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Research on spatial calculating analysis model of landuse change

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Abstract: The spatial calculating analysis model is based on GIS overlay. It will compartmentalize the land in research district into three spatial types: unchanged parts, converted parts and increased parts. By this method we can evaluate the numerical model and dynamic degree model for calculating land-use change rates. Furthermore, the paper raises the possibility of revising the calculating analysis model of spatial information in order to predicate more precisely the dynamic changing level of all types of land uses. In the most concrete terms, the model is used mainly to understand changed area and changed rates (increasing or decreasing) of different land types from microcosmic angle and establish spatial distribution and spatio-temporal principles of the changing urban lands. And we will try to find out why the situation can take place by combining social and economic situations. The result indicates the calculating analysis model of spatial information can derive more accurate procedure of spatial transference and increase of all kinds of land from microcosmic angle. By this model and technology we can conduct the research of land-use spatio-temporal structure evolution more systematically and more deeply, and can obtain a satisfactory result. The result will benefit the rational planning and management of urban land use of developed coastal areas in China in the future.
Key words: land use; dynamic change; spatial calculating analysis model

1 Introduction

The general analysis of the quantity, structure and environment of land-use change is useful to perceive the trend and character of spatio-temporal land-use change. The fixity and distinction of spatial position is one of the remarkable characters of land use. We need to recognize the changing processes of different kinds of land-use spatial structure, the positioning and the quantitative spatial information analysis of change of different kinds of land-use should be carried out. For instance, there may be two different kinds of land-use changes in the same period. In one industrial suburban area, an abandoned brickfield may be changed to arable land; while in the other suburban area, the same acreage of arable land may be used for a newly founded industrial park. In the cases like this, the land-use changes appear to cancel each other out. The actual condition can be revealed only through quantitative spatial information analysis. As shown in Figure 1, during the research period, from $t1(LA_{(i,t1)})$ to $t2(LA_{(i,t2)})$, there are three kinds of spatial models in the changes of the ith land-use category: 1) unchanged part (ULA_i), its land-use type and spatial position has not changed (Proceeding from the consideration of time scale, this paper will take the changing process of initially converted land-use type but eventually transformed to its original type during the research period as invalid change, and will not be discussed); 2) converted part ($LA_{(i,t1)} - ULA_i$), the ith land-use type changing into one of the other non-ith land-use types; and 3) increased part ($LA_{(i,t2)} - ULA_i$), another non-ith land-use type converting into the ith type ($LA_{(i,t1)}$ and $LA_{(i,t2)}$ represent the area of this land-use type at the beginning and end of the period respectively).

GIS spatial information analysis technology provides a strong technique to support the

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spatial information analysis of land-use change. By the calculation and spatial statistic analysis of land-use map for different periods, we can identify the unchanged part, converted part and the part to where it is converted, the increased part from where it comes.

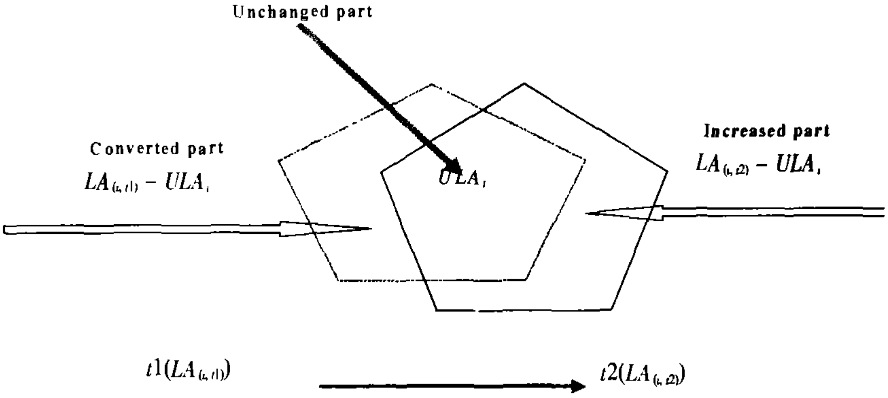

Figure 1 Spatial meaning of land-use change

2 Research method

At present, the quantitative model for calculating land-use dynamic change basically includes a traditional numerical model and a dynamic degree model.

