,543.034
1	4	78,271.517
2	16	39,135.758
3	64	19,567.879
4	256	9,783.940
5	1,024	4,891.970
6	4,096	2,445.985
7	16,384	1,222.992
8	65,536	611.496
9	262,144	305.748
10	1,048,576	152.874
11	4,194,304	76.437
12	16,777,216	38.219
13	67,108,864	19.109
14	268,435,456	9.555
15	1,073,741,824	4.777
16	4,294,967,296	2.389
17	17,179,869,184	1.194
18	68,719,476,736	0.597
19	274,877,906,944	0.299
20	1,099,511,627,776	0.149
21	4,398,046,511,104	0.075
22	17,592,186,044,416	0.037
23	70,368,744,177,664	0.019
24	281,474,976,710,656	0.009
	4^{LEVEL}	$2\pi R / (256 \cdot 2^{\text{LEVEL}})$
	GRS80 (eq)	6,378,137.00 m
	Circumference (2πR)	40,075,016.69 m

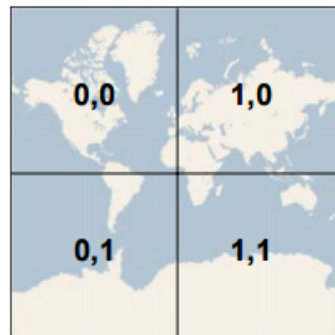


#Tiles & Pixel size / Zoom Level

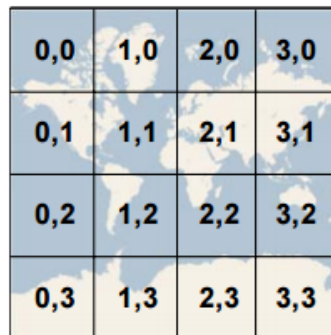
Zoom Level 0: 1 tile



Zoom Level 1: 4 tiles



Zoom Level 2: 16 tiles



Each tile: 256x256 pixels

<http://www.microimages.com/documentation/TechGuides/78googleMapsStruc.pdf>

Folders, Tiles, and File Size by Zoom Level for a Sample Google Maps Tile Overlay (1-m Orthoimage Mosaic of a US State)

(see Technical Guide entitled
Tilesets: Understanding Sizes)

Source image size: **352 GB** (uncompressed)

Image area: 109,185 square kilometers

Tile Size: 256 x 256 Pixels (required)

Tile Formats: JPEG + PNG for edge tiles

Coordinate Reference System:
WGS84 / Spherical Web Mercator (required)

Zoom Level	Number of Folders	Number of Tiles	Size on Disk
5*	1	2	32 KB
6	2	5	92 KB
7	2	7	308 KB
8	3	18	0.98 MB
9	4	43	2.86 MB
10	7	143	6.96 MB
11	13	516	17.1 MB
12	25	1,871	58.8 MB
13	49	7,236	201 MB
14	96	28,388	750 MB
15	192	112,485	2.88 GB
16	382	447,836	10.6 GB
17†	762	1,786,429	40.5 GB

* minimum zoom level: lowest level requiring more than one tile to cover the image area

† maximum zoom level: pixel size equal to or less than the spatial resolution of the input image


Total Number of Folders: 1,551

Total Number of Tiles: 2,384,979

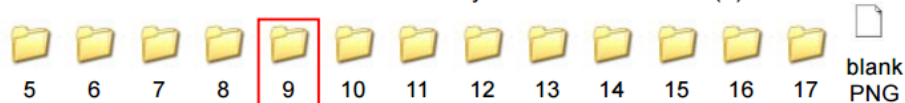
Total Size on Disk: 55.1 GB



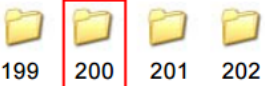
Google Maps Tile Overlay Directory Structure

 TN2008_NC_GoogleMaps_Tiles
(master tile directory)

Zoom Level Subdirectories Named by Zoom Level Number (Z)

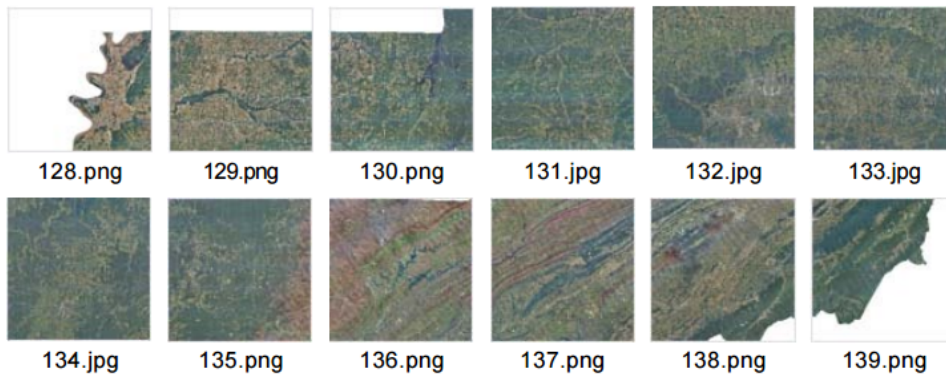


Tile Row Subdirectories
Named by
Tile Row Number (Y)



