Revista Brasileira de Cartografia (2014) N⁰ 66/7 - International Issue: 1465-1473
Sociedade Brasileira de Cartografia, Geodésia, Fotogrametria e Sensoriamento Remoto
ISSN: 1808-0936

MULTIPURPOSE URBAN CADASTRE AND DATA TEMPORALITY

Cadastro Territorial Multifinalitário Urbano e a Temporalidade dos Dados

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Recebido em 21 de Setembro, 2014/ Aceito em 13 de Novembro, 2014
Received on September 21, 2014/ Accepted on November 13, 2014

ABSTRACT

Throughout its history, the Territorial Cadastre has gone through many stages, referred to as "waves", to paraphrase Alvin Toffler. In the first wave, the Cadastre aimed at tax collection; in the second, it aggregated the concept of property rights; and in the third, the multiple purposes of the Cadastre were recognized to support public management. From the fourth wave on, a futuristic vision of the Cadastre expanded data recording and turned it into a public inventory of all legal territorial objects, measured by its boundaries. In the fifth wage, it became a Cadastre that makes use of the latest technological resources, in which temporality (4D) was first mentioned. All these changes directly affected the development method of Territorial Cadastres, following technological breakthroughs or the need for improvement in the management of the territory. Therefore, the Cadastre is no longer made on paper. Instead, it makes use of technologies to store, manage and track the transformations of urban areas. In this context, this paper presents a discussion of the temporality of cadastre data and the method for representation and implementation of these data.

Keywords: Multipurpose Cadastre, Time, Space, Database.

RESUMO

O Cadastro Territorial ao longo de sua história passou por muitas fases, denominadas de "ondas" parafraseando Alvin Toffler. Na primeira onda, o Cadastro tinha por finalidade a arrecadação de impostos, na segunda agregava o conceito de direito de propriedade, na terceira a multifinalidade do Cadastro foi reconhecida para apoiar a gestão pública. A partir da quarta onda, uma visão futurista do Cadastro, amplia o registro de dados e o transforma em um inventário público de todos os objetos territoriais legais, mensurado por seus limites, na quinta um Cadastro que faz uso dos mais modernos recursos tecnológicos, mencionando pela primeira vez a temporalidade (4D). Todas essas transformações afetaram diretamente a maneira de elaboração dos Cadastros Territoriais, acompanhando os avanços tecnológicos ou por necessidade de melhoria no gerenciamento do território. Portanto, o Cadastro não está mais registrado em papéis, e sim, faz uso de tecnologias para armazenar, gerenciar e acompanhar as transformações dos espaços urbanos. Nesse contexto, este artigo apresenta uma discussão sobre a temporalidade dos dados cadastrais, a forma de representar e implementar esses dados.

Palavras chaves: Cadastro Territorial Multifinalitário, Tempo, Espaço, Banco de Dados.

1. INTRODUCTION

The Multipurpose Territorial Cadastre (CTM) is primarily designed to locate and describe the plots, thus being a tool to aid land management.

Urban areas have undergone major geographical changes in recent decades. To represent it is a challenge, particularly so that it may record the population's rights of ownership and use of property. Technological innovation has contributed significantly to the development of CTMs, especially in acquisition, storage, and space viewing. New technologies subsidize the creation of planning policies that are consistent with reality.

Nevertheless, one of the problems of urban planning is the lack of information to support decision making. In the case of the CTM, data exist but are not turned into information that is useful for land management.

To circumvent this situation, the CTM should have current data on land plots, as well as historical data. Brazil lacks standards and models for the Cadastre. Even so, many municipalities rely on paper or Information Systems (IS) for the purposes of taxation. These ISs are transactional, i.e., they lose prior information when updated. In this context, the issue is how to generate historical information on the CTM.

Observing other areas of knowledge, we found that researchers have sought methods of storing historical information, such as Temporal Databases (TDBs). However, the technology has not followed the concepts, and Database Management Systems (DBMSs) do not have the necessary resources for the full implementation of concepts but provide guidelines on how to do it.

In the worldwide scenario of CTM research, a number of researchers have discussed the 4D Cadastre, considering the land plot volume as the third dimension and time as the fourth dimension. There are a few considerations on this subject. First, the 3D Cadastre already exists in a number of countries but is not yet widely used, and second, even in a 2D Cadastre, the time dimension can be inserted and. In the latter case, what would be the most appropriate term to name this Cadastre? Thus, this paper discusses the spatiotemporal CTM and adds the dimension of time to the CTM model available.