2.1 Numerical model

Bruce P and Maurice Y, the famous quantitative geographers, provided a traditional and ordinary model for analysis in 1993. The principle of his model is as follows: the land-use changes during a certain period can be shown by calculating the average changing rate of land-use model in the researched region (Bruce and Maurice, 1993). It is called the single dynamic land-use model (Wang, 1999). The mathematical expression is:

$$K_i = (LA_{(i,t2)} - LA_{(i,t1)}) / LA_{(i,t1)} / (t2 - t1) \times 100\% \quad (1)$$

where K_i is the yearly average changing rate of the land-use type i; $LA_{(i,t1)}$ and $LA_{(i,t2)}$ represents the area of this land-use type at the beginning and end of the period respectively.

The main advantage of the calculating model is conciseness, and we can use it without complicated professional analysis technique. It has been extensively applied in the professional or non-professional reports and papers (Zhao, 2001), but the disadvantage is obvious because:

(1) This model ignores the fixity and particularity of land-use spatial position, and cannot reflect the spatial process and interrelated attributes of land-use dynamic change. For example, two changes happening with different spatial locations and attributes but with the completely same acreage: on one hand, the barren unused land in remote areas is reclaimed; on the other hand, the field of high quality agricultural value may be converted into land for urban construction. The two changing processes counteract each other, and cannot reflect the actual condition when we analyze the dynamic change of the region by this model.

(2) This model cannot calculate and compare the active degree of land-use change, that is to say, it cannot discern the "hot" or "sensible" district, as it has no spatial characters.

2.2 Dynamic degree model

The dynamic degree or land-use changing rate of a certain type of land use in the research region during the changing period can be calculated with the expression below (Liu, 1996; Wang, 2001):

$$S_i = (LA_{(i,t1)} - ULA_i) / LA_{(i,t1)} / (t2 - t1) \times 100\% \quad (2)$$

In the formula, $(LA_{(i,t1)} - ULA_i)$ represents the area of converted part, namely, the total area of the ith category of land-use being converted into the other ith type of land-use in the research period; $LA_{(i,t1)}$ represents the area of the ith land-use type at the beginning of the period; and ULA_i represents the area of the unchanged part of the ith land-use type during the research period (Figure 1).

The expression of land-use dynamic degree in the research district is given below:

$$S = \frac{\sum_{i=1}^{n} \{LA_{(i,t1)} - ULA_i\}}{\sum_{i=1}^{n} LA_{(i,t1)}} / (t2 - t1) \times 100\% \quad (3)$$

This spatial calculating model was developed by Liu Jiyuan based on GIS (Liu, 1996). It considered both the amount and spatial attribute of the ith type of land use that is converted into other land-use type, and it can compare the changing degree of the district land-use, thus, obviously, it is a much better model than the afore mentioned traditional numerical model. But this model only considers a single changing process of the ith type of landuse converting into other non-ith types, whereas that of other non-ith types of land-use converting into the ith land-use type is neglected. Thereby, it is named the single spatial information analysis model. Consequently, one disadvantage is evident: the land-use with high increasing rate and slow transformation for land-use types, especially land for urban construction, is greatly undervalued. Numerous cases indicate that the rapid expansion of land for urban construction is the important character and driving force of land-use change in developed district (He *et al.*, 2001; Zhu *et al.*, 2001). Especially in China, land expansion for urban construction and the resulted resources and environmental effects have attracted widespread attention at home and abroad, and the governmental administrative class attached great importance to them. This phenomenon has become one of the foci in investigating land-use dynamic changes in China. The calculating result for land-use dynamic degree cannot reflect the expansion trend of land use due to its variance with objective reality, which does not agree with the actual condition exactly. However the model is suited for calculating the integrated dynamic degree of land-use as well, since the inter-regional land-use type conversion is a bi-directional and equal process.