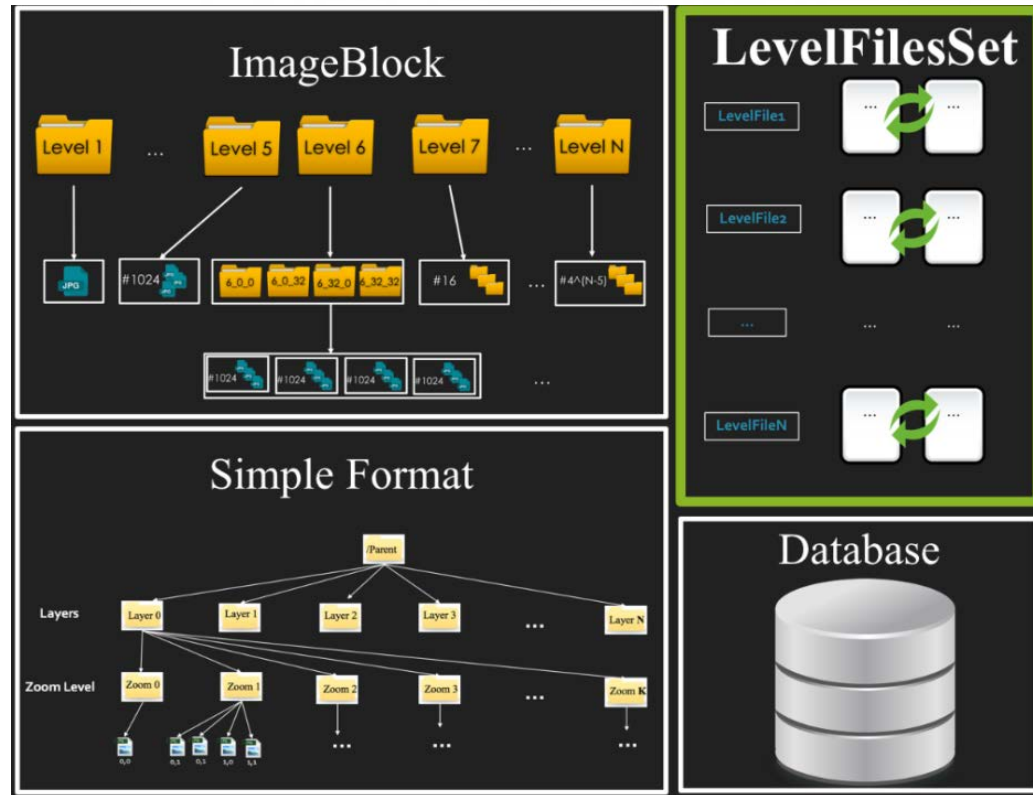
199 200 201 202

Tile Files Named by Tile Column Number (X)





