A Time-Series Animation of Urban Growth in Copenhagen Metropolitan Area

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Abstract. The growth of cities represents huge problems for modern societies. The explanation of the phenomena involves the description of changes. The Danish Building & Dwelling database is a quasi spatio-temporal database containing spatial dimensions as well as a temporal one. Based on this database, a time-series animation of the urban growth in the Copenhagen Metropolitan area is produced. Furthermore, the Internet provides new possibilities for dynamic visualisation using animated GIF files or AVI films.

1 Introduction

The problems related to the growth of cities and the concentration of human population into large metropolitan areas represent huge challenges for modern societies. Economic growth drives urban expansion in the form of construction of businesses, dwellings, roads, leisure centres etc., and the metropolitan regions face the growing problems of urban sprawl, including a decline in natural vegetation, wildlife habitats and agricultural land. The replacement of undeveloped land by residential and commercial development continues at an unprecedented rate.

The study of geography is basically spatial but in order to understand geographical phenomena (e.g. urban growth) it is necessary to study how these patterns change over time. Geographers, planners and cartographers have long attempted to visualise changes by integrating spatial and temporal information on a map. Usually the result is a series of maps showing certain themes at different times.

However, the limitations of static maps to depict changes are widely recognised. Among the methods that can be used to visualise temporal characteristics of geographic data, animated maps seem particularly suitable. The viewer will experience an impression of continuity if the difference between successive frames is not too large, and an appropriate display speed is chosen.

A temporal GIS seems to possess the most suitable environment for time-series animation. The current paper applies a kind of spatio-temporal database to create a time-series animation of urban growth in the Copenhagen metropolitan area from the end of the Second World War in 1945 until today represented by the year 1995.

The current paper is divided into five main parts. First, I present some basic concepts of time and how these concepts can be applied within the current study. Next, various animation techniques are described and advantages and disadvantages are discussed. Third, I describe how to build a quasi spatio-temporal database covering the built environment in Greater Copenhagen. Fourth, I present how to generate animations based on the quasi spatio-temporal database and discuss the general quality of the animations. Finally, some concluding remarks and a presentation of subsequent research.

2 Concepts of time

Usually, time is assumed to be linear and similar to space. Therefore, time can be considered as the fourth dimension in addition to the three-dimensional space. The most general way of storing temporally referenced real world data is in the form of four-dimensional(4D) objects in a 4D time-space. Temporal GIS incorporates time as a fundamental component of the database. In comparison to a traditional GIS, a temporal GIS is able to search for temporal patterns. Thus, the user can search applying both the “where” and “when” clause.

Time in a spatio-temporal information database may be measured as a discrete or continuous variable (Worboys, 1995). While a continuous variable assumes that values at any time can be obtained by interpolation, a discrete temporal variable means that the variation is discontinuous between the time of measurements. Obviously, urban growth phenomena belong to the last category.

Traditional spatial information systems retain only the latest state of the modelled system, presenting an up-to-date, but static view of the world. However, there is a need for functionality to handle time as well as space, but until now a general spatio-temporal database isn’t available. Furthermore, there is a general lack of data with a time dimension as well as space dimensions. Nevertheless, some data sources can provide the needed information for time-series animation of spatial processes. Below various approaches to this so-called cartographic time are described:

- The space-time cube. A three-dimensional cube that represents one time and two space dimensions. Following Hägerstrand (1982), time and space can be conceived as resources on which individuals have to draw in their daily social life. Within the space-time cube the trajectory of a two-dimensional object through time creates a worm-like pattern (fig. 1). This approach is often used in modelling the daily space-time activity patterns of human beings. Finally, the space-time cube fits very well into the growing use of GPS.

- Time-slice snapshots are an intuitively appealing space-time model with roots in traditional cartography, imitating the progressive nature of a slow-motion video (Langran, 1992). The individual time slices represented by maps describe the situation at the times of map creation (fig. 1). Thus the snapshots represent states rather than changes, providing no information on how to go from one state to the next. The various map series are usually many years apart, causing a very low temporal granularity. Traditionally, time-slice snapshots have been used extensively in time-series animation (e.g. Acevedo & Masuoka, 1997).
- Spatio-temporal database. Simple cartographic snapshots are not sufficient for highly dynamic phenomena. Time must be incorporated as a fundamental component of a geographic information system. Whenever new data becomes available, the database is updated reflecting the real world situation (fig. 1). Every object has both geometric and temporal attributes. Thus a historical record is built up within the geographic information system, providing very good opportunities for theory building and dynamic visualisation. This kind of spatio-temporal data model was originally developed by Peuquet and Duan (1995).

