Model of land use spatial optimization based on a knowledge guide genetic algorithm

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1. Introduction

As the core issue of land use planning, land use spatial optimization is an important way to promote intensive and economical use of land resources to achieve the goal of sustainable development. It involves determining the optimal land use structure and allocating different uses to specific units of land area on the basis of land natural properties and regional socio-economic status. It is necessary to develop a multi-objective spatial optimization model to solve the problem of allocating land uses reasonable in quantity, quality and space, which have always been a hot issue in past researches (Zhang et al., 2010). Genetic Algorithm (GA), first introduced by Holland in 1975, is a kind of intelligent optimization algorithms based on the mechanism of natural selection (Holland, 1992). A substantial number of studies incorporated GA in land use spatial optimization, and these researches indicate that GA is an effective way to solve multi-objective land use spatial optimization (Cao et al., 2011; Matthews, 2001; Stewart et al., 2004). But GA in past models mainly adopt random search strategy in the process of genetic evolution operation, and lack the guidance or constraint of the field knowledge in land use, leading to the local optimal solution and relatively slow convergence.

2. Model

In this article, a land use spatial optimization model based on a knowledge guide GA is proposed to overcome the shortcomings of past studies. The model (Figure 1) modifies traditional GA with the field knowledge in land use, which consists of the spatial characteristics of land use optimization and the land use transition rules. Traditional one-dimension encoding finds it hard to maintain the spatial relationship between the genes, so the model employs two-dimension encoding to design chromosome (Cao et al., 2012; Fotakis and Sidiropoulos, 2012). Combined genes are developed to represent a land use cluster, which is a combination of adjacent land use units with the same type. The land use transition rules are made up of succession rule, suitability rule, neighbourhood rule, and constraint rule, and they are expressed as the land use transition possibilities index quantitatively. The objectives of the model are to maximize the land use suitability and spatial compactness, and the model applies weighted sum method (equation 1) to solve multi-objective spatial optimization problem.