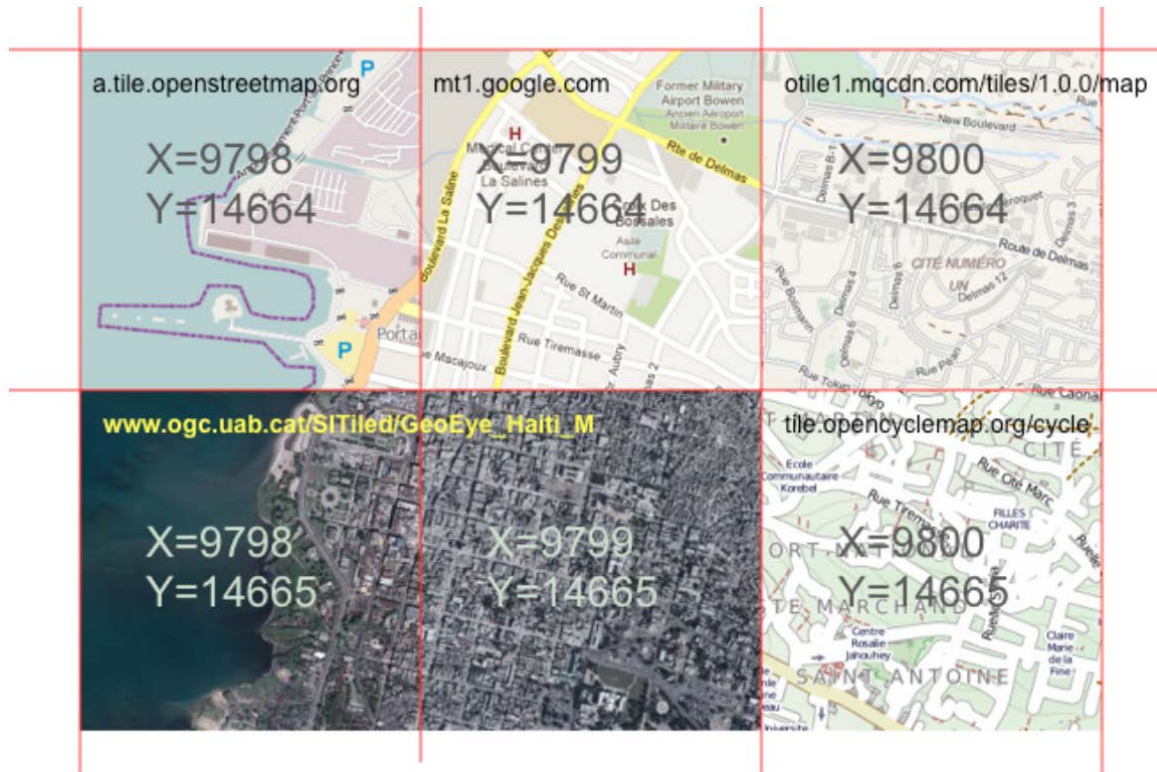
Alternative methods for a scalable web tiled map management system



Kotsolaris, 2017



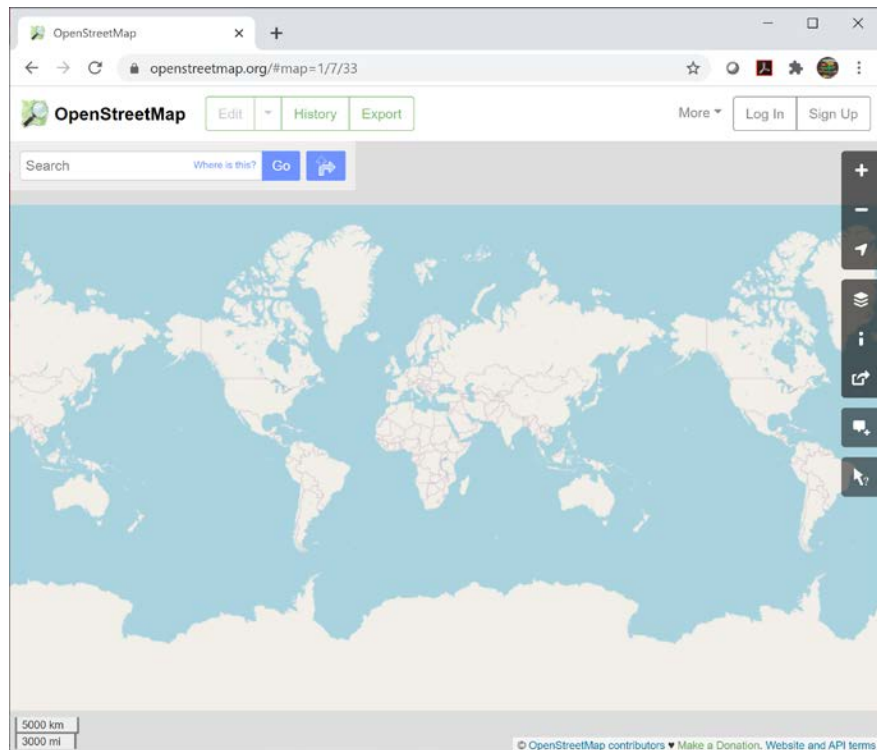
Interoperability across multiple Map Providers





