Which Way Is Jerusalem? Which Way Is Mecca? The Direction-Facing Problem in Religion and Geography

Daniel Z. Levin

ABSTRACT

Determining the direction in which to face another location on the globe is a problem with significant social and religious meaning, and one with a rich and interesting history in the Western world. Yet a fully satisfying geographic solution to this problem is hindered by our intuitive perception of the world as a flat surface—where a "straight" path (1) is the shortest distance, and (2) maintains a constant angle. On a curved surface, however, only one of these two properties can be satisfied: the first, by a great circle; the second, by a rhumb line. These two solutions are analyzed, compared, and applied to the direction-facing problem.

Key Words: direction facing, religion, great circle, rhumb line

Daniel Z. Levin (Ph.D., Northwestern University, 1999) is an assistant professor of organization management at Rutgers University. Ordinarily, his research interests include organizational learning, change, and innovation, but they also extend to intellectually interesting problems in social science, geography, and the overlap between the two.

Why would a mosque in New York City face toward the northeast when "everyone knows" that Mecca is south and east of New York? This question is an example of the direction-facing problem in geography: When standing at a particular point on the globe, in what direction is another point elsewhere on the globe? As in the above example of the New York mosque oriented more or less toward Greenland, the answers can be surprising. Perhaps even more surprising, though, is that, from the perspective of mathematics and cartography, there is not just one scientific answer to the direction-facing problem, but two potentially valid mathematical answers. As we shall see, the reality of compass direction on a round earth does not always fit with what our intuitive notions of distance and direction would have us believe.

For religious Jews and Muslims, for example, this issue is not merely academic. In both faiths, worshippers have been conducting their prayers for centuries while facing a holy city: for Jews, Jerusalem; for Muslims, Mecca. Thus, beyond its usual importance to social science, public policy, and industry, the tools and techniques of geographic analysis in this case have significant social (even theological) meaning to religious institutions as well. Although religions have relied upon various folk traditions and rules of thumb, modern worshippers might also wonder if mathematics, geography, and cartography can provide a scientific answer to the direction-facing problem. Yet, deciding what exactly is the direction in which to face another point on the globe turns out, for theoretical reasons, to be far from straightforward, even scientifically. In fact there are two potential mathematical solutions to the direction-facing problem: either the initial compass direction of a great circle (i.e., the shortest path) connecting the two locations; or the constant direction of a rhumb line (i.e., the path of constant compass direction) connecting the two locations. In this article—designed to spark the interest of students of geography and requiring no more than high-school trigonometry—I review the diverse history of prayer orientations and then describe how and why we might use the great circle versus the rhumb line to solve the direction-facing problem.

DIRECTION FACING IN WESTERN RELIGIONS

Several major religions—Judaism, Christianity, Islam, and Bahá'í—have historically observed the practice of orienting prayer in a particular geographic direction. Moreover, over time, these groups have approached the direction-facing problem in a number of different ways.

Judaism

The tradition among Jews to face in the direction of Jerusalem while praying is an ancient, biblical one. According to the Bible, King Solomon (10th century B.C.E.) built the first Temple in Jerusalem and then stated when dedicating that structure that the Israelites would "pray to the Lord in the direction of the city which You have chosen [Jerusalem], and in the direction of the House [Temple] which I built to Your name" (I Kings 8:44). After the destruction of this

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Temple, the Bible notes that Daniel (6th century B.C.E.), while in exile in Babylonia, faced in the direction of Jerusalem while praying (Daniel 6:11). After the final destruction of the second Jewish Temple (70 C.E.), located on the same site as the first, this tradition remained and was soon codified into Jewish law. For the most part, however, it appears that in actual practice Jews have had a rather flexible attitude toward the direction of Jerusalem and moreover, even in theory, have never been extraordinarily precise about determining its direction.

The earliest rabbis, whose views were first recorded around the year 200 C.E., believed that Jews should physically face Jerusalem when praying, but added that someone on a boat could simply direct his "heart" to the site of the destroyed Temple in Jerusalem (Babylonian Talmud, *B'rachot* 28b). Another source from the same time period elaborated, "Those in the north face the south, those in the south face the north, those in the east face the west and those in the west face the east so that all Israel [i.e., the Jewish people] prays toward one place" (*Tosefta B'rachot* 3:16). By the late 5th century, subsequent rabbis had reiterated this viewpoint but added the opinion that a blind man or someone who does not know the direction should simply direct his "heart" towards his Father in heaven (Babylonian Talmud, *B'rachot* 30a). Archaeological evidence confirms that 2nd- to 5th-century synagogues were roughly oriented to face Jerusalem (Avi-Yonah 1971).