Based on the Brazilian reality, we note that the CTM, albeit computerized, does not follow a standard and aims at taxation, with little updating and being based on transactional systems. In this context, a few actions should be taken to generate information to support decision making. With few resources to be applied by the government, the concept of Spatiotemporal Database (STDB) applied to free DBMSs emerge as an option to generate historical information based on the CTM data.

2. HISTORY

The territorial Cadastre was used by ancient peoples for territory planning. There is evidence of land documentation for taxation and other contributions to the state, since 3000 BCE. In Egypt, due to the periodic flooding of the Nile, a descriptive inventory of the land was drawn up based on a coordinate system. Since then, rulers continually sought a resource for management and distribution of land use. In the contemporary world, the framework of Cadastre took place in 1807, in France, with Napoleon. After the French Revolution, Napoleon decreed a complete cadastral survey of the entire French national territory, as all as occupied lands, with the aim of mapping strategic areas and encouraging citizenship and fair taxation of property (LARSSON, 1996).

In Brazil, the first territorial measurements appeared with the Allotment system, when the Portuguese government distributed land to develop agriculture, livestock, and, later, plant extraction. The Allotment system ended in 1822 and after that date, there was no formal policy of territorial occupation, so the only way to acquire land at the time was informal occupation (LOCH, 2007).

To regularize land demarcation, in 1850, the first Brazilian land act, Act 601, was created. However, it was not related to the Territorial Cadastre. This relationship only happened with the creation of the Land Statute, Act 4,504, of

November 1964, which regulated the rights and obligations related to rural assets and property, with the aim of developing agrarian reform and promoting agricultural policies (LOCH , 2007).

In 1973, Act 6015/1973, on the public record, was created, including "Title V: Property Registry". In this act, each property is registered individually, i.e., no property has more than one record and no record has more than one property, among other guidelines.

In 2001, Act 10,267/2001 on georeferencing of rural properties was established, standardizing procedures from the characterization of the property to its location by the coordinates of the vertices defining the boundaries, demanding that the accuracy be less than 50 cm (AMORIM et al, 2007).

The abovementioned acts had no provisions on urban property. Only in 1998, the Brazilian Association of Technical Standards (ABNT) published the standard NBR – 14166/1998 setting forth detailed rules for the implementation and maintenance of the Municipal Cadastral Reference Network (AMORIM et al, 2007).

In 2009, the Ministry of Cities issued Ordinance 511, establishing guidelines for the CTM. This ordinance defines the CTM as the "official and systematic territorial inventory of Brazilian municipalities. It will be the official and systematic territorial inventory of the municipalities and will be grounded in surveying the boundaries of each land plot, which receives an unambiguous numerical identification" (BRAZIL, 2009). Based on this ordinance, a few actions have been developed for the realization of the CTM.

This history allows us to check how the CTM is a subject that has been discussed for some time in other countries, which seek their development and application for land management. On the other hand, it is a relatively new subject in Brazil, mainly due to the lack of a specific legislation for urban areas, policies to guide and encourage the creation and maintenance of computerized CTMs to support the public administration.

3. TERRITORIAL INFORMATION SYSTEM

Since the emergence of the Cadastre, several types of cadastral systems were developed over time. The Cadastre is usually divided into three categories, according to their application (DALE; MCLAUGHLIN, 1990): the Legal Cadastre, which serves as a legal record of land ownership; the Economic Cadastre, which was developed initially to estimate property values; and the Multipurpose Cadastre, which unites the tax and legal cadastres while adding other information on the land plot, referred to as the CTM in Brazil.

Factors influencing the format and management of the Cadastre include (FIG, 2010): history, culture and land ownership arrangements; area; physical and economic geography; population distribution; level of technology; public administration plans; property and land bills; and political priorities of the land for the jurisdiction.

According to the FIG (French acronym for the International Federation of Surveyors) (2010), a Cadastre is a Territorial Information System (TIS), often based on land plots, that keeps a record of the interest on land, such as rights, restrictions and responsibilities, which may be established for fundraising for legal purposes and/or planning support, always seeking social and economic development, but without the need for a standard cadastre for all countries.