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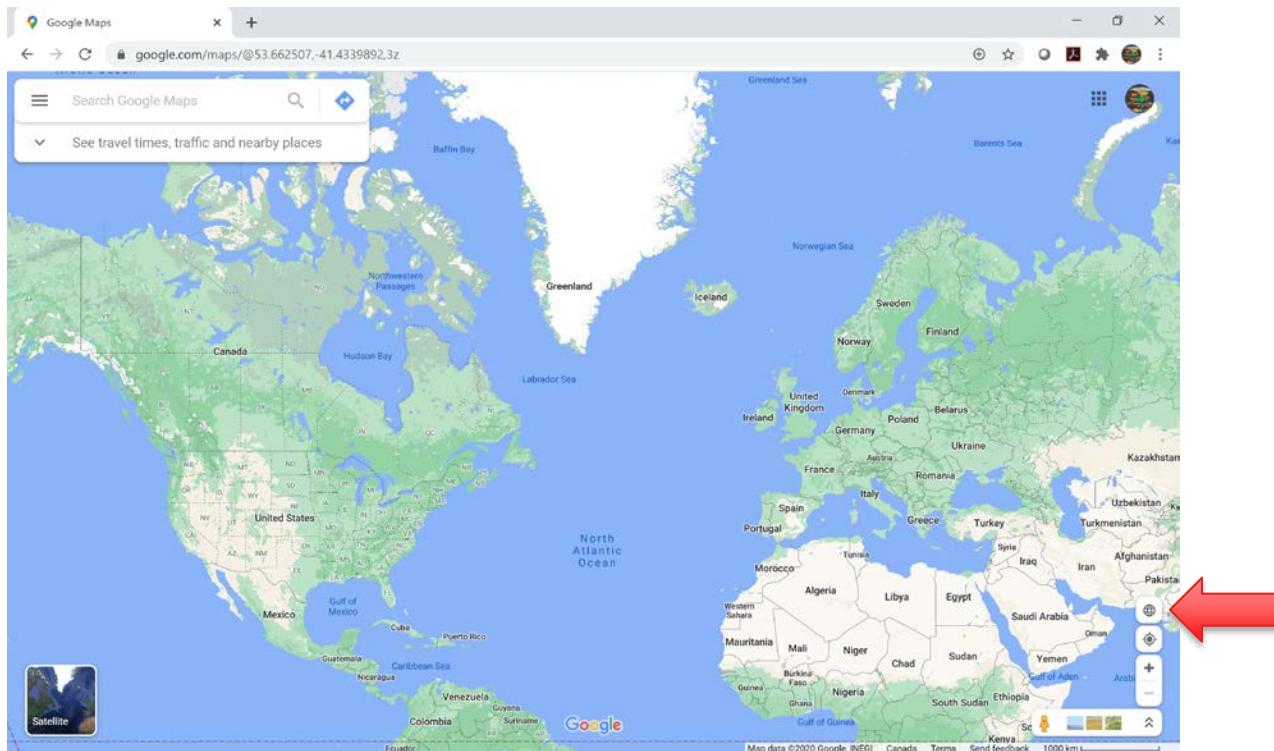
From the Flat map to Globe View





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From the Flat map to Globe View