As Jews migrated to North Africa and Europe, later commentaries on this Jewish law—e.g., rabbis writing in 13th-century Germany (*Mord'khai, B'rachot* 30a) and in 14th-century Spain (*Tur*, O.H. 94)—noted simply that Jews to the west of the Land of Israel should face eastward. Interestingly, in Arab lands—where Muslim astronomers and others focused intensely on the direction-facing problem—medieval Jewish scholars showed no interest in treating more scientifically the direction of prayer (Goldstein 1996). Perhaps the only scientific treatment of this issue was by a 15th-century Jewish astronomer in Lisbon who wrote in Hebrew of finding the direction of Jerusalem using geographic coordinates, although he did not indicate what method he used or what direction he found (Langermann 1999). By the 16th century in Poland, one legal codifier (a rabbi) wrote of facing eastward, but then added that Jews should build a synagogue such that the direction of prayer is actually southeast, since facing directly east (toward where the sun rises) is the way Christians pray (*Mappah*, O.H. 94:2). Subsequently, another 16th-century scholar—one who lived in Prague, Venice, and Poland—also expressed concern about directly emulating the Christian custom of facing due east, and further wrote:

> For all the lands in which we dwell are all northwest of the Land of Israel, and we are not located due west of the Land of Israel. Therefore it appears to me to be the proper thing to do that, when we make a synagogue, we should be careful when we make the eastern wall—where we place the ark and we pray opposite it—that it should lean a little towards the southeast.
> (*L'vush*, as quoted in *Mishna B'rurah, O.H.* 94:2)

However, a rabbi writing in 17th-century Prague noted that he had only witnessed Jews facing directly eastward. He therefore concluded—even though his own opinion was to face southeast—that most Jews must be taking the view that simply choosing one of the four compass directions mentioned 1,400 years earlier in the Talmud was sufficient (*Divrei Hamudot, B'rachot* 30a). In fact, most synagogues from the middle ages to the 18th century placed the ark along a wall that was due east; one notable exception, though, was the 16th/17th-century "Spanish synagogue" in Venice, which was oriented to face south by southeast (Kashtan 1971). At the turn of the 20th century, yet another Jewish legal authority—one who lived in Lithuania and Poland—again reiterated that Jews in Europe should face southeast; that is, toward where the sun is 30-60 minutes after sunrise in the spring or fall (*Mishna B'rurah, O.H.* 94:2). Despite these admonitions, however, today all, or nearly all, synagogues in Europe and North America (if they have any intentional geographic orientation at all) are oriented to face due east.

Besides *praying* in the direction of Jerusalem, 3rd- to 5th-century rabbis also applied the direction-facing principle to a Jewish law that one should avoid showing disrespect by relieving oneself while facing the Temple in Jerusalem when it is in view. These early rabbis debated and differed over whether this prohibition applies when the Temple is not in existence (i.e., after 70 C.E.), or when Jerusalem is not in sight, or when one is not due north or due east of Jerusalem, or when one is outside the Land of Israel entirely. Interestingly, those who followed this prohibition would avoid facing Jerusalem *and* avoid turning their backs to it; thus, many rabbis argued that someone to the east of Jerusalem should face north or south when relieving himself (Babylonian Talmud, *B'rachot* 61b). Many centuries later, Jewish burial also became associated with the direction of Jerusalem. One early-19th-century European rabbi wrote that, although it is not mentioned in ancient or early Jewish texts, it had become an established Jewish custom in Europe to bury a person with the legs to the east (or sometimes south) "as symbolic of the faith in resurrection of the dead, indicating that he will stand up from his grave and leave...to travel to the Holy Land [when the Messiah comes and ends the Jewish exile]" (Responsum Hatam Sofer Y.D. part 2, section 332). This rabbi also noted that the journey from Europe to the Holy Land starts out on either a southerly route (that then turns east) or an easterly route (that then turns south), so either direction for burial is proper. Again, we see that Jews typically have been content, even in theory, to approach the direction of Jerusalem with approximate solutions.

Christianity

The "early Christian practice of facing the east for prayer...could well have begun in conscious contrast to the Jewish custom [of facing Jerusalem], but it would also have

been influenced by the general pagan understanding of the time that the east is the direction in which the good divine powers are to be found, a view originally connected with sun worship" (Davies 1986, 421). Along with these particular rationales, however, Christian scholars and theologians have also offered numerous other historical, theological, or biblical explanations for the custom of facing eastward (Davies 1986; Hassett 1913; Lang 1989; Yarnold 1994). In addition, a related custom has been the practice among some Christians of burying the dead with the lay person's feet placed to the east (Lang 1989). Interestingly, the early Church's adult baptism (i.e., conversion) ceremonies—instituted after the Roman Empire legalized Christianity in the 4th century—included having the candidate face west to renounce the devil, then turn away in the opposite direction "to face Christ, the source of light, in the east" (Yarnold 1994).

Historically, this custom of facing eastward has found expression in the geographic orientation of churches. From the 4th century to the 8th century, Christian basilicas in the Western world were typically built with their entrance on the east side, whereas later basilicas, influenced by Orthodox and French church architecture (Foley 1991; Redmond 1967), came to be built with the opposite orientation, with the apse (i.e., the area containing the altar, opposite the entrance) on the east side. In both cases, however, apparently the "presider stood on whichever side of the altar allowed him to face east, the place of the rising sun and a symbol of the resurrection" (Foley 1991, 70). The latter custom of both presider and congregation facing eastward continued in Roman Catholic churches until the decades after World War II, when priests gradually switched their orientation so that they now face the congregation, even though this change means that the priests may thus be facing westward (Cross and Livingstone 1983). Protestant ministers have generally faced the congregation since the Reformation, although their churches have not been oriented in any particular direction (Cope 1986). In fact, throughout Christian history, from the earliest days to the present, "orientation has never been considered absolutely essential and many churches have been built regardless of it to accommodate them to the site available" (Davies 1986, 421).

