Visualizing Cyclic Spatio-Temporal Patterns in Polar Coordinate Systems

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Abstract

Spatio-temporal phenomena used to be represented in Cartesian Coordinate Systems, and time is perceived linear. This way of representing time may not be appropriate for representing and analysing some types of natural and human phenomena, which occur in time cycles. This paper thus proposes the use of polar coordinate systems. Polar angles are used to represent time, which can be clock time at daily, monthly or yearly resolution. Polar distances are applied to represent moving extensions in space, i.e., distances of natural or human objects to their reference places (such as the home of a person or an animal, or the average temperature of a month). A human activity pattern example is used to illustrate and demonstrate how spatial and temporal patterns can be fully represented in polar coordinate systems. We will also argue that the proposed approach has great advantages in identifying the characteristics of spatio-temporal patterns.

1. Introduction

There are in general three ways of representing spatio-temporal phenomena, though different classifications exist: state-based, symbol-based and animation-based. In the state-based approach, spatio-temporal patterns are represented by snap-shots, i.e., spatial patterns at different points in time are recorded (Langran, 1992; Peuqeut and Duan, 1995). In the symbol-based approach, legends of different sizes, colours or shapes are used to represent changing thematic values or boundaries, or/and changing speeds of movement (Kraak et al 1997; Peterson, 1999). Recently, dynamic symbols such as blinking, glowing, growing and marquee are used to draw attention and show speed (Yeh et al., 2000). With the diffusion of multimedia technology, the use of animation as a means of spatio-temporal representation and visualization is gaining momentum. In this approach, the time series images panning or zooming are displayed around two-dimensional static maps or showing them one after another in a temporal order or as a 3D cube (MidtbΦ, 2000; Jomier et al, 2000).

In almost all of the existing approaches, spatial information is represented in a Cartesian coordinate system and time is perceived linear. Such presentation of time may not be appropriate for accurately visualizing and analysing some types of human and natural phenomena, which occur in cycles, e.g., the seasonal movement of migratory birds and human activities, which are conducted according to man-made calendars of cyclic time. It is important for the representation of these kinds of phenomena to reveal their cyclic patterns.

This paper thus proposes the use of polar coordinate systems. Polar angles are used to represent time, which can be clock time at daily, monthly or yearly resolution. Polar distances are applied to represent moving extensions in space, i.e., distances of natural or human objects to their reference places (such as the home of a person or an animal, or the average temperature of a month). A human activity pattern example is used to illustrate and demonstrate how spatial and temporal patterns can be fully represented in polar coordinate systems. We will also argue that the proposed approach has great advantages in identifying the characteristics of spatio-temporal patterns.

This paper is structured as follows. The next section introduces the polar coordinate systems and explores the possibility of using polar coordinate systems (PCS) to represent spatial and temporal patterns. Section 3 demonstrates the representation of spatio-temporal movement in the PCS, using the human activity pattern example. Section 4 discusses the application of the PCS representation in identifying the characteristics and measurements of spatio-temporal patterns. The last section summarizes the major finding and suggests future research issues.

2. Representing spatial-temporal patterns in Polar Coordinate Systems

2.1 Cyclic natural and human phenomena

There are many natural and man-made events that occur in time cycles. In Winter, migratory birds temporarily migrate from the North to the South to avoid the harsh weather in the North; sea levels are usually lower in the morning and higher in the evening due to the movement of tide waves; In most areas of the world, climate changes in four seasons every year; human beings arrange their activities according to calendar times: they usually have schedules for each day, each month or each year. The economy of a country or even the whole world may experience recessions in every few years.

All the phenomena mentioned above have a common characteristic: they all occur in time cycles, in other words, they commit to cyclic spatial and temporal patterns. It is important for the visualization of such patterns to reveal the cyclic feature of these phenomena.

2.2 Polar coordinate system

The coordinates of a point can be given in two ways – using the Cartesian coordinate system or using the polar coordinate system. In the Cartesian coordinate system, two orthogonal axes are used to measure the relative spatial position of points, in other words, a pair of real numbers (representing the position of the points on the two axes), called coordinates, shows the spatial position of a point in a planar surface. In the polar coordinate system, a different way of representing spatial positions is adopted. We shall explain it in more details in the following paragraph.