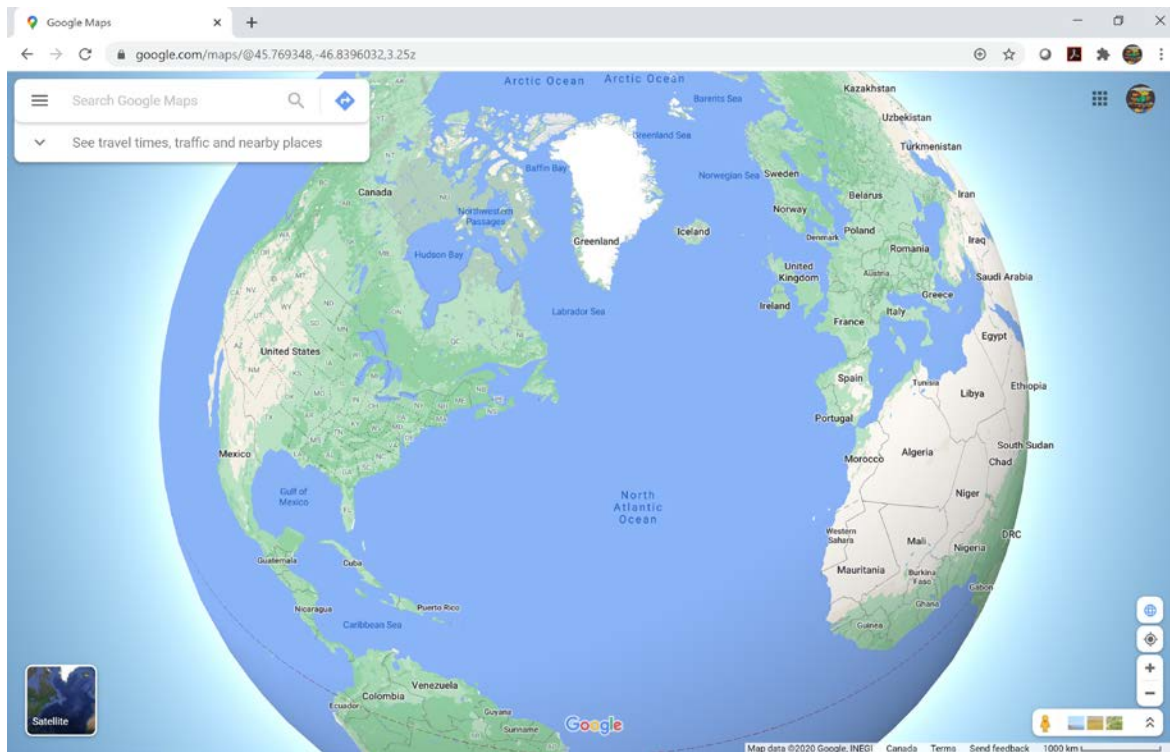


<https://www.google.com/maps/@53.662507,-41.4339892,3z>



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From the Flat map to Globe View

