Geographic Information Technology Training Alliance (GITTA) presents:

Introduction to Time Change and Spatial Dynamics

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1. Introduction to Time Change and Spatial Dynamics

Change in *Land Use/Cover Change (LUCC)* [1] is continuous especially in areas around urban developments. Changes are the result of many interacting processes. Each of these processes operates over a range of scales in space and time. Theses processes are driven by one or more of different variables that influence the actions of the agents of the change involved. These variables are called driving forces which underline the proximate cause of LUCC, such as deforestation or agricultural expansion. These driving factors include demographic factors, economic factors, technological factors, policy and institutional factors, cultural factors, and biophysical factors. Some of theses factors directly influence the rate and quantity of LUCC. Other factors determine the location of the LUCC, e.g. the suitability of soils for agricultural land use.

Considering that analysis is carried on Geographic information, changes may occur in the 3 components of the geographic information model: *Thematic:* [2] changes in phenomenon properties; *Geometric:* [3] changes in spatial feature identification and shape; *Spatial* [4] (thematic + geometric): changes in spatial structure and pattern distribution (spatial distribution dynamics). Thus the original *time dimension:* [5] is embedded into this 3 components.

Objectives of Time change analysis and Spatial dynamics are to explore, to model and to forecast distribution of changes in the real world.

Learning Objectives

- You will be able to identify the main components composing the context of change analysis.
- You will be able to build up the methodological process of a change analysis according to the defined objectives.

[1] The cover or the use of the earth surface is described with a set of category types. Throughout time these cover or use categories can change. The objective of a LUCC analysis is to describe, to understand or to predict such changes in the spatial distribution of landcover or landuse

[2] The context of an environmental study (the biosphere in Geoscience) can be structured with 3 dimensions: thematic, geometric and time. The thematic dimension expresses the properties attached to a list of observations (features, entities,…) for a single or a set of phenomenon (variable)

[3] The context of an environmental study (the biosphere in Geoscience) can be structured with 3 dimensions: thematic, geometric and time. The geometric dimension expresses the geometric properties attached to a list of observations (spatial features, entities,…) such as location, length, size, as well as spatial relationships

[4] The context of an environmental study (the biosphere in Geoscience) can be structured with 3 dimensions: thematic, geometric and time. When analysing spatial features it is necessary to combine their thematic and geometric properties. This combination of the thematic and geometric dimensions is called the spatial dimension

[5] The context of an environmental study (the biosphere in Geoscience) can be structured with 3 dimensions: thematic, geometric and time. The time dimension expresses the thematic properties attached to a list of observations (features, entities,…) for different moments or periods of time. It carries also the geometric changes of spatial features throughout time

1.1. Time content in geographic information

Illustration

How Time is expressed through Geographic information?

- By a sequence of phenomena and spatial features status:
  - Phenomena status: thematic properties
  - Spatial features status: geometric and pattern properties
- By a degree of richness of the time dimension (from low to high):
  - 2 limits for the time period
  - several regular or irregular intervals (discrete description): time series
  - a function of time (continuous description, rare!)