To define a polar coordinate system, one needs to select a point *O* in the plane and a ray extending outward from the point along the positive *x*-axis (See Figure 1.) The point is called the **pole** and the ray is called the **polar axis**. The **polar coordinates** of a point *P* are pair of real numbers (r, θ), where r is the distance of *P* from the pole and θ is the angle that the line segment $\overline{OP}$ makes with the polar axis (See Figure 1.) The pole is assigned the coordinates (0, θ)□, where θ represents the angle, can be any number between 0 and 360.

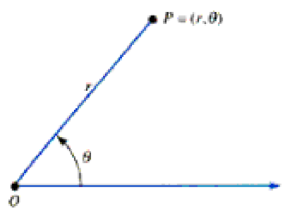

Figure 1. Polar coordinate system

2.3 Representing spatial-temporal dimensions in PCS

When an event changes over time, it is essential for the visualization of that event to include a variable that shows the time dimension. In other words, the time dimension needs to be presented in together with the main phenomena we want to show. Two types of representation have been adopted: legends in a separate display area (such as analogue clock, side bar, or numerical) or embedded into map display as a variable on the map (Kraak et al, 1997).

Conventionally time is represented as a third dimension in the Cartesian coordinate system, orthogonal to the two spatial dimensions: x and y (Langran, 1992). This representation assumes that events occur in linear time, not in cyclic time. This view of time is very different from human's general view of time: in clock. It is needed to represent the time dimension in accordance with human being's general perception of time.

In the polar coordinate system, the polar angle can be used to represent the time dimension, which can be a clock at daily, monthly or yearly resolution. It means the full range of (360^0) can represent a cycle of 24-hours, 30-days, 12-months or any other time duration that is a time unit for an event to repeat. The status of the event (or a object) can be represented by the polar distance, which shows the distance between the current status and its reference status (or place) (such as the home of a person or an animal, or the average temperature of a month). In such a way, the changing pattern (e.g., the moving extension in space) can be clearly revealed.

Therefore, the spatio-temporal information of an object *P* are represented by triple elements (r, θ, a), with $r \geq 0$ representing the distance of the current position of *P* to the central point *O*, with angle θ in the negative direction to the polar axis representing the time dimension, and with *a* representing the attributes of the object. Based upon these triple elements, the states of the object, i.e. the spatial, temporal and thematic information are represented. This supports the clock view of time.

In case we need a duration view of time, one more dimension of time is added to the triple elements. Therefore, a four-tuple representation can be created as $P(r, \theta_1, \theta_2, a)$, which means during time (θ_1, θ_2) the object has the attribute *a*. Of course in our term, the attribute a can be a single or a set of thematic attribute(s) of *P*.

3. Illustration: visualizing people's daily activity patterns in PCS

To illustrate and test the idea of representing spatio-temporal patterns in PCS, let us examine the activity pattern of a hypothetical person in 24 hours:

0:00 – 8:30 staying at home
8:30 – 9:00 travelling from home to office
9:00 – 12:00 working
12:00 – 12:15 going to restaurant
12:15 – 13:00 having lunch
13:00 – 13:15 going back to office
13:15 – 18:00 working
18:00 – 18:10 going to a shop
18:10 – 19:00 shopping
19:00 – 19:30 going back home
19:30 – 24:00 staying at home

We may display this activity pattern in a Cartesian coordinate system with the horizontal axis representing the clock time (in a linear way) and the vertical axis representing the spatial relations of the activity destinations. Figure 2 shows the graphic representation of the activity pattern. The horizontal solid lines indicate that the person stays in activity destinations (the length of the lines represents the duration of stays), while the dash slant lines suggest that the person is travelling between activity destinations.