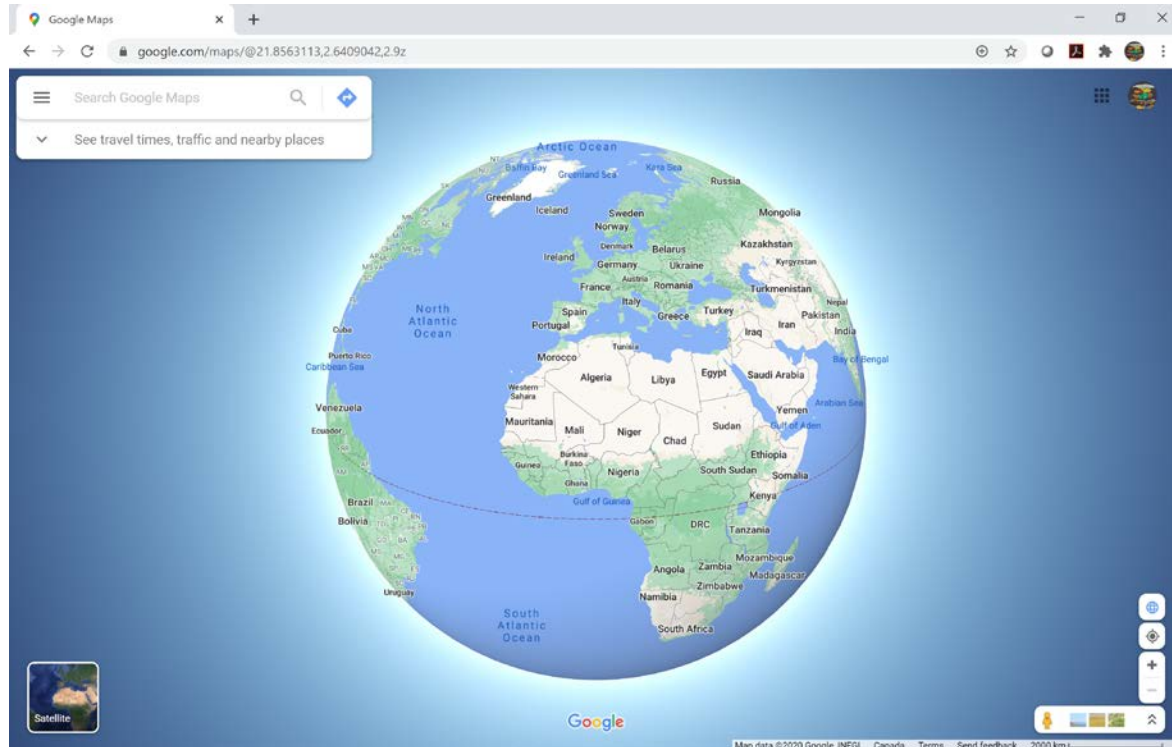


<https://www.google.com/maps/@53.662507,-41.4339892,3z>



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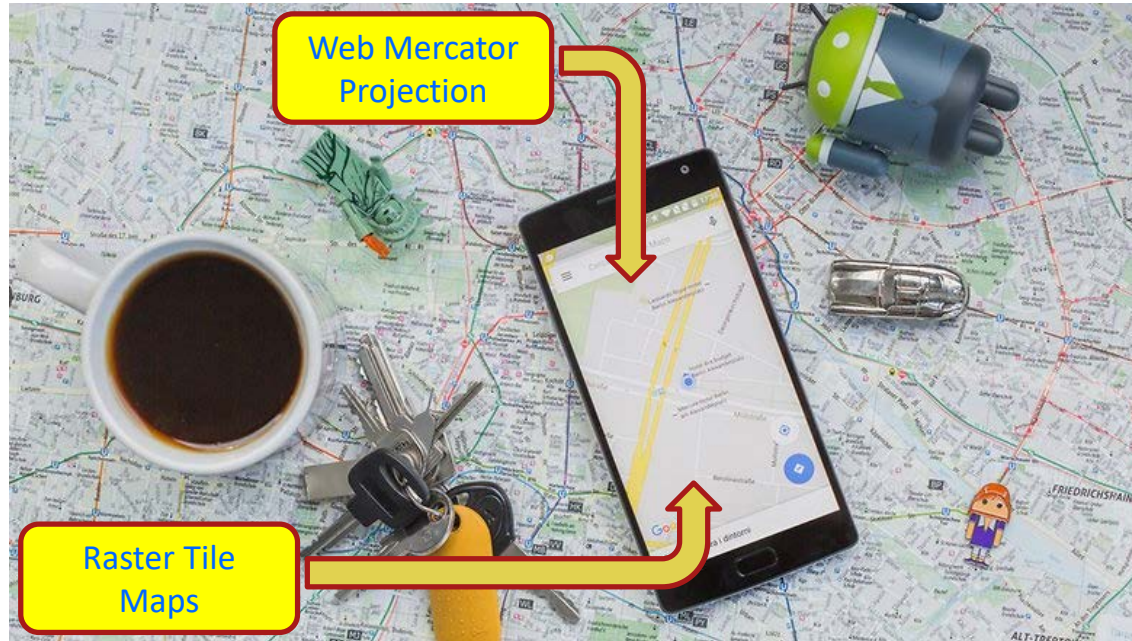
From the Flat map to Globe View





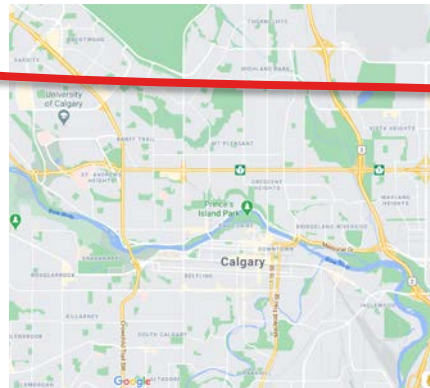
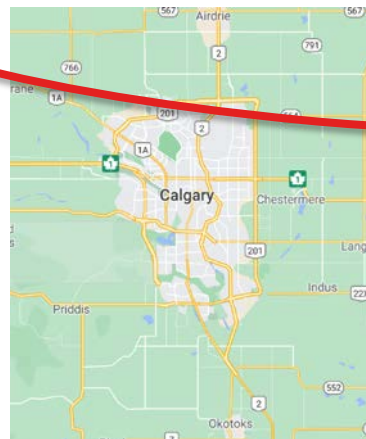
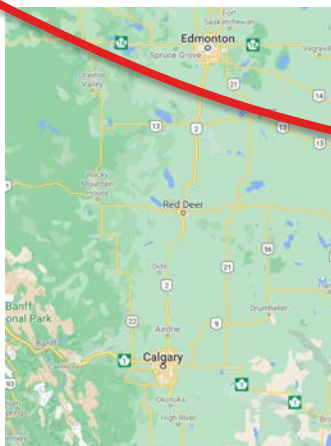
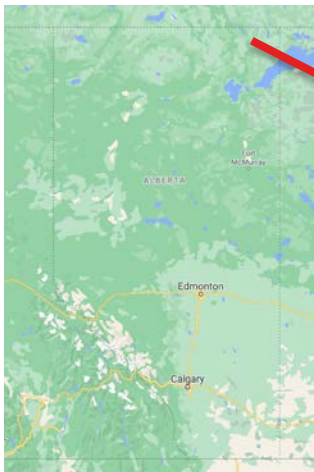
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Online Map Service Providers



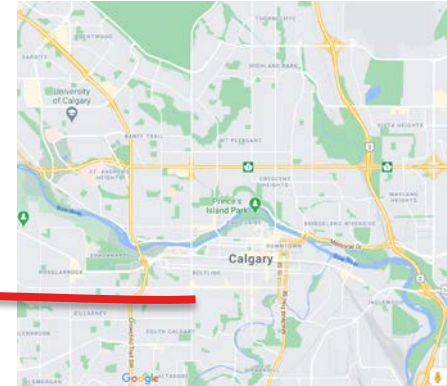
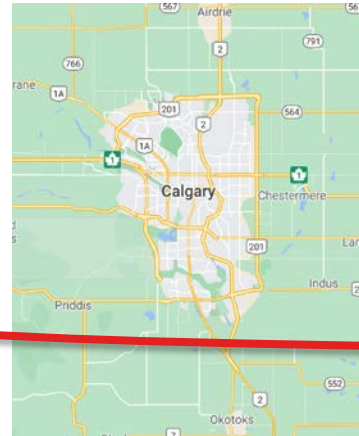
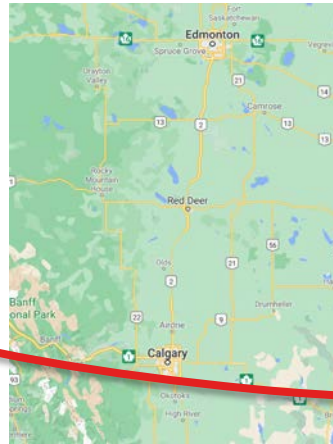
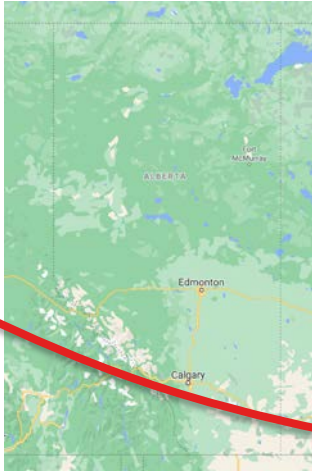