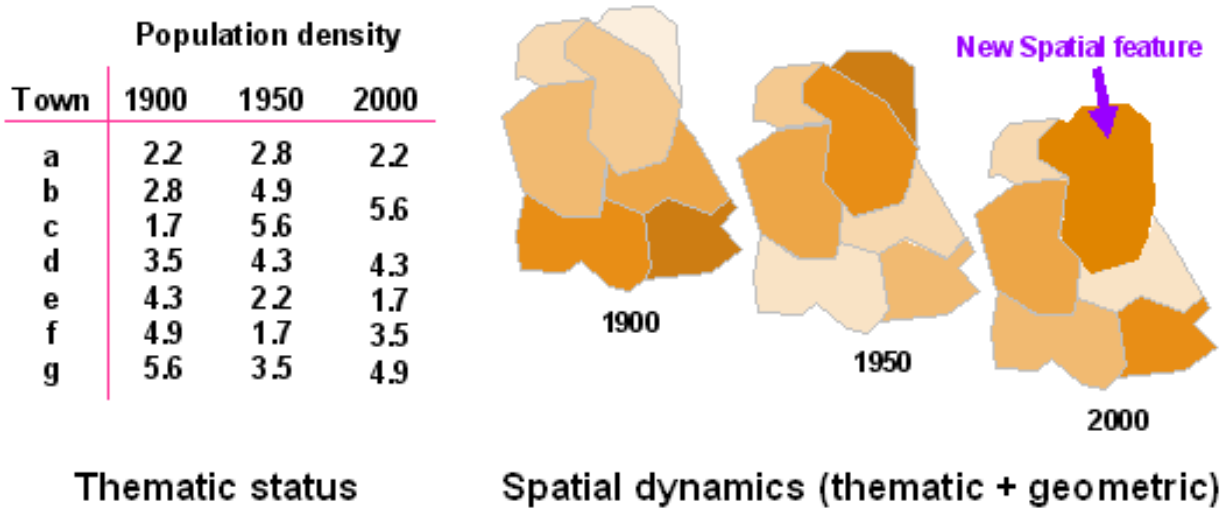


Illustration of time change in thematic, geometric and spatial dimensions

Time change analysis

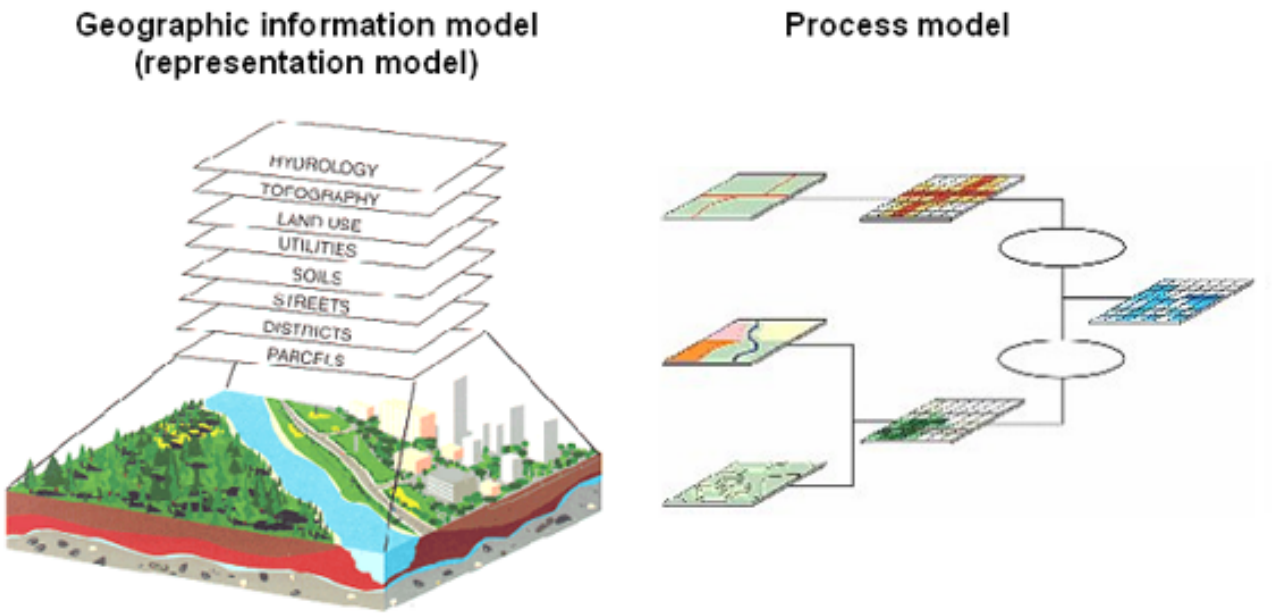
There are different levels, views and contexts of time change analysis.

- 3 levels of analysis
- 2 views of change analysis
- 3 levels of information content
- single or multiple features analysis
- single or multiple phenomena analysis (uni, multi-variate analysis)

1.1.1. 3 levels of analysis

They correspond to the three steps of the scientific approach:

- *Exploration:* [6]the aim of this early level of time change analysis is to describe changes of considered phenomena, of their properties and their spatial distribution. It is an important step of synthetic description.
- *Modelling:* [7] a process model describes the interaction between objects that are organised within the geographic information model. A process model allows to derive current status of phenomena and is then often used to predict their future changes.
- *Forecasting:* [8] in this advanced level of time change analysis, process models predict future changes that can occur taking in account many factors and constrains in constructing these models to reach this result.