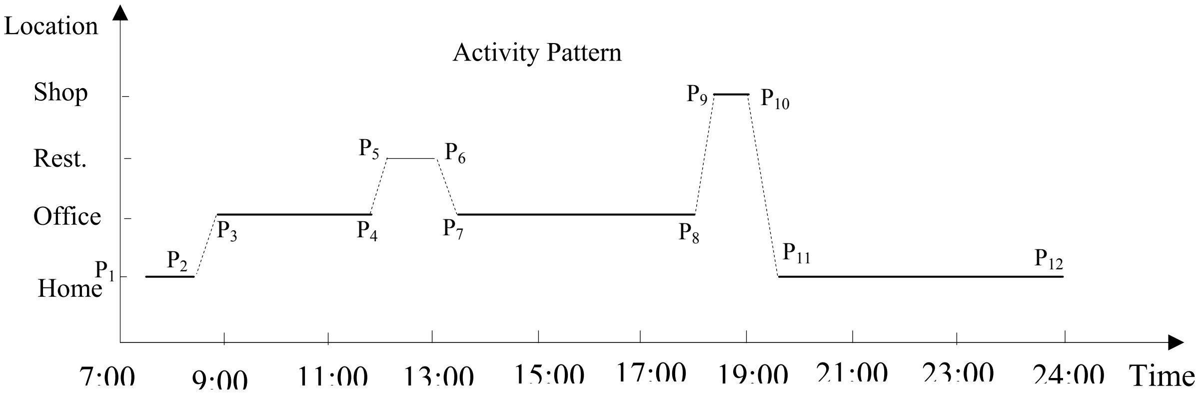

Figure 2. Display the activity patterns in a two dimensions (Wang & Cheng, 2001).

Although it is easy to tell from the representation the mobility status (stay or travel between) of the activity pattern, the spatial relations between activity destinations, however, cannot properly represented. As a result, the representation gives no information as for how far apart the activity destinations are. In the following paragraph, we will explain how this same activity pattern may be represented in the PCS.

We may use home as the pole and all other activity destinations are represented in reference to this pole by polar distance, which indicates the actual spatial relations between activity destinations and home. As we understood from previous discussion, activity patterns can be considered as a series of stay (in activity destinations) and travel between (activity destinations), the key to represent activity patterns is thus to accurately visualize these two mobility statuses. Since a travel-between is the moving between two activity destinations, which have different distances from home, it is represented by a curve between two points: a starting point and an ending point. The starting point represents the location and the ending time point of the previous stay in the activity pattern. The two coordinates of this starting point are respectively the polar distance r (indicating the spatial relation of the location of the previous stay to home) and the polar angle θ (indicating the clock time of the ending time of the previous stay). The ending point represents the location and the starting time point of the next stay in the activity pattern. The two coordinates of this ending point are respectively the polar distance r (indicating the spatial relation of the location of the next stay to home) and the polar angle θ (indicating the clock time of the starting time of the next stay). This curve between the two points is not parallel to the cycles, because as travel-between proceeds, the spatial relation of the person to home is constantly changing. The representation of stay is straightforward. It also requires two points to show its starting time point and ending time point. In this case, since the person stay in the same place, there is no change in the spatial relationship to home, the curve between the two points is thus a curve parallel to the cycles. Table 1 shows the starting and ending points of all stay and travel-between segments of the activity pattern explained earlier. Table 2 lists the polar coordinates of these points.

Table 1 Starting and ending points of stay and travel-betweens

Activity	Starting	Ending
S_1	P_1	P_2
T_1	P_2	P_3
S_2	P_3	P_4
T_2	P_4	P_5
S_3	P_5	P_6
T_3	P_6	P_7
S_4	P_7	P_8
T_4	P_8	P_9
S_5	P_9	P_{10}
T_5	P_{10}	P_{11}
S_6	P_{11}	P_{12}

Table 2. Coordinates of Polar Points.