- To generate the map tiles is VERY time consuming!
 - As we are zooming-in more and more data as mapped



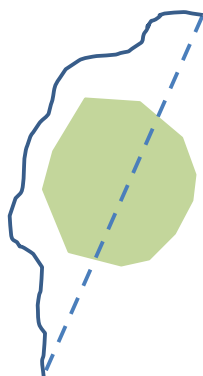
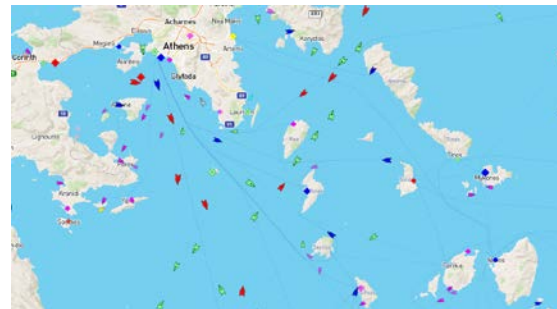
Zoom-in

- Automatic Creation of tiles at various resolutions
 - Map Generalization

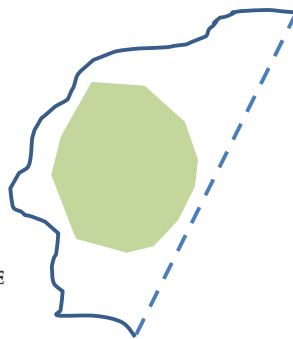
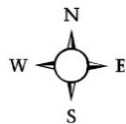




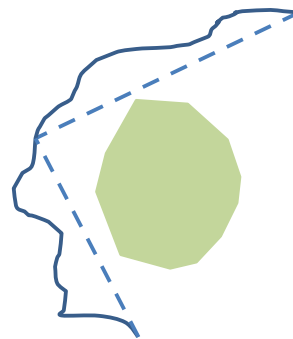
- Point elimination may cause inconsistencies...
 - Violation of spatial relations among mapping objects