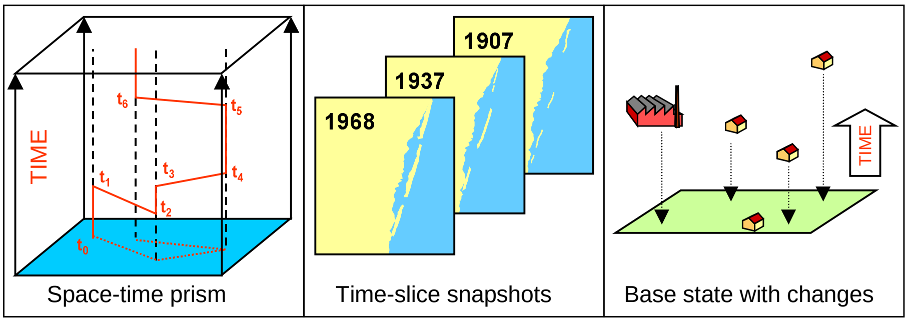

Fig. 1. Models of space and time.

3 Animation techniques

Following Peterson (1994) computer animations can be grouped into two main categories: frame-based animations and cast-based animations. The frame-based animation represents the simplest type of animation, where the individual frames are created by GIS or graphics software. Displaying the frames quickly creates an illusion of movement or change. Cast-based animation is based on the concept of the 'cel', which is an individual layer of an animation frame. A frame of animation can be composed of many layers – e.g. a background layer and some foreground layers containing an object that can move on the background. The first generation of computer games like PacMan was based on this animation technique.

Evidently, the cast-based animation appears to be well suited in connection to the space-time cube concept, where an object (e.g. a person) is moving on top of a land surface (e.g. an urban landscape). Thus, the foreground layer contains the moving object whereas the land surface is represented by the background layer.

Based on the time-slice concept, a simple frame-based animation can be generated by displaying the original maps sequentially. Usually, the time interval differs between the map sheets, and consequently the spacing of real time might be irregular. Mapping real time evenly to display time can be obtained by duplicating the original input data an appropriate number of frames. However, this technique may give the user an impression of long periods of steadiness, followed by sudden changes. One way to circumvent this situation is to provide intermediate frames using interpolation techniques. This may improve the visual perception of changes.

Instead of generating intermediate frames, a spatio-temporal database can be used to create the frames. Thus, frames can be created for each time step, and this approach is applied in the current project.

Producing a time-series animation requires various issues to be taken into consideration. However, please note that the optimal animation has to be measured in the light of the original data provided.

- The number of original data frames is decisive for the overall quality of the animation – the greater the number of original data frames the better the representation of the real-world situation. If the animation is based on cartographic products, it may be difficult to provide enough original data frames. Consequently, interpolated frames will make up a significant part of the animation. However, working with discrete variables like urban growth will make it difficult to interpolate intermediate frames. On the other hand a spatio-temporal database will support the creation of as many data frames as needed – only the temporal resolution will define the limit.

- The display speed for a spatio-temporal animation is decisive for the communication of changes in space and time. Following Acevedo & Masuoka (1997) the optimal display speed is dependent on human visual perception and cognition, the objectives of the animation, and the rate of change within the data. Obviously, an interactive display environment, which encourages the user to select an appropriate display speed, is preferable.

4 Data

Traditionally, topographic maps have been applied to time-series animation of geographic data. Since 1945, six topographic maps in scale 1 : 100,000 covering the years 1959, 1975, 1981, 1987, 1992 and1998 were produced by the Danish National Survey & Cadastre. Before the Second World War, three topographic maps covering the years 1902, 1918 and 1933 are available. Clearly, this is insufficient to produce a time-series animation of urban growth. Therefore I turned my attention to other data sources.

The current study is based on two national data sets, of which the Danish Building & Dwelling database (BBR in Danish) is the most important data set. This database contains detailed information concerning every building in Denmark and has been in operation since 1977. The Building & Dwelling database is maintained by the Danish local authorities as a part of the general administration of real estates and buildings. The database uses 3 levels of registration (fig. 2):

- Property level - type of ownership, sewage disposal system etc. are stored. A unique *property number* is the primary key at this level.
- Building level - purpose for which the building is used, year of construction, material of outer walls etc. are stored. The individual buildings are identified by a composite key made by *property number* and a *building number*.
- Unit level - area of the unit, number of rooms, kitchen facilities etc. are stored. The dwelling units are identified by *addresses*.

