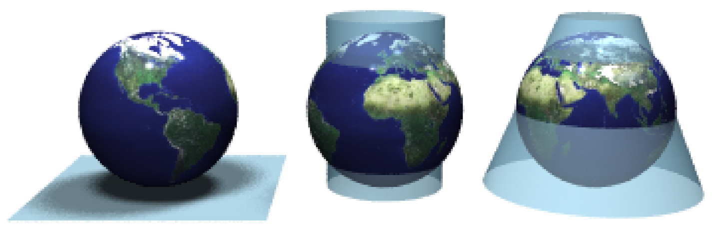
Basic Definitions and Concepts

Maps, Globes and Projections

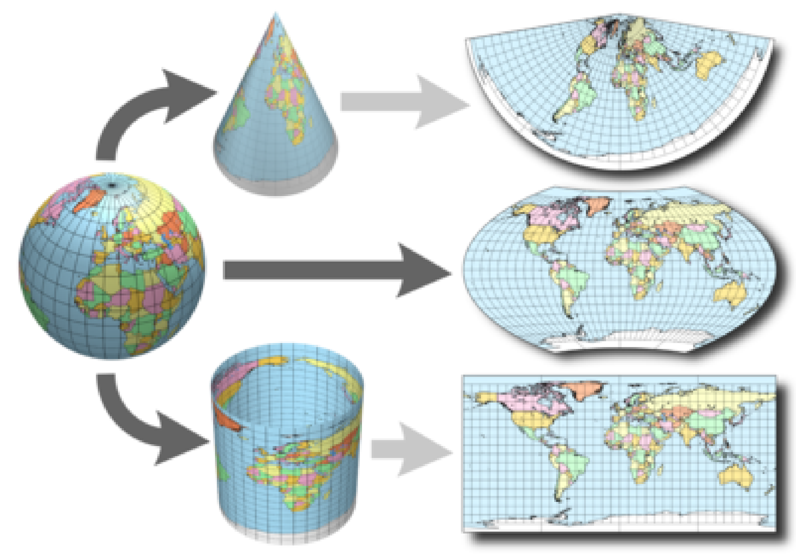
Any study in geography requires a reduced model of the Earth, like a **globe** or **map**. Neither is perfect: a globe is seldom practical, and flat maps are never free from errors. Selecting or creating a good map involves interesting choices and trade-offs.



"To project" means transferring features from Earth to a suitable surface, like a tangent plane, a secant cylinder or a secant truncated cone. Regions nearer the surface are usually better presented.

What's a Projection?

A cartographical **map projection** is a formal process which converts (mathematically speaking, **maps**) features between a spherical or ellipsoidal surface and a **projection surface**, often flat. Although many projections have been designed, just a few are currently in widespread use. Some were once historically important but were superseded by better options, several are useful only in very specialized contexts, while others are little more than fanciful curiosities.



From ellipsoid or sphere (left) to flat map (right). A conceptual intermediary surface (center) may be useful for either actual construction or mere visualization, but the darker conversion paths unavoidably incur in distortion.

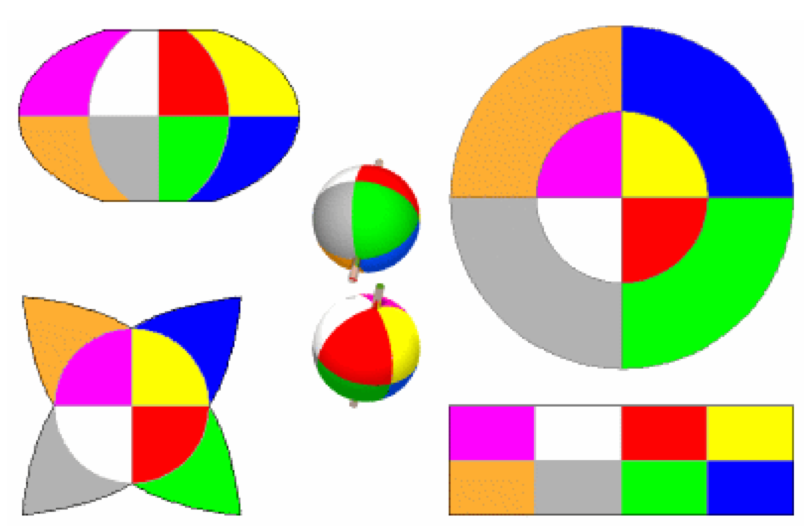
Projection Surfaces

The map's support, the projection surface is usually created, i.e., **developed**, conceptually touching the mapped sphere in one (the surface is *tangent* to the sphere) or more (the surface is *secant*) regions. Intuitively, portions of the surface nearer the touching regions depart less from the original spherical shell; therefore, the corresponding portions on the map are more faithfully reproduced. Some projections are actually composites, fitting separate surfaces to different regions of the map: overall error is reduced at the cost of greater complexity.