topology



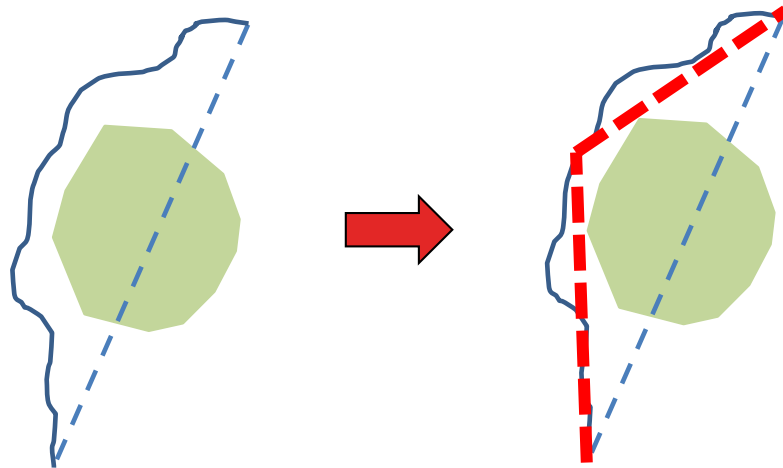
direction



distance



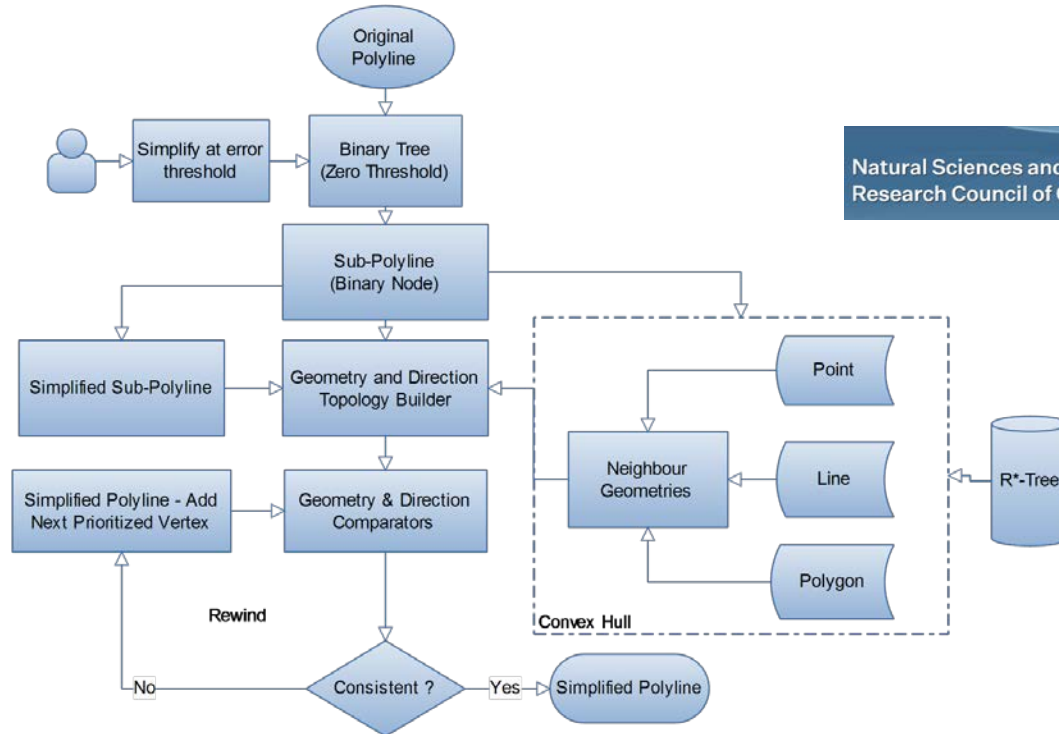
- Prevent inconsistencies:
 - Consider neighbouring objects/space during the simplification



Contextual line simplification

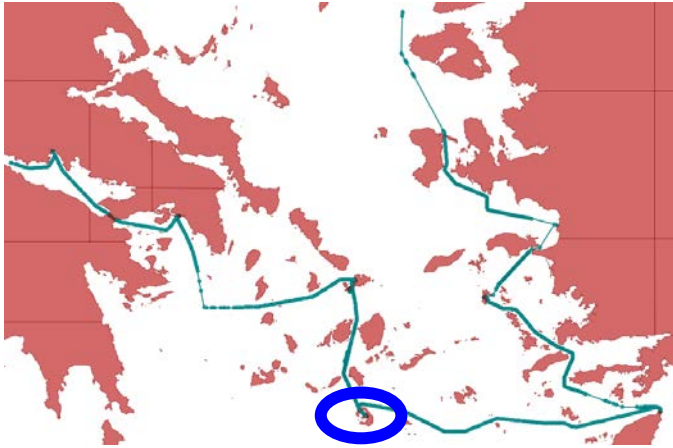


Natural Sciences and Engineering
Research Council of Canada





Research Directions





- Stefanakis, E., 2017. Web Mercator and Raster Tile Maps: Two Cornerstones of Online Map Service Providers. *Geomatica Journal*. Vol. 71(2). CIG Press.
- Stefanakis, E., 2015. Web Mercator: the de facto standard, the controversy, and the opportunity. *GoGeomatics*. Magazine of GoGeomatics Canada. October 2015.
- Stefanakis, E., 2015. Map Tiles and Cached Map Services. *GoGeomatics*. Magazine of GoGeomatics Canada. December 2015.
- MapTiler. Tiles à la Google Maps: Coordinates, Tile Bounds and Projection. <http://www.maptiler.org/google-maps-coordinates-tile-bounds-projection/>
- Tilesets: Google Maps Structure – MicroImages. <http://www.microimages.com/documentation/TechGuides/78googleMapsStruc.pdf>
- Kotsollaris, M., Liu, W., Stefanakis, E., and Zhang, Y., 2019. LevelFilesSet: An efficient Data Structure for Scalable Web Tiled Map Management Systems. In the *Proceedings of the ICA*. International Cartographic Conference 2019. Tokyo, Japan. ICA Press
- Tienaah, T., Stefanakis, E., Coleman, D., 2015. Contextual line simplification. *Geomatica Journal*, Vol. 69, No. 3. CIG Press.