In Brazil, the term TIS is not widely used; however, it is well known in other countries as part of the Property Registry Cadastre (AMORIM; SOUZA; YAMASHITA, 2008). However, Articles 4 and 5 of Ordinance 511 provide that, when the CTM data are related to the data of Property Registry, they comprise Territorial Cadastre and Registry System, while the TIS is established with the addition of data from thematic cadastres.

In addition to these two definitions, other authors provide other definitions for cadastral systems. In this article, for the purposes of simplification, the term used is the TIS, defined as an automated Territorial Information System, composed of hardware, software, people, data, and network, with the aim of managing the CTM and possibly registering property, as well as providing alphanumeric and geographic data to support the territorial management.

The TIS is sometimes confused with the GIS. Both, however, are different. Their integration assists the decision-making processes in the public administration (AMORIM; SOUZA; YAMASHITA, 2008).

In TIS, it is important to establish the need for systematic collection, updating, processing and distribution of spatial data to support administrative, economic and legal decision making. It should also be applied in the planning of territorial development and to assess the consequences of different alternative actions (LARSSON, 1996).

The TIS can provide this information in the form of a product (such as certified maps or deeds) or as services (such as professional consulting). It can provide: attribute data, which can be presented in textual or numerical form; spatial data, which can be displayed on maps; and temporal data, which indicate their occurrence (DALE; MCLAUGHLIN, 1990).

4. TIME

The historical information represents a description of events occurred in the past, recording when and where the events occurred and how these events have changed over time. The knowledge of the data that make up these notes, referred to as temporal data, allows us to understand events, prevent risks, guide decisions, and predict future events.

Temporal data represent real-world events marked by time. Temporal data models have one added dimension compared to conventional data models, i.e., time dimension. In conventional data models, dimensions are lines (entity instance) and columns (attributes) of a table showing values. If the values are changed (updated), the prior ones are lost. The third dimension – time dimension – links each piece of temporal information to a value. Thus, when a value is changed, the previous value is not removed from the database, and a validity time is linked to the value. Therefore, we can access the entire history of records. The third dimension in temporal data models is different from the third dimension (3D) of the Cadastre, which refers to viewing each cadastral plot. The 3D Cadastre was introduced and defined by Stoter and Van Oosterom (2006).

To define the real-world events to be recorded with the time of occurrence, a few considerations should be made about time. These considerations are based on the definition of a number of temporal features, which have been gathered in the Glossary of Temporal Database (JENSEN et al., 1998), namely:

- time dimension: temporal data models have one additional dimension (time dimension) compared to conventional data models;
- order in time (Fig. 1): a linear order, in which a point in time will have only one predecessor and one precursor; a branched order that allows a point in time to have more than one predecessor and more than one precursor; a circular order that models recurring processes, such as holidays, with a repetition of events, instead of time;
- absolute time and relative time: absolute indicates that a valid time considers the granularity associated with the fact, while relative indicates that the valid time of a fact is related there some other time;
- granularity in time: size of the unit of time considered in the system; it may be time, day, month, or year;
- temporal variation: can be represented by continuous time (there can be another time instant between two consecutive time instants) or discrete time (based on a timeline composed of a sequence of consecutive time intervals that cannot be decomposed, with the same duration);
- time instant: represented by a chronon in the temporal axis of the model, for discrete time;
- interval: has a start time (*s*) and an end time (*e*), defining the set of all times (*t*), so that that $s \leq t \leq e$;
- time element: a finite union of intervals; and

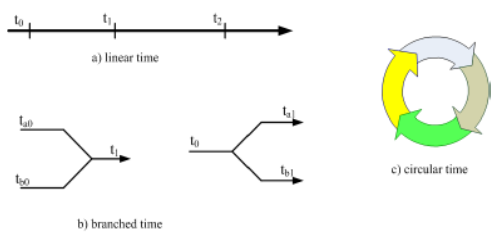


Fig. 1 - Types of temporal order.
Source: SASS (2013).

- time duration: depends on the context, can be fixed or variable.

These basic concepts on the temporal data represent the intention of unifying concepts related to TDBs. Based on these concepts over time, the process of development of the TIS should consider the time element as feature of cadastral data. In this context, the TIS should be designed to support data temporality.