Sometimes a conceptual auxiliary surface like a cone, open cylinder, ellipsoid or torus is employed: the sphere's features are (often by perspective construction) transferred to that surface, which is then flattened. Many projections are classified as "cylindrical" or "conic"; however, for most of them, the naming is just an analogy or didactic device, since they aren't actually developed on an intermediary surface; rather, the *resulting* map can be rolled onto a tube or a cone.

An orange's peel provides a classic demonstration of distortion in maps: it cannot be completely flattened unless compressed, stretched or torn apart.

The Unavoidable Distortion



Two quasi-orthographic views of a sphere (plus polar axis) divided in eight equal sections, surrounded by four maps at the same scale using, clockwise from top right: azimuthal equidistant, Lambert's equal-area cylindrical, Maurer's equal-area star with four lobes, Winkel Tripel projections.

A few selected projections illustrate how the same spherical data can be stretched, compressed, twisted and otherwise distorted in different ways. The azimuthal equidistant map has interesting properties regarding directions and distance from the central pole, but the outer hemisphere is greatly stretched: its pole becomes a circle. Both poles become lines in the equal-area cylindrical map, but it covers the same area as the original sphere; also, all octants have identical shape. This particular star projection has unequal octants and marked loss of continuity; however, it also preserves area. In the Winkel Tripel map, octants have different shapes, area is changed and poles are linear, but overall distortion is subjectively smaller. Finally, the orthographic views, projections themselves, show only part of the sphere.
All projections suffer from some distortion; none is "best" for *all* purposes. Octants would assume even stranger shapes in oblique aspects.

No matter how sophisticated the projection process, the original surface's features can never be perfectly converted to a flat map: **distortion**, great or small, is always present in at least one region of planar maps of a sphere. Distortion is a false presentation of angles, shapes, distances and areas, in any degree or combination.

Every map projection has a characteristic distortion pattern. An important part of the cartographic process is understanding distortion and choosing the best combination of projection, mapped area and coordinate origin minimizing it for each job.

Cones and cylinders are **developable** surfaces with zero Gaussian curvature (in a nutshell, at every point passes at least one straight line wholly contained in the surface). Therefore, although distortion always occurs when mapping a sphere onto a cone or cylinder, their reprojection ("unrolling") onto a plane incurs in no further errors.

The Choice of Coordinate Origin

Another key feature of any map is the orientation, relative to the sphere, of the conceptual projection surface.

A particular projection may be employed in several **aspects**, roughly defined by the graticule lay-out and the sphere's region nearest the conceptual projection surface, commonly the center of a whole-world map (not necessarily the actual center, due to cropping or recentering):

- a **polar** map aligns the north-south axis with the projection system's, so it is useful when one of the poles must lie at the map's conceptual center;
- an **equatorial** (occasionally known as *meridian*, or *meridional*) map is centered on the Equator, which is set across one of the map's major axes (mostly horizontally);
- an **oblique** (seldom referred to as a *horizon*) map has neither the polar axis nor the equatorial plane aligned with the projection system.

Also, orthogonally,

- the most "natural" aspect of a projection, called **normal**, **conventional**, **direct** or **regular**, is ordinarily determined by geometric constraints; it demands the simplest calculations and produces the most straightforward graticule. The polar aspect is the normal one for the azimuthal and conic groups of projections, while the equatorial is the normal for cylindrical and pseudocylindrical groups. The normal graticule for azimuthal and conic projections comprises exclusively straight lines and circular arcs; normal cylindrical ones have altogether straight grid-like graticules
- the **transverse** aspect is created by rotating the polar axis by 90°: if the normal aspect is centered on a pole, the transverse is centered somewhere on the Equator; if the normal aspect is aligned with the Equator, the transverse is aligned with a meridian, and so on.