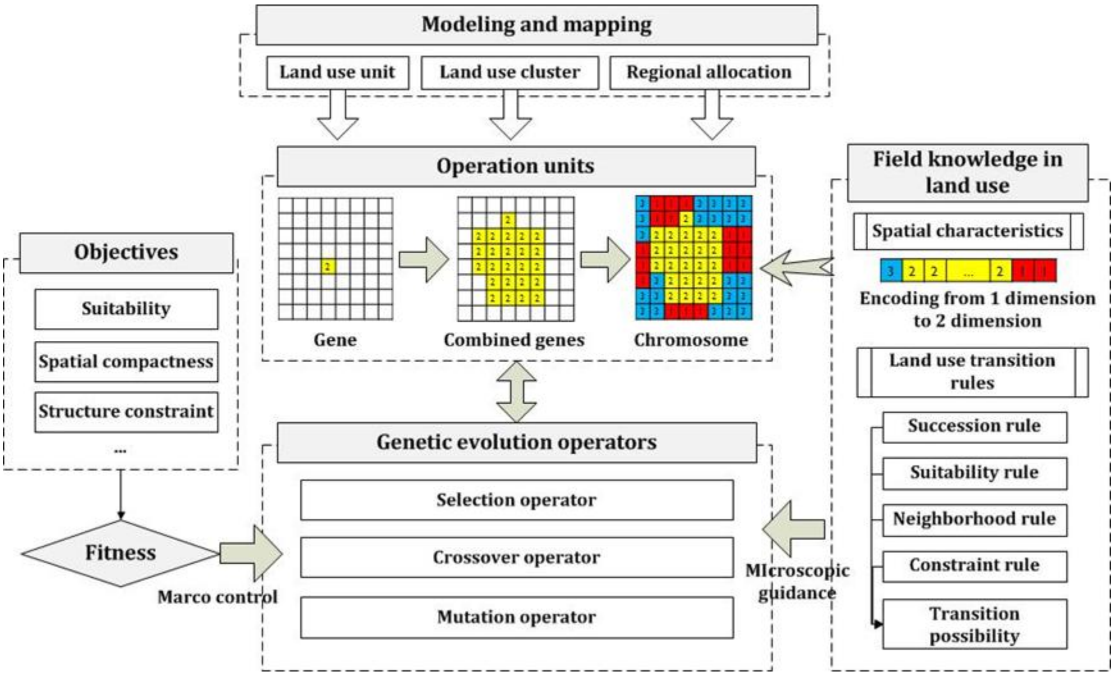

Figure 1. Model frame

$$F = w_s f_{norm}(S) + w_c f_{norm}(C) \quad (1)$$

2.1 Land use transition rules

Land use transition rules represent the necessary conditions and probabilities that land use unit changes from one type to another. The succession rule uses the determinate initialization method instead of the random initialization method, and generates the chromosomes according to the actual land use spatial pattern. Suitability rule uses the result of suitability evaluation and promotes the transition of land use to the appropriate type, to maximize land production potential. Neighbourhood rule gives consideration to compatibility and structure in the buffer area, to improve the compatibility and compactness of the allocation result. Constraint rules are designed for some special areas where it is not suitable for land uses to change with random probability. The model combines the rules above and devises the land use transition possibilities index, as equation 2 shows. P_{ijk} stands for the probability of the unit (i, j) to select type k and μ is the neighborhood index, indicating the importance of the neighborhood rule.

$$P_{ijk} = P_{\text{suitability}}(x_{ijk}) * P_{\text{neighbour}}(x_{ijk})^{\mu} * P_{\text{constrain}}(x_{ijk}) \quad (2)$$

2.2 Genetic evolution operation

The model defines combined genes as basic spatial operation units of genetic evolution operation to promote the operation space of GA from land use unit level to land use cluster level. Combined genes are made up of boundary genes and core genes, as Figure 2 shows. The crossover and mutation operators are carried out on boundary gene, and core genes are kept unchanged. The model uses the crossover and mutation operators based on the land use transition rules to search for optimal allocation results. The mutation operator (Figure 3) calculates the land use transition possibilities index at first, and then determines the value by roulette. The crossover operator (Figure 4) is a self-crossover operator and searches for two genes in the neighbourhood, whose current value and optimal value are just opposite. The genetic evolution operators act on a local level, but they produce global results.