Many applications of geoinformation technologies use static representations of spatial phenomena, not allowing us to view changes occurred over time. To improve the representation of these phenomena, spatiotemporal models attempt to represent them adequately, showing its variations in both space and time.

The time concept applied to geographic information is not a new theory. Since the 90s, time was already considered in data models. Worboys, in 1995, stated that geographic information had three components: attribute, space, and time, which made it possible to answer the following questions: "What?", "Where?", and "When?" Each of these components of determined a dimension category along which values were measured (WORBOYS, 1994), as shown in Fig. 2.

5. TECHNOLOGIES

According to Langran (1993), a temporal GIS should track the change of state of the study area, store its history, and anticipate geographical states. This definition can be applied to the TIS. Thus, for the storage of different types of data (alphanumeric, spatial, and temporal), new database technologies have been developed in recent years. Conceptually, a database can be defined as "a collection of related data" (ELMASRI; NAVATHE, 2005), " a collection of persistent data used by the application systems"

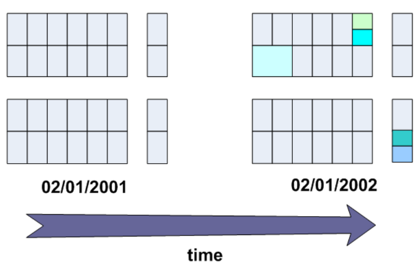


Fig. 2 - Status of the land plots as of 2/1/2001
Source: SASS; AMORIM (2013).

(DATE, 2000) or as "a shared and integrated computational structure storing a set of: end-user data [...] and metadata [....]" (ROB; CORONEL, 2011).

Traditional databases store alphanumeric data (e.g., integer, date, real, and text) and are commonly referred to as conventional databases. When other types of data are stored (such as spatial and temporal data), databases are not referred to as non-conventional. For the storage of different types of data, new database technologies have been developed in recent years, taking into account their peculiarities.

The key element of the databases is the data, which may be conventional or non-conventional. Conventional data are already a part of the everyday life of organizations and are well known, but non-conventional data are still the subjects of much research.

According to Silberschatz, Korth and Sudarshan (2005), a Geographical Database (GDB) is a database used to store spatial data, such as maps.

Databases typically store a real-world event in its current state. They do not store information on past states. The databases that store the event states over time are known as TDB (SILBERSCHATZ; KORTH; SUDARSHAN, 2006).

Date (2000) considers a TDB "is one that contains historical data instead of, or in addition to, current data. [...] The data [...] are only inserted, and are never deleted or updated", differing from conventional databases, "which contain only current data, and prior data are deleted or updated."

In the TDB, time is distinguished between the time measured by the system and the time observed in the real world. The transaction time – measured by the system – for an event is the time interval during which the event is occurring within the database system, and is automatically generated by the system. The valid time for an event is a set of time intervals during which the event is true in the real world, and cannot be generated automatically by the system, but must be supplied to the system (SILBERSCHATZ, KORTH; SUDARSHAN, 2006).

In the development of the TDB, when the data model is defined, the temporal attributes of the model should be defined, because there is information that does not change over time and does not need to be treated as temporal data. Although the research with TDB is not recent, there are few usable systems. In most cases, the temporal models are mapped to the conventional databases.

Considering the need to represent the geographical position of the data, its evolution and the realization that it is often necessary to keep the history of this evolution have led to the concept of the STDB. They allow us to store all states of an application (present, past, and future), recording their evolution over time. Temporal information is associated with the geographical and non-geographical data and stored (transaction time and/or period of validity) to identify them over time.

6. TEMPORAL CTM

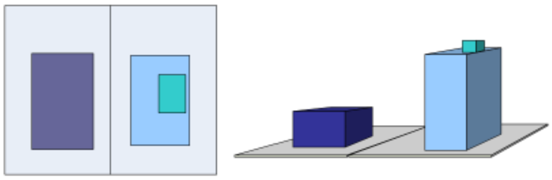
The use of ISs in CTMs has brought benefits for the management and control of cadastral data. Since the end of the last century, cadastral entries in developed countries began to be converted from analog to digital records. Spatial information on the land plot is kept in the GIS and on Computer-Aided Design (CAD), and no longer on paper maps (STOTER; VAN OOSTEROM, 2006).