A process model and its related Geographic information model (ArcInfo Documentation)

[6] The objectives of an analysis -and a spatial analysis- can be of 3 levels: exploration, explanation and forecasting. At the first level, exploration concentrates on the description of the concerned distribution. From this exploration activity the analyst draws several hypothesis and assumptions about factors that are influencing this distribution. They are then validated and their interactions will be modelled during the explanation phase and finally future states of the distribution can be predicted during the forecasting stage (see forecasting)

[7] The action to construct a simplified but structured system including relevant elements and interactions of the studied object. A model can be theoretical or operational. It is used to describe, to explain or to forecast processes

[8] The objectives of an analysis -and a spatial analysis- can be of 3 levels: exploration, explanation and forecasting. At the first level, exploration concentrates on the description of the concerned distribution. From this exploration activity the analyst draws several hypothesis and assumptions about factors that are influencing this distribution. They are then validated and their interactions will be modelled during the explanation phase and finally future states of the distribution can be predicted during the forecasting stage (see exploration)

1.1.2. 2 views of change analysis

Change analysis is an approach to analyse changes occuring throught time. For a set of spatial features change analysis can focus on their thematic changes (non-spatial) or on their geometric changes. Time changes can be analysed either non spatially or spatially:

- *Non spatial:* [9]the aim of the analysis is focused toward property change of phenomena. This type of analysis concentrates on the thematic dimension of information.
- *Spatial:* [10]this more complex analysis investigates not only property change of phenomena, but also their distribution throughout space. This allows to analyse *spatial dynamics* [11].

1.1.3. 3 scales of measurement

As seen before, the Geographic information richness content is partly expressed through the scale of measurement used to describe properties of each phenomenon:

- *Nominal scale:* [12] thematic properties are coded as mutually exclusive categories. Properties can be identified and differentiated through numerical coding.
- *Ordinal scale:* [13] properties can be ranked in a hierarchy of states (classes). As with the nominal scale, a quantitative analysis of ordinal measurements is restricted primarily to counting observations in the various states. However, we can also consider the manner in which different ordinal classes succeed one another. This is done, for example, by determining if states tend to be followed an unusual number of times by greater or lesser states on the ordinal scale. Ordinal level is rarely used for the description of properties in the geometric dimension, except for some topological properties. Time dimension is often expressed by sequence of ranked levels (periods of time).
- *Cardinal scale:* [14] it is so named because of the length of successive intervals is a constant and is generally considered as continuous. Digits and the sign of numbers as well as their unit of measurement fully describe the rich content of properties. Cardinal level is mostly used to describe properties in the geometric dimension (coordinates, geometric properties, proximity, …). Time can be expressed at this level as a continuous scale (time continuous function).

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[9] A process or a phenomenon distribution that is not related to spatial properties (non-spatially dependant). Or when the information model does not take space into consideration (no geometric dimension)

[10] Related with geographical space. It combines the properties of the thematic and the geometric dimensions to characterise spatial features (objects) or spatial units of observation and the distribution pattern of thematic properties

[11] Evolution of the spatial distribution of phenomenon properties throughout time. It concerns the change of thematic and geometric properties of spatial features. It also includes the movement of features throughout space

[12] The nature and the content of information can be ranked into a 3 levels scale: nominalnominal, ordinal and cardinal. At the nominal level, properties (values) express categories. Property values can be interpreted as a label to identify a category and to differentiate from other categories

[13] The nature and the content of information can be ranked into a 3 levels scale: nominal, ordinal and cardinal. At ordinal level, properties (values) express a position in a ranked set of properties. Property values can be interpreted to identify the property and to rank it in the hierarchy

[14] The nature and the content of information can be ranked into a 3 levels scale: nominal, ordinal and cardinal. At the cardinal level, properties (values) express a position in a continuum of properties. Property values can be interpreted to identify the property and to rank it in the hierarchy as well as to measure the interval between values (interval-ratio level)

Remember that the level of measurement strongly influences the potential use of descriptors and operators applied to process numerical information.

1.1.4. Single or multiple features analysis

Change analysis can concentrates on property change of a single or a set of spatial feature:

- **Single feature analysis:** properties of a single feature are described for a numerous sequence of time periods *(time series)*. The analysis concentrates on the property change of that feature during the whole period of time.
- **Multiple features analysis:** properties of multiple features for different intervals of time are analysed. This approach allows comparison in change behaviour between features.