Islam

In contrast, Islam has been perhaps the most concerned among the major Western religions with the direction-facing problem. Interestingly, among Muslims the direction of prayer (*qibla*, in Arabic) was initially, as it is among Jews, toward Jerusalem. However, within a year or two of Muhammad's founding of Islam (7th cent.), the Muslim *qibla* (also spelled *kibla*) was changed from Jerusalem to Mecca, due perhaps in part, some have speculated, to Muhammad's disappointment that few Jews were converting to Islam (Wensinck 1986). Thus, Muslims were instructed, "Turn then your face in the direction of the Sacred Mosque: wherever you are, turn your faces in that direction" (Koran 2:144); that is, in the direction of the Ka'ba (sacred mosque), which is in Mecca. To this day whenever a mosque is constructed, the building is oriented to face in the direction of this *qibla* (Wensinck 1986). In addition to its considerable importance in Muslim prayer, "according to Islamic law, certain ritual acts such as reciting the *Qur'an*, announcing the call to prayer, and slaughtering animals for food, are to be performed facing the Ka'ba. Also Muslim graves and tombs were laid out so that the body would lie on its side and face the Ka'ba" (King 1999, 47). In addition, "it is forbidden to turn towards Mecca when relieving nature" (Wensinck 1986, 82).

Historically, Muslims have used a number of different approaches in determining the direction of Mecca. In the first two centuries of Islam, for example, the *qibla* was sometimes determined by using the direction of the road on which pilgrims left for Mecca (Goldstein 1996), or it was simply to face south because "the Prophet Muhammad had prayed due south when he was in Medina (north of Mecca)" (King 1993, I 253). Later in the medieval period, however, two main traditions, each existing alongside the other, emerged: mathematical astronomy, which used geographic coordinates and trigonometric formulas, and legal scholarship, which used a number of different rules of thumb not requiring computations. Interestingly, as King (1993, X 8) notes, "It is quite apparent from the orientations of mediaeval mosques that astronomers were seldom consulted in their construction. Indeed...several different and often widely-divergent *kiblas* were accepted in specific cities and regions."

The medieval legal scholars, drawing on a kind of folk astronomy, began with the observations that the Ka'ba, a rectangular-shaped building, is oriented so that, roughly speaking, (1) the two shorter walls face the rising point of the star, Canopus, (2) the two longer walls face the summer sunrise or winter sunset, and (3) each of the walls face head on into one of the four Arabian winds. These observations were then combined with a view of the Ka'ba, in Mecca, as the center of the world. Muslim legal scholars then divided the world into either 4, 8, 11, 12, or 72 sectors radiating out from the Ka'ba, so that each sector of the world could be said to face a particular section of the perimeter (or wall) of the Ka'ba. Muslims living in a particular sector could then determine the *qibla* based on the rising (or setting) of the sun or stars or the winds in their location. Thus, the legal tradition's

> attempts to define the *kibla* for different localities in terms of astronomical risings and settings [or even of wind directions] stem from the fact that these localities were associated with specific segments of the perimeter of the Ka'ba, and the *kiblas* adopted were the same as the astronomical directions which one would be facing when standing directly in front of the appropriate part of the Ka'ba. (King 1993, XI 1-2)

So, for example, early Iraqi mosques faced the winter sun-

set, and early Egyptian mosques, the winter sunrise, so that these mosques would be in some sense "parallel" to the relevant wall of the Ka'ba. Nevertheless, even within the same city "there were differences of opinion, and different directions were favoured by particular groups" (King 1993, I 255).

Although the increasingly accurate approximations and formulas of mathematical astronomers from the 8th to 15th centuries were circulated only within the scientific community, and were largely ignored by Muslim legal scholars and by the wider community, this mathematical approach eventually, by the modern era, came to dominate. Today, mosques are built according to the *qibla* found by calculating the initial compass direction of the shortest distance to Mecca (i.e., the great-circle route) using precise geographic coordinates (King 1993).

Bahá'í

The Bahá'í faith, which began in the Middle East in the mid-19th century and today has millions of followers worldwide, has its own *qiblih* for the direction of certain prayers. Individual Bahá'ís recite the daily obligatory prayer while facing in the direction of the tomb of Bahá'u'lláh, located at Bahjí, just north of Acre, Israel (near Haifa). According to Bahá'u'lláh's Book of Laws, "When ye desire to perform this prayer, turn ye towards the Court of My Most Holy Presence, this hallowed Spot that God hath... decreed to be the Point of Adoration for the denizens of the Cities of Eternity (Kitáb-i-Aqdas, ¶6). In addition, this *qiblih* towards Acre is used during a communal prayer recited twice per year and whenever visiting two particular Bahá'í shrines. It is also customary for Bahá'ís to be buried with their feet in the direction of Acre (Yancy 2000).