Most CTMs have 2D data representing the land plot in the plane (X, Y), as shown in Fig. 3 (a); however, this representation no longer meets the needs for information on a particular area. This representation generates constraints to record the increase of complex features (overlays) and constraints of the current world (SASS, 2013).

As a solution to resolve this problem, the concept of 3D (three dimensions) Cadastre emerged, as shown in Fig. 3 (b). The 3D Cadastre is based on a complex topological structure with volumes, faces, edges, and nodes.

The Cadastre itself is not 3D, but the cadastral plot is three-dimensional. Thus, many authors have used the term 3D Cadastre; however, the Cadastre is a dimensionless, abstract concept. The third dimension added to the Cadastre may be a topic of interest and not necessarily the addition of a coordinate (X, Y, Z) or (E, N, h) (SOUZA, 2011).

Complementing the concept of CTM, the time variable has always had an important role



(a) 2D (b) 3D

Fig. 3 - Land plot representation.
Source: SASS; AMORIM (2013).

in TISs, but the temporal aspect has been dealt with regardless of the spatial aspect, 2D or 3D (SASS, 2013, p. 31). The time record allows us to identify, for example, who has what rights in a given moment, for that space and period. Therefore, an integrated approach of spatial and temporal aspects should be investigated aiming to identify improvements for Cadastres (VAN OOSTEROM et al., 2006).

The 4D Cadastre is created considering the 3D Cadastre plus time. The 4D Cadastre, according to Van Oosterom et al. (2006), introduces the attribute of time to describe various plots and their historical trajectories, as shown in Fig. 4. The 4D Cadastre is used when the historical record of a Cadastre is important to understand the evolution of land use over a period of time, supporting public policies.

The concept of the 4D Cadastre maintains the concept of the 2D and 3D Cadastres, considering the temporal dimension in parallel. This dimension can be integrated by the spatial dimension or an attribute. One way to implement this Cadastre is to use a topological structure in the 4D space-time as a foundation. Nevertheless, this structure is not yet available in software. An alternative to implementing the 4D Cadastre is to use the techniques of the 3D Cadastre and define temporal attributes, with restrictions, to obtain the 4D Cadastre (DONER et al., 2008).

Despite the existing settings on the 4D Cadastre, this article will consider the term 4D Cadastre. As previously reported, the Cadastre is abstract, and thus dimensionless. In addition,

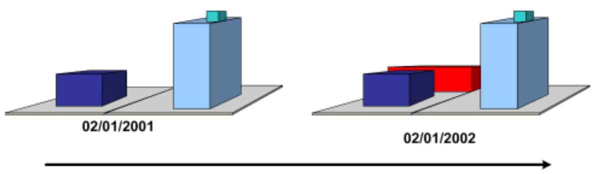


Fig .4 - 4D land plot representation.
Source: SASS; AMORIM (2013).

in the Brazilian context does not have a 3D Cadastre available to insert a fourth dimension, i.e., time. Therefore, the terms temporal Cadastre or temporal CTM are considered to name the 2D Cadastre + time.

According to Langran (1993), functions that may be supported by the temporal component in the CTM and the land registry are:

- inventory (full description): this may be an initial register comprising a long time period;
- analyzing (explaining, exploring, predicting): this is relevant in the case of the use of cadastral data for space planning and land consolidation, trend analysis and new properties registered on mortgages, for indexing property sold for a longer period of time, to identify transactions over a given time to request a prognosis for purposes of human resource planning;
- updates (replacing old information with new information): this is a key point, which can also include the generation and provision of updates relating to a given period for citizens;
- quality control (monitoring and evaluating new data while checking consistency compared to older data): this can be important in many cases; for example, in an update, it represents the generation of a new full version of the cadastral map with impacts on a particular area;
- scheduling (identifying limit states that trigger predefined actions): a few actions for maintenance and update processes need to be executed in a sequential order;
- presentation (generation of maps or tables of a temporal process): this may be a process of consolidation of the land in case of CTM and land registration.

According to Langran (1993), a temporal GIS should track the change of state of the study area, store its history, and anticipate geographical states – a definition directly applying to the temporal CTM.