1.1.5. Uni or multi-variate analysis

Change analysis can concentrates on property change of a single or a set of phenomenon:

- *Univariate analysis:* [15] a single phenomenon characterised with a single variable is processed in this analysis. The population density analysis, illustrated **before** is an example of univariate change analysis concerning several spatial features. Each row of the table corresponds to a time series that express the change in population density for each spatial feature, a municipality.
- *Multivariate analysis:* [16] the change analysis can concern the simultaneous changes of several phenomena expressed by multiple variables. This allows for the study of relationships and interactions between changes of phenomena. Such multivariate approach can be applied to either a single spatial feature (multivariate single feature analysis) or several (multivariate multiple features analysis). Spatial analysis is primarily concern with this latter. In order to simplify the complexity of this analysis, often *change indicators* are first derived for each spatial feature with respect to each variable.

[15] Description of the distribution properties of a single variable or individual description of a set of variables (see Multivariate analysis)

[16] Description and inter-relation analysis of a set of variables (see Univariate analysis). Most analyses are multivariate as many factors influence a studied phenomenon and interact with each other

1.2. Methods for time change analysis

According to the various views and contexts of time change analysis, methods can be organised in the following structure presented as two distinct tables. The first table lists a series of non spatial methods as the second groups spatial methods that allow for spatial dynamics analysis.

1.2.1. Non spatial time change analysis methods (thematic changes)

Overview of non spatial methods where spatial features are simply considered as a list of observations, without consideration for their location, their shape nor their spatial relationships. Methods are organised according to the criteria described above.

	TIME DIMENSION	
	2 limits	Intervals
UNIVARIATE	**Production of change indices:**	
Multiple Observations	Property differencing (Quant) Property ratioing (Quant) Cross-tabulation / classification (Qual) Transition matrices (Qual)	Central tendancy / variability (Qual/Quant) Regression score (Quant) Allometric score (Quant) Standardised PCA scores (Quant)
Single Observation (Time series)	**Detailed description:**	Runs test (Qual) Markov chains / Transition matrices (Qual) Auto-association (Qual) Auto-correlation (Quant) Filtering (Qual/Quant) Fourier series (Quant) Time regression function (Quant) Allometry (Quant)
MULTIVARIATE	Change vector analysis (Quant)	Cross-association (Qual) Cross-correlation (Quant)

Qual: qualitative data (nominal) Quant: quantitative data (ordinal, cardinal)

Overview of non spatial time change analysis methods

1.2.2. Spatial time change analysis methods (spatial dynamics)

With this type of methods the dynamics of a spatial distribution can be analysed. Spatial arrangement changes as well as spatial feature changes can be taken into account with these methods. Discussed methods are structured into two groups:

- The first group is composed of methods that make use of change indices produced by non spatial time change analysis methods. They express and characterise the spatial distribution of change indices attached to spatial units.
- The second group includes methods that fully model the dynamic of space in its thematic and geometric dimensions.

SPATIAL DYNAMICS
1. For spatial distribution of change indices:
Spatial filtering (Qual/Quant)
Trend Surface Analysis (Quant)
Double Fourier Series (Quant)
2. For spatial dynamics modelling:
Cellular Automata (Qual)
Spatial Diffusion Models (Quant)

Qual: qualitative data (nominal) Quant: quantitative data (ordinal, cardinal)

Examples of spatial dynamics analysis methods

1.3. Summary

What has changed? Where? When? How? What could change in the future? How do things or organisms move through space?

Change analyses are very ambitious studies in a sense that they integrate the dimension of time. This is particularly true when applied to spatial analyses. In our model of reality – the biosphere – we have structured it into three basic dimensions: thematic, geometric and time. The static analysis of the spatial distribution of phenomena has required a context called the spatial dimension; it combines both the thematic and geometric dimensions, in order to investigate the spatial distribution and its pattern.

With change analyses the time dimension has to be integrated into the context. Change analysis encompasses both the evolution of thematic properties of spatial features as well as the spatial dynamics. The objective of this Lesson is to review methods used in these different types of change analyses. It is structured into three Units with the following content.

As an introduction to this topic, Unit 1 presents a variety of contexts in which time changes occur. In order to identify specific objectives and methodologies within these contexts, this Unit proposes a list of key factors controlling contexts of time analysis. This leads also to isolate two complementary approaches: the evolution of thematic properties of spatial features (Thematic changes) and the evolution of spatial distribution and patterns, that includes the analysis of movements in space (Spatial dynamics).