2.3 Spatial calculating model

In our opinion, while calculating the rate of land-use dynamic changes, it is necessary to consider the increased part, that is, the process of the other non-ith land-use types converted into the ith land-use type should be taken into account. In order to describe and calculate the land-use changing degree more accurately, hereby we introduce the spatial calculating model modified based upon the land-use dynamic model.

$$TRL_i = (LA_{(i,t1)} - ULA_i) / LA_{(i,t1)} / (t2 - t1) \times 100\% \quad (4)$$

$$IRL_i = (LA_{(i,t2)} - ULA_i) / LA_{(i,t1)} / (t2 - t1) \times 100\% \quad (5)$$

$$CCL_i = \{(LA_{(i,t2)} - ULA_i) + (LA_{(i,t1)} - ULA_i)\} / LA_{(i,t1)} / (t2 - t1) \times 100\% = TRL_i + IRL_i \quad (6)$$

where TRL_i represents the converting rate of the ith land-use type during the monitoring period; IRL_i represents the increased rate; CCL_i is the changing rate; and 'n' represents the number of the land-use types in the research region, $i \in (1, n)$. The formula for regional land-use changing rate agrees with that of the dynamic model, hereby we ignore it.

By comparing the formulas from (1) to (6), we can find the main distinction between the spatial calculating model and numerical model or dynamic model is how to treat the relationship between converting rate and increasing rate. In the numerical model, the changing rate (K_i) of the ith land-use type actually is the margin's absolute value between converting rate (TRL_i) and increasing rate in the spatial calculating model, as only the numerical change of the land-use type is taken into consideration. While in dynamic model, the result of changing rate (S_i) of the ith land-use type is the converting rate (TRL_i) in the spatial calculating model as a result of ignoring the increased process. The spatial calculating model gives attention to both converted and increased process; the changing rate is the sum of converting rate and increasing rate, i.e.:

Numerical analysis model: $K_i = |TRL_i - IRL_i|$

Dynamic model: $S_i = TRL_i$

Spatial calculating model: $CCL_i = TRL_i + IRL_i$

3 Case analyses

In China, suburban areas of a metropolis such as Guangzhou city, witnessing the fastest urbanization and industrialization process and the most complicated urban-rural land-use changes, are the ideal locations for research (Cui, 1990). Located in the south of Guangzhou city, Haizhu District surrounded by the Pearl River is adjacent to Panyu District in the south. It is a relatively new and fast developing urban area covering 90.4 km^2. Comparing with other districts of Guangzhou city, much of Haizhu District is a transitional zone between urban and rural areas where land has a greater proportion. In the continuous urbanization and regional economic development process, land use changes are frequently in this district. Because of this, it can serve as a perfect case for the study of the land-use dynamic changes and developing trend (Zhang, 2002).

According to existing spatial data, this paper studies land-use changes of Haizhu District from 1997 to 2001 with the help of the spatial calculating model. The current situation maps of the two years can be overlaid aided by GeoMedia 4.0 GIS software, and the unchanged area can be calculated. Here we calculate it with the spatial calculating model, and the result is listed in Table 1. We can see from the table: in the agricultural land of the first land-use type, the largest acreage of converted part is garden land, the other types of agricultural land and cultivated land, the percentage is 46%, 32% and 18% of the total area respectively. For the land for infrastructure construction of the first land-use type, the largest increase in acreage is transportation land and land for city and town construction, the percentage is 65% and 15% of the total increased area of land for infrastructure construction respectively. It indicates that the second land-use type mentioned above plays an important role in the land-use changes of the research region. We can take cultivated land, garden land and other agricultural land, city and town land and transportation land in land for infrastructure construction for example and use land cover map of Haizhu District in Guangzhou in 1997 and 2001, and the map showing main land-use type changes obtained by spatial overlaying and calculating analysis (Figures 2-4) to represent the evolution of increasing land uses and spatio-temporal convertion of land-use in Haizhu District from 1997 to 2001.

As far as the cultivated land is concerned, from 1997 to 2001, the unchanged part is 560.34 ha, accounting for 94.579% of the total area in 2001; the converted part is 109.93 ha, 18.55% of the total area accordingly; and the increased part is 32.18 ha, 5.43% of the total area. The converted part is 13.12% higher than the increased part, which indicates obviously that the net cultivated land area is decreasing continuously in Haizhu District. As for garden land, the unchanged part is 1460.44 ha, making up 96.53% of the total area; the increased part is 52.46

Table 1 Change rate of land-use in Haizhu District of Guangzhou (1997-2001) (area unit: ha)