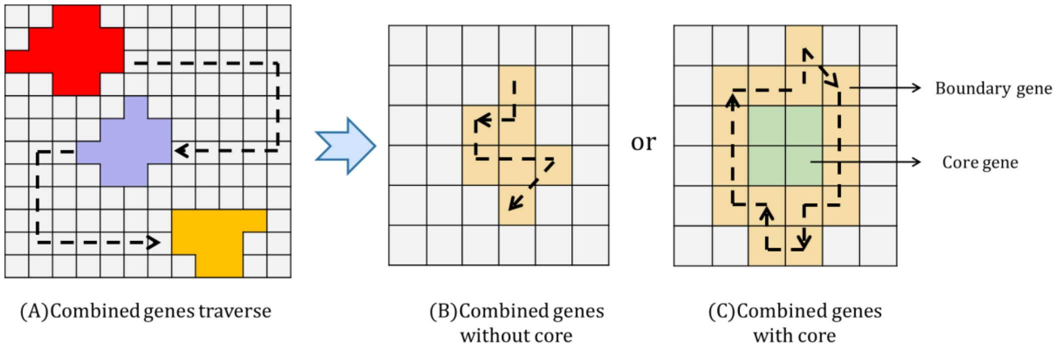

Figure 2. Combined genes

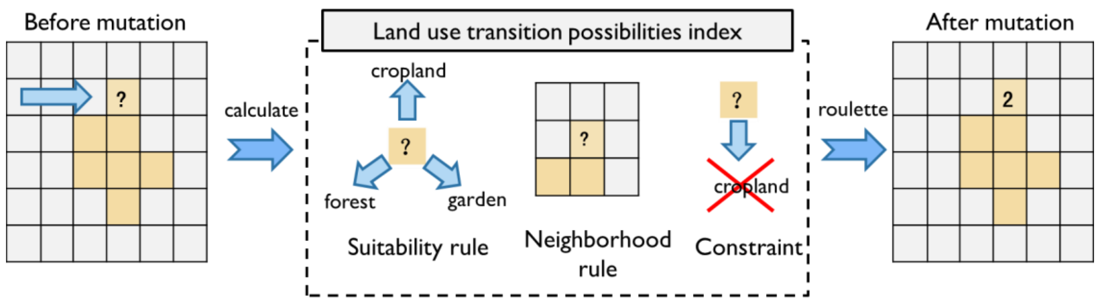

Figure 3.Mutation operator

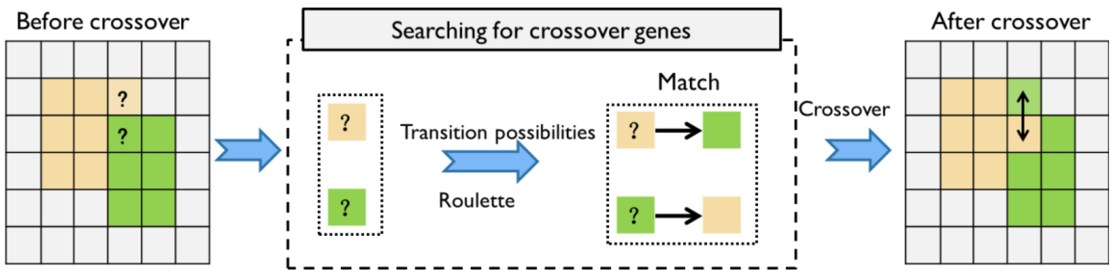

Figure 4.Crossover operator

3. Study area and data

The study area (Figure 5), Gaoqiao Town, lies in the northern Fuyang City of Zhejiang Province, China. The fast economic development has brought the problems of excessive growth of construction land and extensive land use, so it is urgent to optimize land use structure and allocation in order to promote intensive and rational land use. The data consist mainly of actual land use map, land suitability evaluation maps, restrictive maps, and socio-economic statistical data.

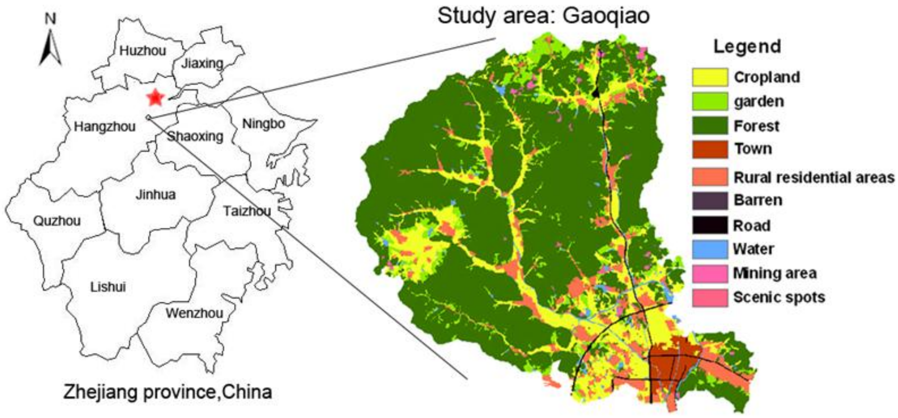

Figure 5.Location of the study area

4. Results and discussions

The model is employed to optimize the land use spatial allocation pattern of the study area (Figure 6). The results show that the model improves suitability, compactness, and weighted goal from 513538 to 521476, 1317960 to 1323320, and 0.319442 to 0.684414, respectively. We make an overlay analysis between the actual data and the optimal planning pattern to evaluate the rationality of the result. About 2.92% of the total units are changed and most of these changes are the conversation of cropland, rural residential areas, and barren land. Most of the sloping croplands convert to forest land and garden under the policy of grain for green, and the basic farmland zones protect the cropland from human disturbance and keep highly yielding farmland contiguous. Some fragmentary rural residential areas are reclaimed for cropland, garden, or forest by relocation or inner reform to satisfy the requirement of new village construction, and others near the town are urbanized. By analysing landscape indexes, cropland and rural residential areas have an obvious improvement after optimization. In general, the optimization result meets the requirement of large-scale, intensive, and economic land use to promote the sustainable development.