Only the building level is considered within the current project. Besides this, the Building & Dwelling database contains some additional foreign keys (e.g. municipality number, road code and house number / letter). In the current context, the year of construction plays a key role, making possible the assignment of a temporal dimension to the data. The temporal granularity in this case is one year, although the Building & Dwelling database is updated continuously. The spatial dimensions are provided through the address assigned to all buildings in the database.

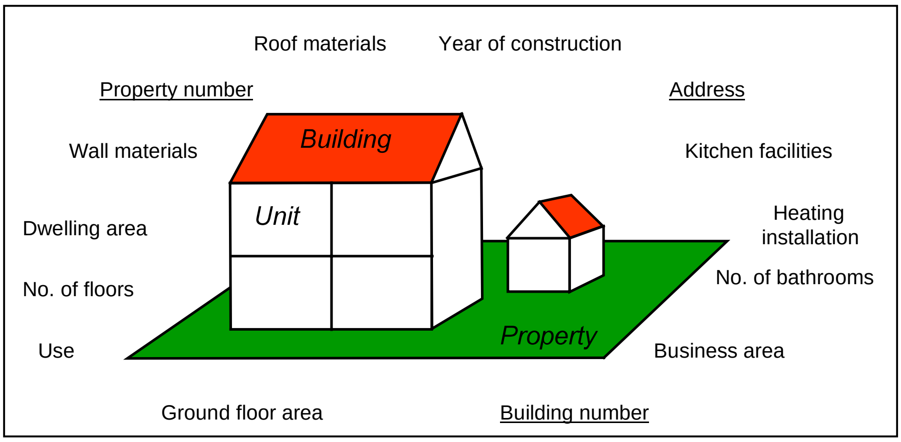

Fig. 2. The Building & Dwelling database – entities and attributes.

As mentioned earlier, nation-wide address points are not available now, but from the beginning of year 2001 a national address database with a very high accuracy should be available. Currently, the most obvious replacement of real address points seems to be the Danish Address & Road database (DAV in Danish) containing nearly every Danish road. Every road segment is assigned a municipality number, a road code and separate address range fields for each side of the road. Using ordinary address matching techniques, the records of the agricultural databases can be assigned x-y co-ordinates and presented as point events.

In order to fit into ArcView's Address concepts, a new string type column called Address is added to the Building & Dwelling database and the values of this column is calculated using Avenue syntax by the following expression:

Address = Roadname ++ HouseNumber,

where HouseNumber is a string type column because it may contain a letter as well. The ++ operator indicates insertion of a blank character between two added strings. Most of the address matching is done automatically, but in some cases manual matching is necessary. This is generally due to bad representation of Danish letters 'Æ', 'Ø' and 'Å'. Of-course, there are differences between real addresses located within each building and addresses generated by address matching. However, in the current project these approximate addresses are able to locate the buildings within the square cells, nearly as good as ordinary address points (fig. 3), but a few address points are located in cells adjacent to the "correct" one.

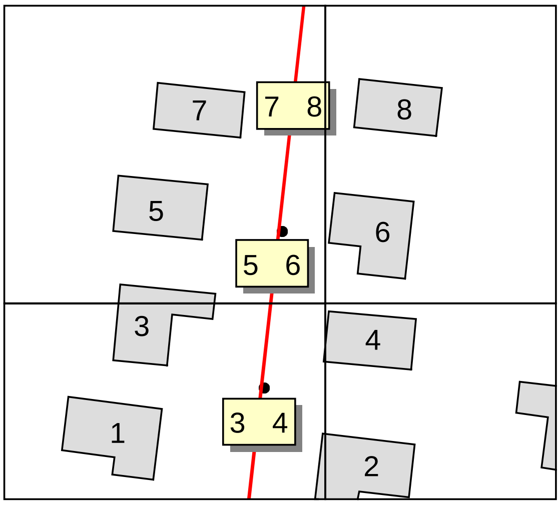

Fig. 3. Comparing geocoded addresses with real world address points

Altogether, a quasi spatio-temporal database of points with an associated time attribute is created from the Building & Dwelling database – currently from year 1998. The Building & Dwelling database were acquired from the Association of Local Authorities, whereas the Danish Address & Road database was obtained from the DAV Consortium (encompassing Danish telephone companies, regional natural gas companies and private map producers). In addition 100 meter square cells covering the Copenhagen Metropolitan area were generated. Each square cell was assigned a unique identifier. Finally, the square cells are assigned a year of construction - in this case the oldest building is decisive. This is carried out through a three step procedure (illustrated in figure 4) using ArcView GIS 3.2:

1. Overlaying the point based building theme with the cell polygon theme assigns cell identifiers to each building (a so-called *spatial join* in ArcView).
2. The cell theme table is summarised based on the identifier field. Thus the minimum year of construction is found for each unique occurrence of the identifier and the result is stored in a new table.
3. The table containing the result of the summarise is joined to the cell theme using the cell identifier as common join item.