Land type	Unchanged part	Converted part			Increased part			Changing rate
		Area	Total area %	Converting rate	Area	Total area %	Increasing rate	
Agricultural land	2098.46	588.90	6.52	5.48	103.10	1.14	0.96	21.56
Cultivated land	560.34	109.93	1.22	4.10	32.18	0.36	1.20	5.30
Garden land	1460.44	275.25	3.05	3.96	52.46	0.58	0.76	4.72
Woodland	41.01	3.92	0.04	2.18	1.25	0.01	0.70	2.88
Grassland	2.08	8.03	0.09	19.86	5.37	0.06	13.28	33.14
Other agricultural land	34.59	191.77	2.12	21.18	11.84	0.13	1.31	22.49
Land for infrastructure construction	5730.96	186.50	2.06	0.79	686.27	7.60	2.90	3.50
City and town land	4648.27	30.44	0.34	0.16	451.84	5.00	2.41	2.57
Industrial and mining land	333.84	33.93	0.38	2.31	43.62	0.49	2.97	5.28
Community land	356.75	31.89	0.35	2.05	61.88	0.68	3.98	6.03
Transportation land	315.35	68.14	0.75	4.44	106.13	1.17	6.92	11.36
Water conservancy land	20.26	22.10	0.24	13.04	22.80	0.26	13.46	26.50
Special land	56.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unused land	129.12	315.88	1.43	17.51	286.59	3.17	16.62	33.13
Unused field	10.30	9.89	0.11	12.25	7.96	0.09	9.86	22.11
Other land	118.82	305.99	1.32	18.62	278.63	3.08	16.95	35.57