1.4. Recommended Reading

- **Abler R., Adams J., Gould P.**, 1972. *Spatial Organization, The Geographer's View of the World*. USA: Prentice Hall.
- **Caloz R., Collet C.**, 2011. *Analyse spatiale de l'information géographique*. Lausanne, Switzerland: PPUR.
- **Davis, John C.**, 1986. *Statistics and data analysis in geology*. New York: John Wiley&Sons.
- **Eastman, R.**, 2008. *IDRISI - Taiga GIS and Image processing software, Reference Manual*. Worcester, Clark Labs, Clark University, USA: Worcester.

1.5. Glossary

Cardinal scale (level):

The nature and the content of information can be ranked into a 3 levels scale: nominal, ordinal and **cardinal**. At the cardinal level, properties (values) express a position in a continuum of properties. Property values can be interpreted to identify the property and to rank it in the hierarchy as well as to measure the interval between values (interval-ratio level)

Exploration:

The objectives of an analysis -and a spatial analysis- can be of 3 levels: exploration, explanation and forecasting. At the first level, **exploration** concentrates on the description of the concerned distribution. From this exploration activity the analyst draws several hypothesis and assumptions about factors that are influencing this distribution. They are then validated and their interactions will be modelled during the explanation phase and finally future states of the distribution can be predicted during the forecasting stage (see forecasting)

Forecasting:

The objectives of an analysis -and a spatial analysis- can be of 3 levels: exploration, explanation and forecasting. At the first level, exploration concentrates on the description of the concerned distribution. From this exploration activity the analyst draws several hypothesis and assumptions about factors that are influencing this distribution. They are then validated and their interactions will be modelled during the explanation phase and finally future states of the distribution can be predicted during the forecasting stage (see exploration)

Geometric dimension:

The context of an environmental study (the biosphere in Geoscience) can be structured with 3 dimensions: thematic, **geometric** and time. The geometric dimension expresses the geometric properties attached to a list of observations (spatial features, entities,…) such as location, length, size, as well as spatial relationships

Land Use/Cover Change (LUCC):

The cover or the use of the earth surface is described with a set of category types. Throughout time these cover or use categories can change. The objective of a LUCC analysis is to describe, to understand or to predict such changes in the spatial distribution of landcover or landuse

Modelling:

The action to construct a simplified but structured system including relevant elements and interactions of the studied object. A model can be theoretical or operational. It is used to describe, to explain or to forecast processes

Multivariate analysis:

Description and inter-relation analysis of a set of variables (see Univariate analysis). Most analyses are multivariate as many factors influence a studied phenomenon and interact with each other

Nominal scale (level):

The nature and the content of information can be ranked into a 3 levels scale: **nominal**nominal, ordinal and cardinal. At the nominal level, properties (values) express categories. Property values can be interpreted as a label to identify a category and to differentiate from other categories

Non-spatial:

A process or a phenomenon distribution that is not related to spatial properties (non-spatially dependant). Or when the information model does not take space into consideration (no geometric dimension)

Ordinal scale (level):

The nature and the content of information can be ranked into a 3 levels scale: nominal, **ordinal** and cardinal. At ordinal level, properties (values) express a position in a ranked set of properties. Property values can be interpreted to identify the property and to rank it in the hierarchy

Spatial:

Related with geographical space. It combines the properties of the thematic and the geometric dimensions to characterise spatial features (objects) or spatial units of observation and the distribution pattern of thematic properties

Spatial dimension:

The context of an environmental study (the biosphere in Geoscience) can be structured with 3 dimensions: thematic, geometric and time. When analysing spatial features it is necessary to combine their thematic and geometric properties. This combination of the thematic and geometric dimensions is called the **spatial dimension**

Spatial dynamics:

Evolution of the spatial distribution of phenomenon properties throughout time. It concerns the change of thematic and geometric properties of spatial features. It also includes the movement of features throughout space

Thematic dimension:

The context of an environmental study (the biosphere in Geoscience) can be structured with 3 dimensions: **thematic**, geometric and time. The thematic dimension expresses the properties attached to a list of observations (features, entities,…) for a single or a set of phenomenon (variable)

Time dimension:

The context of an environmental study (the biosphere in Geoscience) can be structured with 3 dimensions: thematic, geometric and **time**. The time dimension expresses the thematic properties attached to a list of observations (features, entities,…) for different moments or periods of time. It carries also the geometric changes of spatial features throughout time

Univariate analysis:

Description of the distribution properties of a single variable or individual description of a set of variables (see Multivariate analysis)

1.6. Bibliography

- **Abler R., Adams J., Gould P.**, 1972. *Spatial Organization, The Geographer's View of the World*. USA: Prentice Hall.
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