Like modern-day Muslims facing Mecca, Bahá'ís compute their *qiblih* based on the initial compass direction of the great-circle route to Acre. So, for example, in North America's Bahá'í House of Worship, which was designed in the mid-1920s and is located just north of Chicago, the chairs in the auditorium face roughly northeast, or east by northeast (Stockman 2000; Yancy 2000). Interestingly, though, local folklore at this particular House of Worship near Chicago has it that the sidewalk leading (in a southeasterly direction) from the temple to the nearby intersection forms an "arrow" pointing towards Acre (Yancy 2000). This southeastward sidewalk is fairly consistent with a rhumb line from Chicago to Acre, although, as already noted, the actual seating inside the temple is based on the initial compass direction of the great-circle route (i.e., people face northeast). In practice, many Bahá'í followers, like Jews facing Jerusalem, are not especially strict about following the *qiblih* towards Acre (Brown and Bromberek 2000; Yancy 2000). For those followers who are interested, though, the Bahá'í Computer and Communication Association has created a "web-based calculator" that will compute the *qiblih* to Acre based on the initial compass direction of the great-circle route from any latitude and longitude entered (Brown and Bromberek 2000).

Common Themes

Thus, for these world religions, the meaning of physical space and geography has a strong spiritual component. In orienting the direction of prayer, these faiths have historically made use of scientific methods on occasion but also other rules of thumb for determining the proper direction. Moreover, the knowledge by worshippers that all of their co-religionists are praying in the same direction, or in the direction of the same place, can be a source of unity in a number of ways among these worshippers—particularly among Jews, Muslims, and Bahá'ís, who are facing a specific location. Synchronizing geographic direction plays a *symbolic* role in supporting theological notions of unity, such as unity of faith, of the divine, of a people, or of humankind; it plays a *social* role in creating a sense of community and fellowship among worshippers even if they are scattered all over the world; and it plays an *institutional* role in supporting the process of building and maintaining cross-national linkages and unity among members of the same religious organizations.

Geographical Considerations

The Earth Is Round

Yet, ironically, the question of which way to face, despite its purpose as a source of unity, lacks, geographically speaking, the unity of a single answer that worshippers in the modern era might expect. That is, over short distances we can simply assume that the two points essentially lie on a flat surface, and we can draw a straight line between them to determine the compass direction. As the two locations in question become farther and farther apart on the earth, however, the question of which way to face ceases to be just a straightforward math problem. Indeed, for longer distances, we are forced to take into account that the earth's surface is actually curved and thus we must add the constraint that the "line" connecting the two points must remain on the curved surface. With this constraint, however, the very notion of a "straight" line between two points becomes considerably less intuitive than it was on the flat surface, for no line on a curved surface is truly straight; it is, by definition, curved.

Thus, we need some sort of curved-surface analog to the notion of a straight line on a flat surface.

> We all know, for instance, what a straight line is. It is the shortest distance between two points, and it is, well, *straight* [i.e., it forms a constant angle]. But when we try to draw a straight line on the surface of the globe, it is immediately apparent that we can't draw any sort of line which even begins to meet our intuitive idea of what a straight line should be. (Reid 1963, 149)

Since our intuitive notions of direction and distance are derived almost entirely from our visual perception of and interaction with a flat (Euclidean) world, we must make conceptual compromises when defining a "straight" line on

the surface of the earth. This divergence between intuitive concepts based on plane geometry and the realities of spherical geometry (especially for long-range distances) leads to two possible definitions of a curved-surface "straight" line. On a flat surface, a straight line has two properties: (1) it is the shortest distance between two points, and (2) it maintains the same direction (angle) all along its path; psychologically, we take these two properties for granted. On a curved surface like the earth, however, it turns out that we can choose only one of these two properties to define a "straight" line. As a result, two definitions of a "straight" path on a curved surface emerge: the great circle (the line of shortest distance) and the rhumb line (the line of constant direction).

Great Circle

The shortest distance between two points on a sphere is along a great circle, or orthodrome, defined as a "circle on a sphere produced by any plane which passes through the center of the sphere" (Raisz 1962, 292) and through the two points in question. If one point is due north or south of the other—that is, if both points lie along the same meridian (those lines of longitude that converge at the north and south poles)—then the great circle connecting the two points is the meridian itself along which both points lie. More typical is the case of an oblique great circle, a great circle connecting two points (not on the equator) with *different* longitudes. One answer to the question, then, of what is the direction of another point elsewhere on the globe is to say that it is the *initial* compass direction—known as the *azimuth*—of the great-circle path, starting at the initial location. That is, in what direction would we start traveling if we were to trace the shortest path (the great circle) to the destination point.

This particular definition of a "straight" path on the surface of a globe emphasizes the notion of distance. For if the "true" distance between two points, even on a curved surface, is to mean anything, this argument—popular among geographers and mathematicians—goes, it must mean the shortest distance (i.e., along the great circle) between those two points (Reid 1963; Kramer 1970; Robinson et al. 1995). This definition is also the consensus among Muslims in choosing a direction in which to face Mecca (King 1986) and among Bahá'ís for facing Acre (Brown and Bromberek 2000).