Point	R	θ (clock time)	θ (angle)	Attribute
P_1	0	0	0	S
P_2	0	8:30	127.5^0	S
P_3	R_1	9:00	135^0	T
P_4	R_1	12:00	180^0	S
P_5	R_2	12:15	183.75^0	T
P_6	R_2	13:00	195^0	S
P_7	R_1	13:15	198.75^0	T
P_8	R_1	18:00	270^0	S
P_9	R_3	18:10	272.5^0	T
P_{10}	R_3	19:00	285^0	S
P_{11}	0	19:30	292.5^0	T
P_{12}	0	24:00	360^0	S

Graphically, we may represent the information in Table 2 in Figure 3. We may use different colours to represent different activities (stays such as at-home, in office, etc.) and travel between different locations (see also Wang & Cheng, 2001). It is revealed in Figure 3 that the spatial relationships between home activity destinations are clearly visualized. It also shows the shopping (S_5) is conducted on the way home from the office, which cannot be shown in Figure 2.

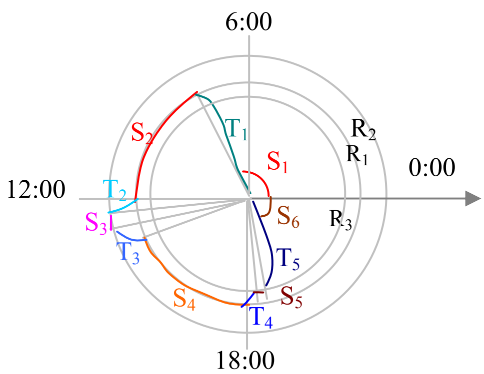

Figure 3. Representing an activity pattern in PCS.

4. Measuring cyclic spatio-temporal patterns

In this section, we will argue that, based on the PCS representation, it is easy to develop indicators that measure the characteristics of activity patterns. The most important parameters for analysing the activity pattern of a person are: the number of trips (NT), number of home based trips (NHT), the total travel time (T) and the total time spend out of home (TOH), etc. This information can be easily obtained from Table 2. If we assume there are in total K ending points in Figure 3, the calculation of these parameters is quite simple and shown as follows.

(1) Calculating the number of trips

```
NT=0;
For i=1,K-1
    If a_{i+1} = T
        then
            NT = NT + 1;
            next i;
```

(2) Calculating the Total-travel-time

```
T=0;
For i=1,K-1
  If a_{i+1} = T
      Then
          t = θ_{i+1} − θ_i;
          T = T + t ;
          next i;
```

(3) Calculating the total time spend out of the home

```
TOH=0;
For i=1,K-1
  If r_i = 0 and r_{i+1} = 0
      Then
          t = θ_{i+1} − θ_i;
          TOH = TOH + t ;
          next i;
TOH = 24 − TOH ;
```

(4) Calculating the number of home based trips

```
NHT=0;
For i=1,K
```

if ($r_i = 0$ and $r_{i+1} \neq 0$) or ($r_i \neq 0$ and $r_{i+1} = 0$)
Then
$NHT = NHT + 1$;
next i;

In the case of Figure 3, we may easily obtain the following results: *NT*=5, *NHT*=2, *T*=100 minutes; *NHT*=9 hours.

As demonstrated above, it is easy to derive measures showing the characteristics of activity patterns. Based on these measures, one may compare and classify activity patterns of different people. In such a way, the representation facilitates the analysis of spatio-temporal patterns.

5. Summary

We have in this paper proposed the use of Polar Coordinate System to visualize spatio-temporal patterns. It was argued that the PCS approach of representation is particularly useful, though not limited to, cyclic spatio-temporal patterns, such as human being's activity patterns, seasonal changes of weather, etc. The advantages of this method are: first, it shows the motion status of objects in a quite obvious way. Secondly, spatial and time dimensions are integrated in one diagram. Thirdly and most importantly, the PCS representation makes it easy to derive parameters that describe the characteristics of spatio-temporal patterns. It greatly facilitates the comparison and classification of different patterns. Finally, the PCS representation nicely structures spatio-temporal pattern information, and thus makes it easy for data management in an information system.

The PCS representation has as well disadvantages. The approach may not be suitable for linear and area objects whose dynamics are manifested in shape changes, rather than changes in spatial positions. It will take some efforts to draw the diagram (Figure 3), although it is possible to develop a computer program to draw it automatically. The latter is the work we shall do in future.

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