Thus a cell theme containing the earliest year of construction within each cell is produced. All cells without buildings were deleted from the cell theme.

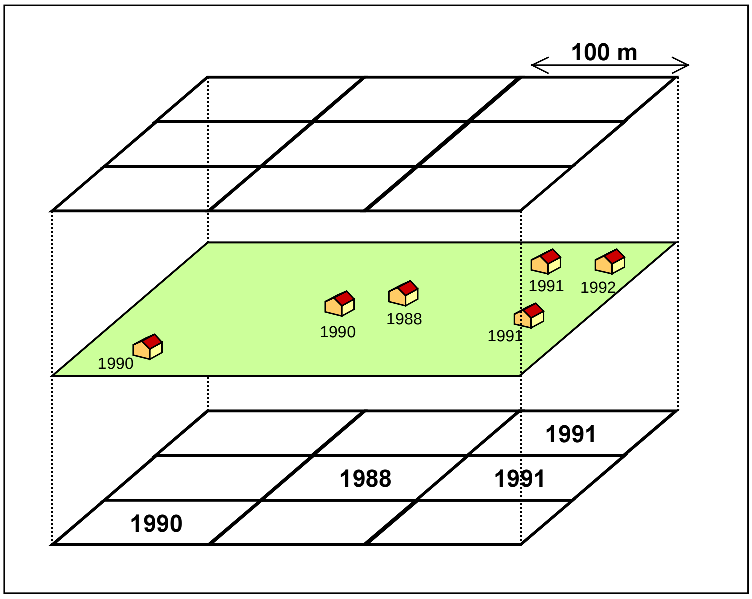

Fig. 4. Assigning minimum year of construction to each cell

The most important source of error in the final cell theme is that the Building & Dwelling database only contains the year of construction for buildings existing today. Thus, we must expect minor errors in areas of urban renewal, but the use of square cells instead of individual buildings might reduce the number errors.

5 Creating the animation

The Internet offers a number of tools for implementing cartographic animation. The advantage of the Internet is that it makes the display of the animation possible on virtually any computer and anywhere using only a standard Internet browser like Microsoft Internet Explorer or Netscape Communicator. A common form of animation is the animated GIF89a file – an extension of the widely used GIF format for distribution of pictures on the Internet. The playback of GIF89a files is done automatically by the Internet browser but is not accompanied by any controls that could adjust the display.

Based on the cell map theme, successive maps for the years 1945 - 1995 were produced and exported into Windows Metafile format. Animation Shop 2 from Jasc Software is a powerful yet easy-to-use program that creates animations from one or more graphic images and offers a wide variety of effects and transitions for enhancing animations (Jasc Software, 1999). Therefore, the individual map frames were loaded into Animation Shop and animated GIF's and AVI files were produced. The individual frames contain 505 x 495 pixels. In order to achieve a reasonable visual impression of the urban dynamics, the display time of the individual map frame was set to 0.5 second. Increasing the frame rate might give more gradual transitions like a film, but at the same time impede the user's ability visually to analyse the changing pattern of urban growth. Figure 5 shows selected animation frames in 5 years intervals.

The produced GIF89a file can be displayed using an ordinary Web-browser and the file size is only 292 KB, thus reducing the download time considerably. The AVI file can be shown using the Windows Media Player, which is generally available through Microsoft Windows. However, the huge file size of 50.8 MB impedes the distribution through the Internet. The file size can be reduced to a few MB by converting the film to MPEG format, which can be played back by the Windows Media Player as well. The main advantage using the AVI compared to the GIF89a is the user's ability to pause the play back and to change the size of the display window.

The animation of urban growth in the Copenhagen metropolitan area tracks the development of the region over time, indicating how minor towns located in and around agricultural areas are becoming large developed cities and continuous corridors. Thus, the user can imagine how the so-called "finger plan", originally presented in 1947 is fulfilled during the nineteen seventies. Later on, the open space between the "fingers" is gradually occupied by urban land.