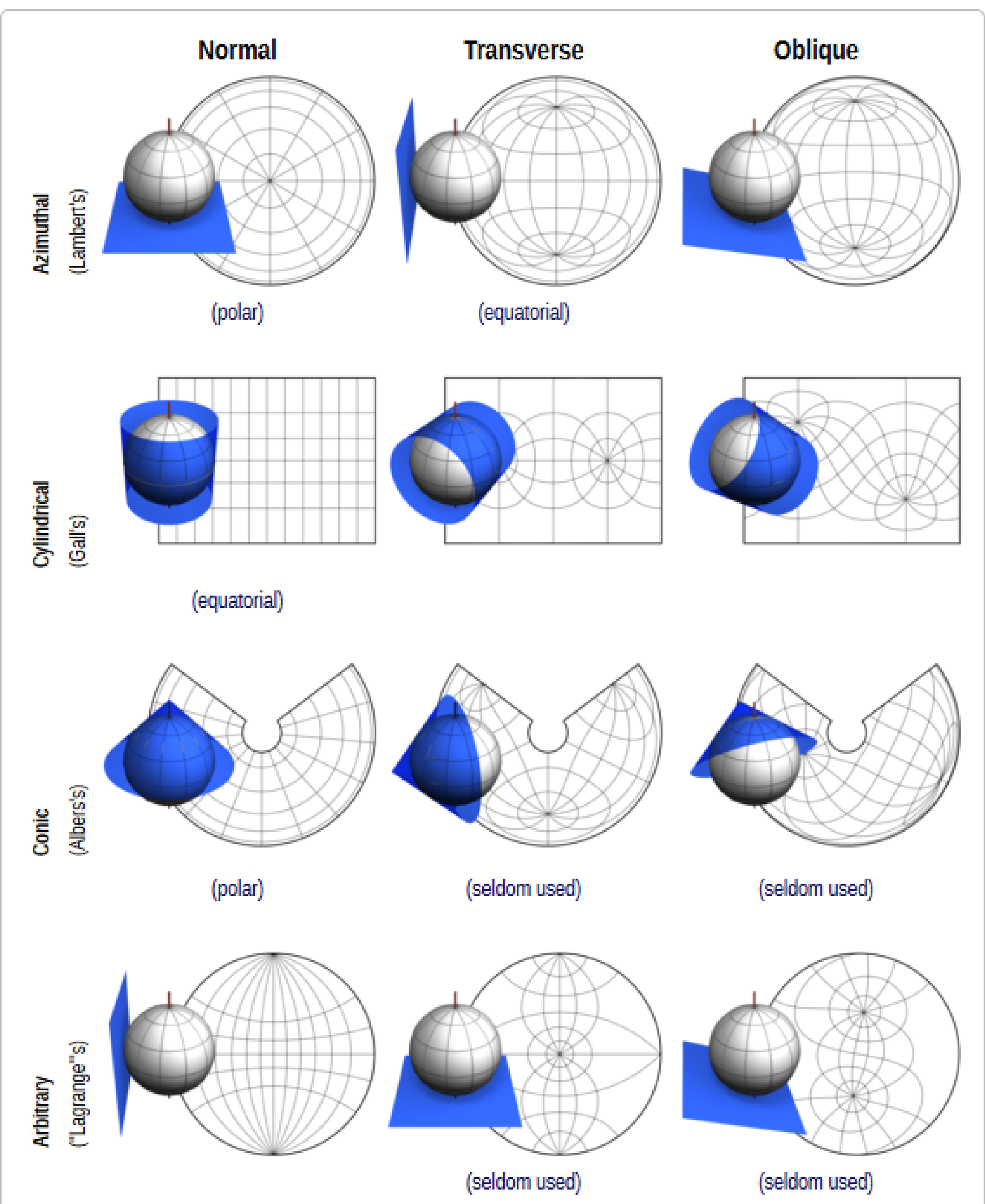
For both normal and transverse aspects, the only remaining choice is how much, if at all, to rotate the Earth around the polar axis, determining the map's **central meridian.** There are infinite choices for the two angles of rotation determining oblique aspects.

Some authors consider a different definition of "aspect": it determines whether the projection surface is secant or tangent to the globe (this is of course a more limited meaning, since many projections are not defined via an auxiliary surface). Still others reserve "aspect" for one meaning and "**case**" for the other, or even for distinguishing equations devised for an ellipsoid versus the simpler sphere.

Theoretically, especially supposing a spherical Earth, any projection may be applied in any aspect: after all, the parallel/meridian system is a convention which might have origins anywhere, although it is hard imagining others more useful than the poles. However, many projections are almost always used in particular aspects:

- their properties may be less useful otherwise. E.g., many factors like temperature, disease prevalence and biodiversity depend on climate, thus roughly on latitude; for projections with constant parallel spacing, on equatorial aspects latitude is directly converted to vertical distance, easing comparisons.
- several projections whose graticules in normal aspects are comprised of simple curves were originally defined by geometric construction. Since many non-normal aspects involve complex curves, they were not systematically feasible before the computer age (indeed, mapping was an important motivation for calculation shortcuts like logarithms).

Even though oblique aspects are frequently useful, in general calculations for the actual ellipsoid are fairly complicated and are not developed for every projection.



Three (normal, transverse and oblique) aspects applied to four (azimuthal equal-area, Gall's stereographic cylindrical, Albers's conic and "Lagrange"'s) projections with different tangent projection surfaces in blue (just a few of infinitely many possible oblique maps are presented). Some projections like Gall's stereographic may actually be derived via perspective geometry; for most, however, surfaces are only illustrative: the map *may* be laid on a developable surface, but is not *calculated* from it.

The distinctive graticules of some projection groups (radially symmetric meridians in azimuthal and conic maps, rectangular grid in cylindrical maps) are only realized using their simple, normal aspects. Despite a common misconception, this classification is not exclusive: most projections involve neither a cone nor a cylinder but are *not* azimuthal either. Trivial rotations of the finished map, like turning it sideways or upside-down, leave both aspect and projection unchanged. On the other hand, modifying the aspect does not affect either represented area or the shape of the whole map.