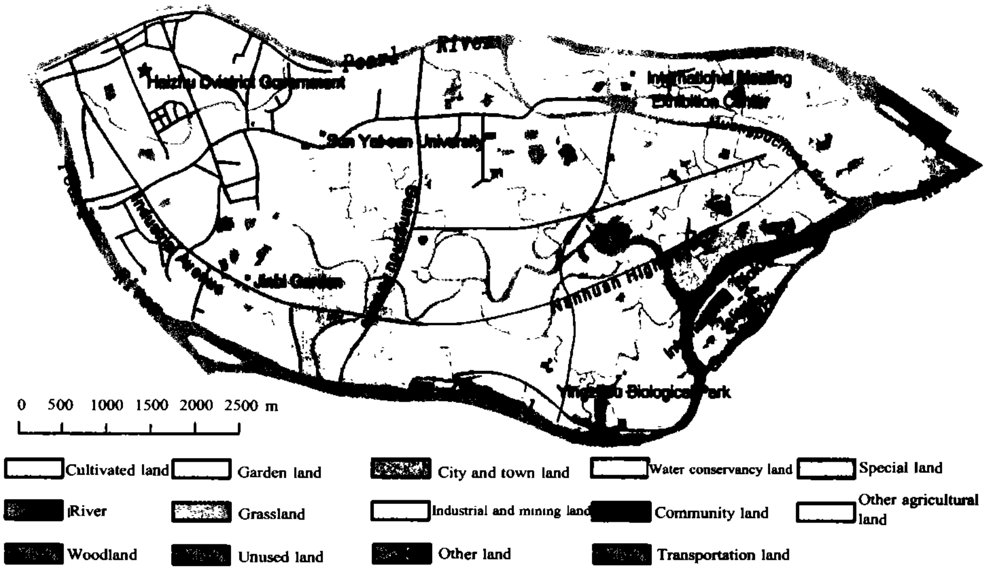

Figure 2 Land-use in Haizhu District of Guangzhou in 1997

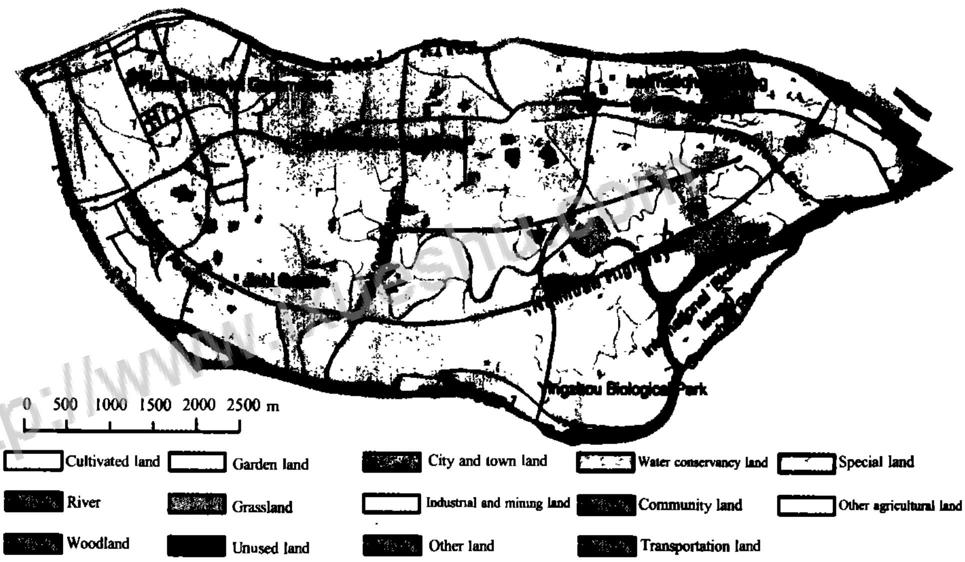

Figure 3 Land-use in Haizhu District of Guangzhou in 2001

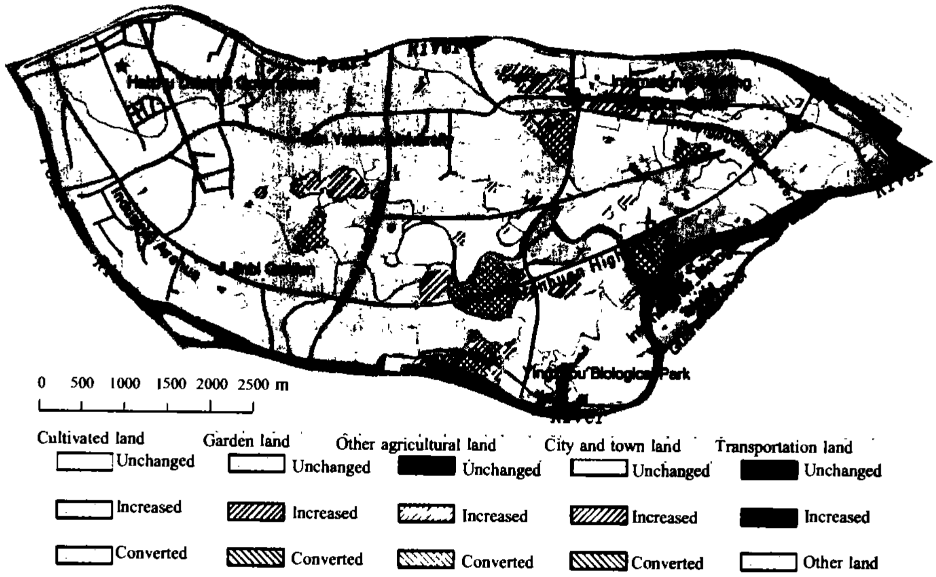

Figure 4 Change of the main land-use types in Haizhu District of Guangzhou (1997-2001)

ha, 3.47% of the total area; and the converted part is 275.55 ha, 18.21% of the total area correspondingly. The converted part is 14.74% higher than the increased part, indicating that the net garden land area is decreasing as well. As for city and town land, the unchanged part is 4648.27 ha, occupying 91.14% of the total area of land for infrastructure construction in 2001; the converted part is 30.44 ha, 0.65% of the total area; the increased part is 451.84 ha, 8.86% of the total area. Contrary to cultivated land and garden land, the converted part is 8.21% lower than the increased part, showing that the net land area for city and town is further increasing. From Figure 1 and Table 1, we can find that in the stream area of the east, as a result of government guidance, a large part of land for infrastructure construction will be changed to a biological garden, most of which derives from city and town land for infrastructure construction in the east of the research region. For land used for infrastructure construction, the second largest portion is used for transport. This indicates the importance of transportation and and communication construction in rapid urbanization process. At the same time, we should know that the percentage of both increased and unchanged parts of cultivated and garden land is over 82%, with the main portion of agricultural land remaining unchanged. This indicates that in the high economic development period, how to ensure the primary agricultural land not to be taken up optionally, how to improve the efficiency of urban land use by regulating and changing the land-use pattern and how to control the scope of land for cities should be paid more attention to. The government should take into consideration the need of land-use more rationally, and will make active effort on the land-use condition. Of course, as some parts of the rivers, lakes and ponds were filled and used for infrastructure construction, the shortened or cut-off the blocked streams, make the already scarce water source even worse.