Comparing figure 5 with the real animation of urban growth exposes the power of dynamic maps in the understanding geographical phenomena and how the patterns change over time. Furthermore, it became clear that the display speed is of great importance for the user's ability to perceive changing complex patterns like urban growth. Thus, the optimal frame rate was found after several trials.

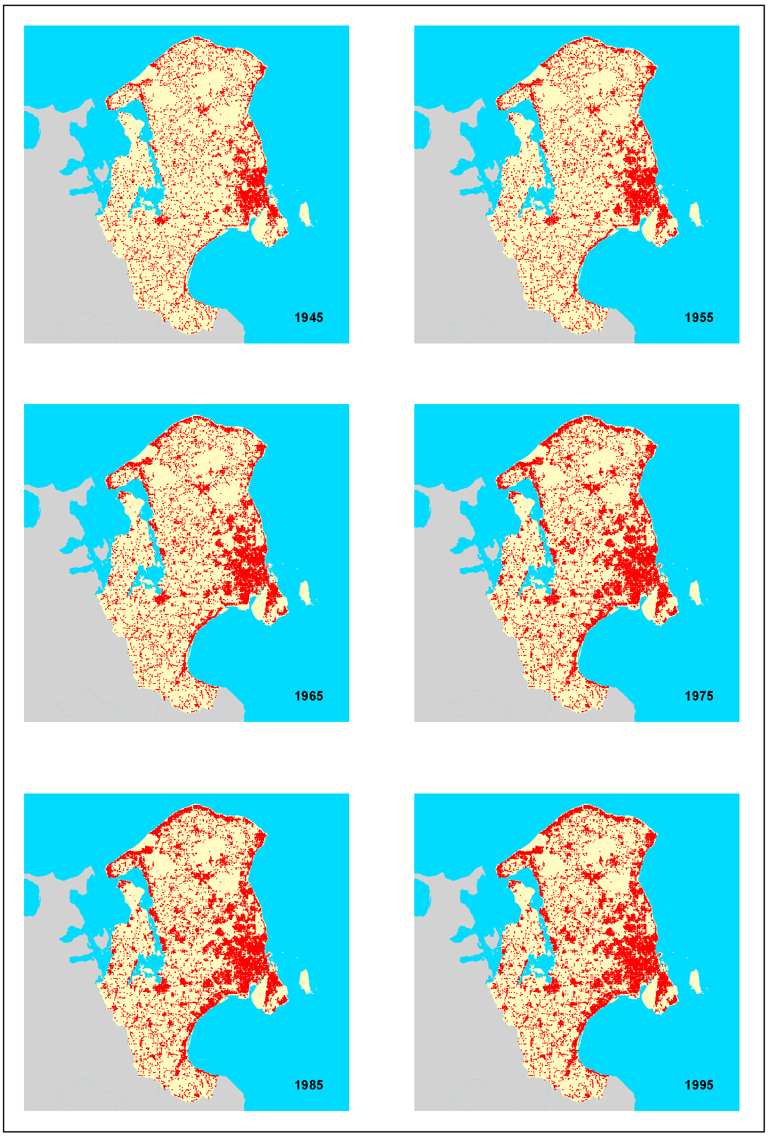

Fig. 5. Urban Growth in Copenhagen Metropolitan area – selected frames

6 Concluding remarks

Time-series animation is a powerful way of visualising and analysing spatio-temporal patterns and changes. Traditionally, this kind of animation is based on topographic map series representing various years, but generally this approach is inadequate due to the often long time interval between successive map series. By contrast, a spatio-temporal database provides a useful foundation for producing time-series animation of land-use changes – in the current study urban growth.

Since 1977, the Danish municipalities have stored detailed information about every single building in Denmark. This so-called Building & Dwelling database includes among other data the address of the building and the year of construction, thus constituting a reasonable foundation for a quasi spatio-temporal database for the buildings in Denmark.

Using the spatio-temporal temporal database, animation frames were created for each year in the period 1945 – 1995, and based on these frames animated GIF89a files and AVI files were created. The animated GIF seems promising for visualising dynamic maps on the Internet, thus increasing the ability to spread the information to a wide audience. Referring to the so-called Aarhus Convention this issue is of particular importance in environmental planning.

As evident from figure 2, the Building & Dwelling database contains several attributes, which might be useful in the study of the urban environment. Furthermore, this database contains a historic part, which tracks all changes to the built environment since its establishment in 1977. However, this part is not public available today, but we will try to get access to this part of the database within the near future. First of all, this will make it possible to do a detailed study of the changing pattern of urban land-use.

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