To compute the initial azimuth (angle), Z, between the line extending due north from point 1 and the great-circle route connecting points 1 and 2 on a sphere,[1] the following equation is used:

$$Z = \text{Arctan}\left(\frac{\sin(\Delta Lo)}{\cos(Lat_1)\tan(Lat_2) - \sin(Lat_1)\cos(\Delta Lo)}\right),$$

In this equation ΔLo is the absolute value of the difference in longitude between the two points (minimum of 0° and maximum of 180°), and Lat_1 is the latitude of point 1 (Lat_2, of point 2); note that, in this equation, *Lat* should be a negative number for latitudes south of the equator. The solution provided by this equation was first determined in Damascus by the 14th-century astronomer al-Khalili, who developed a *qibla* table for each degree of longitude and of latitude in the Muslim world (King 1986).

Choosing the initial direction of a great-circle route, however, does have some drawbacks. For one, "the navigator thinks of an oblique great-circle course as a line of inconstant direction. Though it is indeed the shortest, most direct route between two points on the earth's surface, you must be ever changing your compass direction with respect to those converging meridians if you would stick to the oblique great-circle route" (Greenhood 1964, 130). In other words, the *initial* compass direction of a great-circle route will be incorrect as soon as the journey begins, because an oblique great circle's direction (with respect to the north-south meridians) is different for every point along the route (see Fig. 1). This lack of consistency between the initial direction of the great circle versus subsequent compass headings along it seems to violate part of what it means for a path to be "straight": it must maintain the same direction (angle) all along the line. A related difficulty arises when we examine the special case of two points on the earth that are due east or west of each other. In this special case, a person at the more western location who believes that a "straight" path, first and foremost, should have a constant direction, would face due east along the same line of latitude shared by the city he or she is facing, even though that path is not the shortest. This reasoning is probably closer to the views of the 3rd-century Jewish rabbis who said to face eastward when one is west of Jerusalem (*Tosefta B'rachot* 3:16).

Rhumb Line

In contrast to a great circle, a rhumb line, or loxodrome, is a "line which crosses the successive meridians at a constant angle" (Raisz 1962, 296). In other words, a path

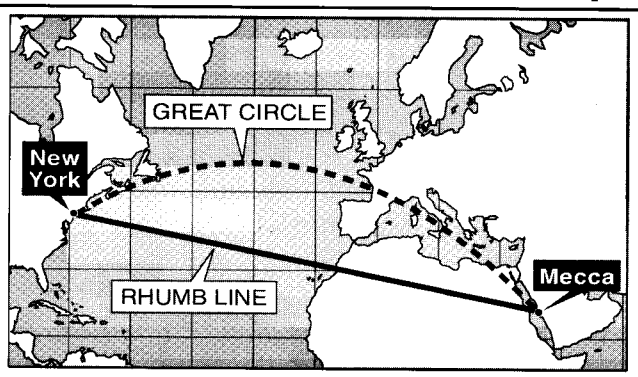

Figure 1. *Example of Great Circle Versus Rhumb Line (as shown on a Mercator map projection). The great-circle route (i.e., the shortest distance) between New York and Mecca is 6,400 miles long. The rhumb line (i.e., the line of constant direction) is 6,800 miles long.*

connecting two points on the earth along a rhumb line—though it will likely not be the shortest path—will maintain the same constant compass direction all the way along the path. Thus, a second definition of a "straight" line on a

curved surface assumes that if the "true" direction between two points—even on a curved surface and even if it is not the shortest route—is to mean anything, it must mean the same direction all along the line between those two points (i.e., along the rhumb line). So of the two possible mathematical solutions to the direction-facing problem, the great circle distorts our intuitive notion of direction (i.e., that direction is constant all along a "straight" line), whereas the rhumb line distorts our intuitive notion of distance (i.e., that the distance along a "straight" line is the shortest distance between two points). In practice, if "the two points are within a few hundred miles, there is little difference between the two [methods], but at great distances they differ widely" (Raisz 1962, 150) in providing an initial compass direction.

The rhumb line is closely tied with perhaps the most well-known map projection—popular in many classrooms—the Mercator projection, which shows all latitude (east-west) lines as horizontal and all longitude (north-south) lines as vertical. Although Gerhard Mercator's map does, at any given location, show the same scale in both directions—thereby preserving the two-dimensional shape of any small area (i.e., the map is conformal)—the scale itself becomes enormously exaggerated at locations toward the poles: "South America is over nine times the size of Greenland, but who would believe it from this map?" (Greenhood 1964, 128). The most notable feature of Mercator's map, however, is that a straight line drawn between two points on the map is the rhumb line between those points:

> "If you wish to sail from one port to another," the Flemish map-maker wrote of his work when he first brought it out in 1569, "here is a chart, and a straight line on it, and if you follow this line carefully you will certainly arrive at your destination. But the length of the line may not be correct. You may get there sooner or may not get there as soon as you expected but you will certainly get there." (Greenhood 1964, 128)

Thus, when navigators talk of Mercator sailing, or of "flying a Mercator course," they mean traveling along a rhumb line, which cuts every meridian (north-south line) at the same angle.