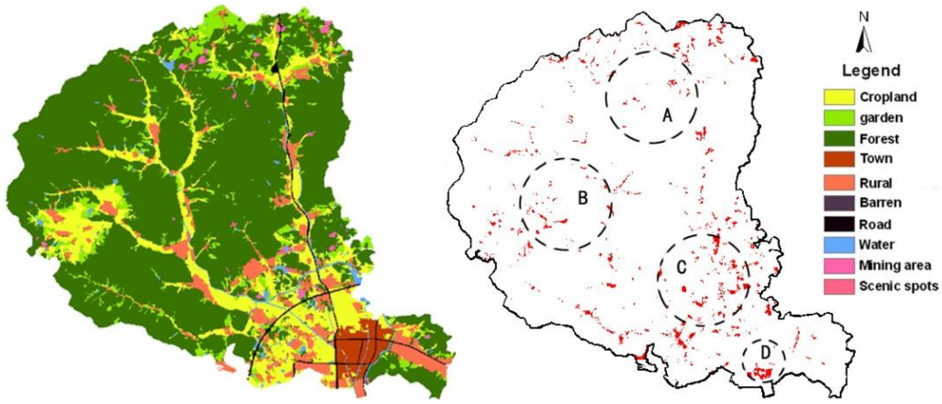

Figure 6.Optimization result and changed areas

Comparisons are made between the modified model and the traditional model based on GA in 3 different weighted scenarios, as Table 1 shows. The results show that the optimal solution acquired by the modified model presents higher suitability and compactness when the convergence curves are flattened out. Additionally, convergence ability and rate have increased dramatically owing to the combined genes and transition rules.

Model	$w_c : w_s$	Fitness	Suitability	Compactness	Running time(s)
Knowledge guide GA	0.4:0.6	0.732254	521442	1322930	1835
	0.5:0.5	0.684414	521476	1323320	1837
	0.6:0.4	0.629477	521396	1324080	1852
Traditional GA	0.4:0.6	0.656041	521174	1309730	2039
	0.5:0.5	0.583234	521110	1309470	2028
	0.6:0.4	0.543975	521086	1310530	2108

Table 1.Model comparison

We compare the results of 7 different methods to analyse the sensitivity of the transition rules. Each method makes a change on transition possibilities index, and incorporates it with crossover and mutation operators. The results show that the suitability rule has the ability of improving the suitability objective largely, but it can't deal with the spatial compactness objective. On the contrary, the neighbourhood rule promotes the compactness value a lot at the cost of decreasing the suitability value. The combination of the suitability and neighbourhood rules can make satisfactory results.

NO	Transition rules	Objectives				
		Compactness	Suitability	Weighted objective		
				Fitness	Suitability	Compactness
A	random	1317960	521192	0.585767	521116	1309570
B	suitability rule	1317960	522121	0.607204	521716	1309040
C	neighborhood rule	1331660	521125	0.673194	520835	1326210
D	both (μ=0.2)	1320350.388	521957	0.644045	521553	1316270
E	both (μ=0.5)	1322697.435	521886	0.665479	521475	1320240
F	both (μ=0.8)	1323957.64	521760	0.684414	521476	1323320
G	both (μ=1.0)	1326479.16	521697	0.693158	521412	1325270

Table 2.Rules analysis

5. Conclusion

This study has demonstrated that the proposed model can be used to solve the land use spatial optimization problem effectively, and it has much better performances than the traditional model based on GA. The problems of the local optimal solution and relatively slow convergence are solved by developing combined genes and transition rules.

6. References:

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