4 Conclusions and discussion

Since the spatial calculating model can analyze land-use changes from microcosmic aspect and take the converted and increased parts of land-use changes into account as well, it can thus reflect the actual land-use changing degree. It is especially to the land-use types with active converting and increasing process (e.g. the cultivated land and garden land). At the same time, the model can accurately calculate dynamic changing degree of all kinds of land-use categories. By analyzing the spatial calculating model and combining regional characteristics with the perfection of economic policies and land laws in China in the last 10 years, we can draw the following conclusions.

(1) The spatial-temporal change process of land use takes place synchronously with the urbanization process, and the urbanization process agrees with the principle of spatial diffusion. According to the locational change characteristics, the land-use diffusing pattern in the observed area can be considered as a kind of continuous diffusion to the surroundings of the active land-use spot. Surrounding the western border of Haizhu District, the Pearl River makes it impossible for the urban land-use to diffuse toward the western area. Therefore, the urban land use area expands from the central region to the river channels network, while in the downtown area, it expands along the transportation artery. The two processes interact with each other, but the speed of the growth of the former is faster than that of the latter. As for the present condition of land use, we can divide the region into three parts: the static area in the west, the developed area in the middle and developing area in the east from the point of land-use changing principle.

(2) Cities, towns and residential area, with inactive changing trend, are the primary land-use type in the western area. Here the land-use changes occur mainly in small units, almost for commercial and residential purposes. The marginal land change spreads toward the central part because of dense population, high increment of land value and saturated spatial capacity. The land change in the central part is more active, and especially the land for towns sprawled at high speed, because it is a transitional zone between city and countryside. The single land unit broken into other types is the primary changes in the area along the Pearl River and transportation

artery. It spreads around the center, and the agricultural land conversion into urban land primarily happens in this case. The land in the east is primarily used for agriculture or even unused. In this area, the cultivated land needs to be protected and the spatial capacity has not been fully utilized. But the area is becoming smaller and smaller as a result of the spreading of the western steady area and the middle developing area as well as the limitation of the Pearl River in the east. The land changes will be active and variable, so the government should protect and manage the development of the land in this area.

(3) As far as the land-use spatial distribution is concerned, the land-use condition of the urban edges is most complex and unstable. And there is great potential to drive the land conversion for infrastructure construction. Without effective controls, the cities and towns will be expanded to a large scale, which can lead to the decrease of agricultural land. On the other hand, some parts of the rivers, lakes and ponds were filled and used for infrastructure construction. This has shortened or cut some streams, and caused "dead streams" and "dead lakes" as they were blocked such as southeast of the region in Figure 4. And some rivers crossing the city were polluted by the wastewater. At the same time, soil erosion caused by vegetation destruction has led to the increase of river sedimentation. In conclusion, the spread of land for infrastructure construction and the decrease of the agricultural land in the suburbs will cause numerous ecological and environmental problems. Thus it is important to reinforce the regulation of land-use control.

According to the analysis, we should take different actions to manage the land-use aiming at particular land-use area for the future. In districts where land use has been stabilized, the main objective is to adjust land-use structure and enhance land-use efficiency to make best use of the land when land-use development, sustainable development, and eco-environmental protection are considered. In developing districts, based on the principle of "strategic planning, comprehensive development, systemic construction, infrastructure in first step", the main objective is to carry out comprehensive development step by step and to achieve planned benefit after construction and planning. In new districts, the main object is to improve the protection of land resource, tap the latent power of urban reserved land resource and make a good general planning of urban land-use so as to make management a standard and scientific process. As for the management of land resource, the limited urban land resource must be properly planned and the urban constructions must be carefully coordinated. In order to maintain the high-yield cultivated land and vegetable land, it is necessary to transform and utilize hilly land and wasteland and to turn them into residential or industrial land or into green belts.

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