To determine the angle (direction), Z, of a rhumb line between two locations on a sphere, we can simply place a straight edge and a protractor on top of a Mercator map. A more precise method,[2] however, is the following mathematical equation:

$$Z = \text{Arctan}\left(\frac{\Delta Lo}{M_1 - M_2}\right),$$

where

$$M = \frac{180}{\pi}\left[ln\tan\left(45° + \frac{Lat}{2}\right)\right].$$

In this equation ΔLo is the absolute value of the difference in longitude between the two points (minimum of 0° and maximum of 180°), *ln* is the natural log, and *Lat* is the latitude of point 1 (for M_1) and of point 2 (for M_2); again, *Lat* should be a negative number for southern latitudes.

Table 1. Adjustment to Angle Z to Compute Compass Direction

For a Great Circle:	If the initial location is to the _____ of the destination city	and if	Direction to Face
	west	0 < Z	Z
	west	Z < 0	180° + Z
	east*	0 < Z	360° - Z
	east*	Z < 0	180° - Z

For a Rhumb Line:	If the initial location is to the _____ of the destination city	Direction to Face
	northwest	180° - Z
	southwest	Z
	northeast*	180° + Z
	southeast*	360° - Z

*Note that cities such as Anchorage and Honolulu are closer to the Middle East via the international dateline than via the Atlantic Ocean. Thus, such cities—located between the international dateline and the line of longitude that is exactly halfway around the world from Jerusalem or Mecca—are considered to be to the *east* of the destination in Tables 2 and 3.

Table 2 Compass Direction to Face Jerusalem for Selected Cities

City	Latitude	Longitude	Direction to Face		Divergence Measure*: R.L. – G.C.
			Rhumb Line (R.L.)	Great Circle (G.C.)	
Anchorage	61°01'N	150°00'W	256°	356°	–100°
San Francisco	37°45'N	122°27'W	93°	20°	+73°
Los Angeles	34°03'N	118°15'W	91°	24°	+67°
Chicago	41°50'N	87°37'W	96°	46°	+50°
Miami	25°45'N	80°15'W	87°	50°	+36°
Toronto	43°42'N	79°25'W	97°	51°	+47°
Washington	38°55'N	77°00'W	94°	52°	+42°
Philadelphia	40°00'N	75°10'W	95°	53°	+42°
New York	40°43'N	74°00'W	96°	54°	+42°
Boston	42°21'N	71°04'W	97°	56°	+41°
Buenos Aires, Argentina	34°40'S	58°30'W	53°	65°	–12°
London, England	51°30'N	0°10'W	127°	114°	+14°
Paris, France	48°52'N	2°20'E	125°	112°	+12°
Budapest, Hungary	47°30'N	19°03'E	142°	136°	+6°
Johannesburg, S. Africa	26°10'S	28°02'E	7°	7°	0°
Kiev, Ukraine	50°25'N	30°30'E	169°	168°	+2°
Tel Aviv, Israel	32°05'N	34°46'E	128°	128°	0°
Haifa, Israel	32°49'N	34°59'E	168°	168°	0°
Moscow, Russia	55°45'N	37°37'E	184°	185°	–1°
Tokyo, Japan	35°40'N	139°45'E	267°	304°	–36°
Melbourne, Australia	37°50'S	144°59'E	304°	287°	+17°

* May appear to be off by 1° due to rounding.

Comparisons

Adjustments to the angle Z, depending on whether or not Z is positive or negative and on the orientation of point 1 vis-à-vis the destination city (Jerusalem or Mecca),[3] are given in Table 1 for the great circle and for the rhumb line.

I estimate the coordinates for the site of the destroyed Jewish Temple in Jerusalem as 31°46'40"N latitude, 35°14'04"E longitude (*American Practical Navigator* 1981; Survey of Israel 1994; 1995), and for the Ka'ba in Mecca as 21°25'17"N latitude, 39°49'32"E longitude (Saudi Publishing House 1970; *American Practical Navigator* 1981). For 21 selected cities, most with large Jewish populations (Institute of the World Jewish Congress 1998), Table 2 shows the compass direction for facing Jerusalem. Anchorage, with only 2,300 Jews (Schwartz and Scheckner 1999), and Tokyo, with only 1,000 Jews (Institute of the World Jewish Congress 1998), are included here because of their interesting geographic location. Table 3 shows the compass direction for facing Mecca from 21 selected cities, most with large Muslim populations (Johnson 1996; Nanji 1996a; 1996b). In both tables the cities are listed in order from west to east. The "direction to face" should be interpreted using the compass of Figure 2, where 0° is due north, 90° is due east, and so on.