Based on the concepts presented, the definition and preparation of the temporal CTM involve temporal concepts, temporal models and technologies to support their development. As for the temporal characteristics presented in Section 4, the following definitions are proposed for the temporal CTM:

1. Branched order, when a land plot is disassembled, it should have two (or more) proceeding time axes; in case of reassembly, the land plot will have two (or more) precursory time axes;
2. Time is continuous. Even if the overall CTM update is performed once a year, a few updates, such as the change of ownership or disassembly/assembly can occur at any time;
3. For the CTM, granularity for temporal data is by "day, as there are certain events that need to be updated at the time they occur;
4. The label of the temporal representation can be specified by a time interval, as an attribute identified in the data model as temporal will include a start time and an end time, making the record valid in the DBMS in that time interval.

Section 5 discusses the technologies that can support the implementation of the temporal CTM. As described, the DBMSs available on the market do not directly serve the implementation of the STDB; however, it is possible to build the spatiotemporal data model in a relational DBMS. Thus, we propose the implementation of the PostgreSQL data model with the PostGIS extension.

PostgreSQL (http://www.postgresql.org/) is an open-source object-relational database management system supporting the SQL standard. It includes the spatial extension PostGIS, which stores spatial data. Its architecture is compliant with the OGC specification.

In the spatiotemporal data model for the temporal CTM, temporal labels are placed only on tables with data that actually change with the passage of time and that are of interest to the CTM. Thus, there may be common, temporal, spatial and spatiotemporal tables. Fig. 5 shows an example of a part of spatiotemporal data modeling. This modeling was based on MADS (PARENT; SPACCAPIETRA; ZIMÁNYI, 1999) and the conceptual framework was built with the use of the ArgoCASEGEO CASE tool

(LISBOA FILHO; RODRIGUES JUNIOR; DALTIO, 2004).

The ArgoCASEGEO tool has stereotypes for time and space that assist in the identification of common, temporal and/or spatial tables. The STDB modeling used the following stereotypes: Time interval ( ), Non-Geographical Object ( ), Geographical Object ( ) and the polygonal spatial representation ( ) (SASS, 2013).

Based on the definition of these characteristics, we are able to design and develop a temporal CTM, taking into account the theoretical definitions and technologies available. It should be noted that free technologies can be used.

7. CONCLUSIONS

Considering the concepts presented, it is understood that, for the definition of a Temporal CTM model, the process of building the TIS should consider a number of constraints, both in models (space and time) and technological resources available for its preparation, development, and implementation.

A CTM using the GIS provides spatial information, while a CTM including the time component provides spatiotemporal information that allows for operations that combine space and time, enabling the preparation of various types of spatial queries. For example, to monitor the aging of the population with historical data, public managers can monitor the data on the age of the residents. These data (age), linked to data on the occupation of the residents, may demonstrate whether these residents are retirees/pensioners, as well as their average income, which may impact the economy of the region they inhabit. Another important bit of information that can be raised is the intersection of the data on the age of the residents and the pathologies that affect them, allowing for the identification of geographical regions that require certain public policies to serve the population.

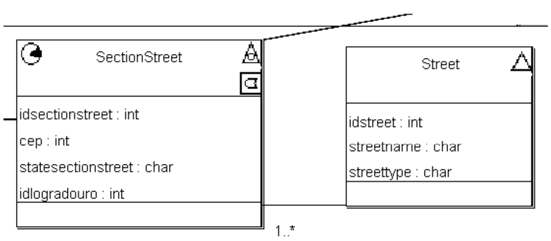


Fig. 5 - Sample spatiotemporal model tables. Source: SASS (2013).

The rapid advancement of technology has provided a series of tools that can streamline the creation, updating and maintenance of the CTMs, including the possibility of use of free tools, which may reduce implementation costs of TISs, allowing smaller municipalities to have access to these resources.

ACKNOWLEDGMENTS

We would like to thank the State University of Mato Grosso do Sul (UEMS) for the support, through the full leave for the doctoral candidate's study.

The Foundation for the Support to the Development of Education, Science and Technology of the State of Mato Grosso do Sul (FUNDECT) for the support, through the granting of the doctoral candidate's scholarship.

The Graduate Program in Cartography of FCT/UNESP of Presidente Prudente-SP, for the laboratories and support for the development of research.

The Spatial Data Analysis and Representation Research Group (GARDE).

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