The difference between the great circle versus the rhumb line methods, shown in the last column of Tables 2 and 3, is minuscule for cities, such as Tel Aviv and Haifa in Table 2, that are within 100 miles of the destination city. In contrast, among the cities listed, the two methods yield markedly different outcomes for the cities of North America. The primary reason for this divergence is that,

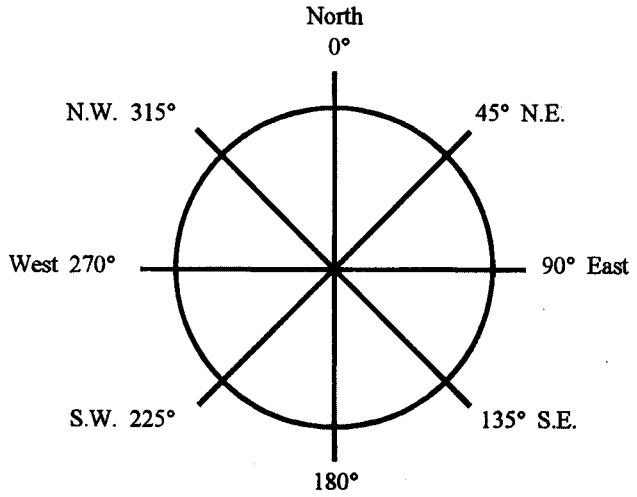

Figure 2. Compass direction

Table 3. Compass Direction to Face Mecca for Selected Cities

City	Latitude	Longitude	Direction to Face		Divergence Measure*: R.L. – G.C.
			Rhumb Line (R.L.)	Great Circle (G.C.)	
Los Angeles	34°03'N	118°15'W	95°	24°	+71°
Chicago	41°50'N	87°37'W	101°	49°	+52°
Detroit	42°23'N	83°05'W	101°	52°	+49°
Toronto	43°42'N	79°25'W	103°	55°	+48°
New York	40°43'N	74°00'W	101°	58°	+43°
Casablanca, Morocco	33°39'N	7°35'W	106°	94°	+13°
London, England	51°30'N	0°10'W	134°	119°	+15°
Paris, France	48°52'N	2°20'E	132°	119°	+13°
Algiers, Algeria	36°50'N	3°00'E	16°	105°	+10°
Istanbul, Turkey	41°02'N	28°57'E	155°	152°	+3°
Cairo, Egypt	30°03'N	31°15'E	138°	136°	+2°
Baghdad, Iraq	33°20'N	44°26'E	199°	200°	–1°
Riyadh, Saudi Arabia	24°39'N	46°46'E	243°	245°	–1°
Teheran, Iran	35°40'N	51°26'E	215°	219°	–3°
Karachi, Pakistan	24°51'N	67°02'E	262°	268°	–6°
Tashkent, Uzbekistan	41°16'N	69°13'E	231°	240°	–9°
Dhaka, Bangladesh	23°42'N	101°42'E	287°	293°	–6°
Jakarta, Indonesia	6°08'S	106°45'E	293°	295°	–2°
Ji'an, China	34°16'N	108°54'E	258°	278°	–19°
Beijing, China	39°55'N	116°26'E	254°	279°	–25°

* May appear to be off by 1° due to rounding.

when two points are located very far apart from each other but are on the same side of the equator (e.g., New York and Mecca), the shortest path between them (i.e., the great circle) "swings by" the nearest pole (see Fig. 1). For example, Mecca is south and east of New York, yet the great-circle route from New York to Mecca begins by facing *north*east (58°) and goes up along the Canadian coastline, then across the North Atlantic, before returning south through Europe and the Mediterranean to arrive in Mecca; in contrast, the rhumb line—which is 400 miles longer—goes southeast straight across the warm waters of the Atlantic and then North Africa, facing 101° the whole time.

When the destination is Jerusalem or Mecca—both of which are in the northern hemisphere—the only major cities far enough away but still also in the northern hemisphere are those in North America and, to a lesser extent, in East Asia. Thus, while the choice of great circle versus rhumb line is, in general, a significant theoretical decision in choosing which compass direction to face, as a practical matter, the difference between the two methods are of major consequence only in North America. Given the long history of Judaism and Islam, then, the problem of which mathematically derived direction-facing method to choose is, relatively speaking, a rather recent conundrum.

Conclusion

Which method is better for solving the direction-facing problem: the great circle, with its shortest distance, or the rhumb line, with its constant angle? Historically, Muslims and Bahá'ís have favored the great-circle definition of a "straight" line on the globe (King 1986), although this choice has occasionally generated considerable controversy among North American Muslims (Eissa 1996). Jews have not chosen any particular definition, and often use only approximate solutions to the problem, such as choosing a direction only among north, south, east, or west. In any event, for most cities around the world, with the exception of North America, the differences between the two methods outlined here are fairly small (see Tables 2 and 3).

This question of which method is better, however, is *not* one we can answer with sophisticated maps and formulas; it is a theoretical issue that ultimately depends on which of the two components of the "straight"-path concept we choose to emphasize, distance or direction. In fact, this issue is analogous to instances in other fields of ambiguous or indeterminate concepts open to rival interpretations. For example, many in political science have concluded that no objective and nonpartisan criteria exist for determining the "fairness" of a redistricting plan (Levin 1988). Similarly, in the field of organization management, researchers have concluded that no objective, mutually

Box 1. *Do the Math: Facing Mecca from New York City*

Students can work through this example (see Fig. 1) and then do the calculations for their own city. To figure out the initial compass direction of the **great circle** from New York City (40°43'N lat., 74°00'W lo.) to Mecca (21°25'17"N lat., 39°49'32"E lo.), the formula is:

$$Z = \text{Arctan}\left(\frac{\sin(\Delta Lo)}{\cos(Lat_1)\tan(Lat_2) - \sin(Lat_1)\cos(\Delta Lo)}\right),$$

where, after converting all coordinates to decimals, we get:

$\Delta Lo = 74° + (39 + 49/60 + 32/3600)° = 113.83°$

$Lat_1 = 40 + 43/60 = 40.72°$

$Lat_2 = 21 + 25/60 + 17/3600 = 21.42°$

Remember that ΔLo is the distance (in degrees) between the two longitudes (minimum of 0° and maximum of 180°). We can now plug these numbers into the formula to get:

$$Z = \text{Arctan}\left(\frac{\sin(113.83°)}{\cos(40.72°)\tan(21.42°) - \sin(40.72°)\cos(113.83°)}\right)$$

$$= \text{Arctan}\left(\frac{0.9147}{0.7579(0.3923) - 0.6524(-0.4040)}\right) = \text{Arctan}(1.6308) = 58.48°.$$

We then look at Table 1 to see if an adjustment to Z (in this case, 58°) is needed: since the initial location (New York) is to the west of the destination city (Mecca) and since 0 < 58°, the direction to face Mecca from New York City, based on the great circle, is 58° (i.e., towards the northeast).

Using the same decimal-based geographic coordinates listed above, we can also figure out the constant compass direction of the **rhumb line** from New York to Mecca. The formula is:

$$Z = \text{Arctan}\left(\frac{\Delta Lo}{M_1 - M_2}\right),$$

where

$$M = \frac{180}{\pi}\left[ln\tan\left(45° + \frac{Lat}{2}\right)\right].$$

Remember that *ln* is the natural log, and *Lat* should be a negative number for southern latitudes.
For New York,

$$M_1 = \frac{180}{\pi}\left[ln\tan\left(45° + \frac{40.72°}{2}\right)\right] = \frac{180}{\pi}\left[ln\tan(65.36°)\right] = \frac{180}{\pi}[ln(2.180)]$$

$$= \frac{180}{\pi}(0.7794) = 44.66.$$

For Mecca,

$$M_2 = \frac{180}{\pi}\left[ln\tan\left(45° + \frac{21.42°}{2}\right)\right] = \frac{180}{\pi}\left[ln\tan(55.71°)\right] = \frac{180}{\pi}[ln(1.466)]$$

$$= \frac{180}{\pi}(0.3829) = 21.94.$$

We can now plug these numbers into the rhumb line formula for Z to get:

$$Z = \text{Arctan}\left(\frac{113.83°}{44.66 - 21.94}\right) = \text{Arctan}(5.01) = 78.7°.$$

We then look at Table 1 to adjust Z (in this case, 79°): since the initial location (New York) is to the northwest of the destination city (Mecca), the direction to face Mecca from New York City, according to the rhumb line, would be 180° – 79° = 101° (i.e., east by southeast).

Using both the great circle and rhumb line, in what direction would you face another city on the globe from *your* hometown?

agreed-upon criteria exist for evaluating the "effectiveness" of an organization (Hirsch and Levin 1999). Ultimately, then, the definition of the "straight-line-on-a-curved-surface" concept is likely to remain unsettled and open to debate.

Thus, the direction-facing problem, in addition to its importance to major religious institutions, underscores an important point about the inter-connections among social ideas, intuitive assumptions, and scientific analysis. For when social ideas, such as unity among a group's members, are translated into concrete action, such as having a central location for directing thoughts and prayers, the actions will likely be based on prevailing—often unstated—norms and assumptions (DiMaggio and Powell 1983); in this case, the assumption that a "straight" path (even on a curved surface) has a unique meaning. When confronted with new realities, however, such as immigration to North America, where the two possible geography-based "straight"-line options differ markedly, problems may arise. Ultimately, while a mathematical and geographic analysis of the direction-facing problem can help frame the scientific issues, it cannot solve the problem fully—this task is a theoretical (even theological) matter, with which the relevant groups and institutions themselves must grapple. Still, students of geography should realize the next time they are in a synagogue, church, mosque, or temple that even here we can apply the principles and techniques of geographic analysis.

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Notes

1. Note that the equations used in this article assume that the earth is a perfect sphere, although it is in fact spheroidal, flattened slightly at the poles. "On the spheroidal earth the shortest line is called a *geodesic*. A great circle [however] is a near enough approximation of a geodesic for most problems of navigation" (*American Practical Navigator* 1981, 700) and is therefore used here. Readers interested in the (extraordinarily complicated) formula for the initial angle of a geodesic may wish to consult a text on geodesy (e.g., Bomford 1983).
2. For even greater precision in determining a rhumb line, one can take into account that the earth is not a perfect sphere by slightly modifying the equation for M (see Pearson 1984, 83); I have found, however, that this result rarely differs by more than one-sixth of a degree, so the more complicated rhumb line formula is not used here.
3. To calculate the Bahá'í *qiblih*, based on the great-circle path toward Acre, see Brown and Bromberek (2000).

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NOTE: All biblical or classical Jewish, Muslim, and Bahá'í texts are cited in the body of the article and not by their author(s) in the References section.

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