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Metamorphic Testing of a Superficial Area Calculation Program

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Abstract- In this paper, we try to apply metamorphic testing in a superficial area calculation program, which is common for most of the GIS systems. We construct metamorphic relation (MR) with different properties and characters of the program and its algorithm. These MRs construction methods are also useful for other programs testing of GIS system. At last, we compare effectiveness of different MRs based on the failure detection ability. This exploration would provide a feasible method for GIS program testing.

Index Terms – Metamorphic testing, metamorphic relation, superficial area calculation.

1. Introduction

Superficial area calculation refers to calculating the area of certain circumscription on earth, and it is one the most basic and common parts of spatial measuring of GIS [1]. Software testing is a common and practical way to validate the correctness of the program [2]. It validate the correctness of program under test with a set of test cases. Then, checking whether the outputs are correct or not is a vital but not necessarily a trivial task. Sometimes, verification of computed outputs is straightforward. But for superficial area calculation program, the computation may be very expensive to measure the practical area of a location. Ideally, for any input to program under test, there is a mechanism to verify the correctness of the output. The mechanism of verifying the expected result is referred to as a test oracle but test oracles are not always available [3]. This limitation is refered to as test oracel problem. Unfortunately, for superficial area calculation program, most of the expected results of the corresponding test inputs are not easy to get, except only a few special value test inputs.

Metamorphic testing (MT) [5] provides an effective method for alliviating oracle problem, which checks the metamorphic relations (MR) between inputs and outpus to determine whether the program satisfies the necessary properties. It is reported that MT is one of the most practical methods for alleviating test oracle problem [5]. This paper studies MT in superficial area calculation program testing.

2. Test Oracle Problem of Superficial Area Calculation Program

(1) A terrain calculation program models landscape with digital terrain model (DEM), and represents and storage the values of real word targets with digital vector. Thus, it is not easy for testers to compute the corresponding correct results with manual calculation to validate the program outputs. More important, the computing process is error-prone. Therefore, the dependability of manual calculation is not satisfied. (2) A terrain calculation program is based on digital data representation and modeling of real-world morphological elements. The precision of original data collection and the error of the model will result in differences between DEM program outputs and real-world measurements data. Therefore, it is impossible to validate the outputs of programs with the real-world measurement data. (3) A terrain calculation program is a kind of complex scientific computing program. The functions, such as superficial area calculation, brae gradient calculation and shortest path searching, refer to derivative computing, power computing and some other type scientific computing. These characters determine the inputs of the calculation program are infinite.

All the above factors result in the oracle problem for the testing of superficial area calculation program.

3. Method and Results

3.1 Method

MT checks MRs between inputs and outputs to determine whether the program satisfies the necessary properties or not. In this way, it will be unnecessary to assume the existence an oracle for individual inputs, and hence the test oracle problem can be alleviated. The necessary properties of the program under test are called MRs. Usually, MT is designed as a general technique for creating follow-up test cases based on metamorphic relations and existing test cases, particularly those that have not revealed any failure, in order to try to find uncovered flaws. The follow-up test cases are created based on MRs, and the outputs from these test cases can then be predicted, if the real outputs deviate from the predicted ones, then faults exist in the program tested.

3.2 Metamorphic Relations

We generated metamorphic relations from different characters of the program and its algorithm, such as geometric properties of the program outputs, mathematical properties of program outputs, focusing properties of DEM, algorithm of triangular irregular network (TIN), and general characters of superficial area program.

3.2.1. Construction MRs with geometric properties

No matter how the programs of superficial area calculation are implemented, the area of a target domain should remain unchanged, when a target domain of superficial area rotates in a direction or translates in a vector. For example, if the target domain rotates around Z axis, the superficial area holds in line. With this property, we can define a metamorphic relation.

$$\begin{aligned} MR_{1-1}: &\forall i((X'_i = X\cos\theta - Y\sin\theta) \wedge (Y'_i = X\sin\theta + Y\cos\theta)) \\ &\wedge (Z'_i = Z)) \quad \Rightarrow (S(X,Y,Z) = S(X',Y',Z')) \end{aligned} \tag{1}$$

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If a target domain translates in vector (d_x, d_y), the superficial area of it remain unchanged. Thus, a metamorphic relation is also constructed.

$$MR_{1-2}:\ \forall i((X'_i = X_i + d_x) \wedge (Y'_i = Y_i + d_y)) \wedge (Z'_i = Z_i)) \Rightarrow (S(X,Y,Z) = S(X',Y',Z') \tag{2}$$

3.2.2. Construction MRs with mathematical properties

As the target area is composed of several different grids, the sequence of the grids would not affect the computation result of superficial area calculation. With this consideration, we construct metamorphic relation with reverse order of the grids:

$$MR_{2-1}:\ \forall i((X'_i = X_{n+1-i}) \wedge (Y'_i = Y_{n+1-i})) \wedge (Z'_i = Z_{n+1-i})) \Rightarrow (S(X,Y,Z) = S(X',Y',Z') \tag{3}$$

$$MR_{2-2}:\ \forall i((X_i' = k \bullet X_i) \wedge (Y_i' = k \bullet Y_i) \wedge (Z_i' = k \bullet Z_i) \Rightarrow S(X_i' \quad Y_i' \quad Z_i') = k^2 \bullet S(X_i \quad Y_i \quad Z_i) \tag{4}$$

3.2.3. Construction MRs with focusing properties of DEM

Consider the TIN method and mesh grids G_i(i=1,2,3) in target area we introduced earlier. At first, the superficial area is divided into several mesh girds. Then we compute the superficial area of a target grid with two triangles division. At last, the total area of all grids is the superficial area of target domain.

Let S(G_i) be the superficial area of the mesh grid G_i. The precision of G3 is two times of G2, which precision is two times of G1. As the mesh grid is the covering graph of practical space superficial area, a relation could be generated.

$$\mathrm{MR}_3:\ G_1 \subset G_2 \subset G_3 \Rightarrow S(G_1) \le S(G_2) \le S(G_3) \tag{5}$$

3.2.4. Construction MRs with algorithm of TIN

Consider the algorithm of TIN. The basic computation component is a triangle. Therefore, with the property of triangle area computation algorithm, the following formulas could be generated.

$$MR_{4-1}: (a' = \sqrt{2\times c^2 + 2\times b^2 - a^2}, b' = b, c' = c) \Rightarrow S(a',b',c') = S(a,b,c) \tag{6}$$

3.2.5. Construction MR with the characters of superficial area

At last, we also could construct metamorphic relations based on the characters of superficial area. For a target domain, if it could be divided into two parts, then the superficial area of the domain is the total of the sub parts. Thus, this metamorphic relation could be represented.

$$\begin{aligned} MR_5:\ & X' = \{X_0, X_1, \cdots, X_m\} \wedge Y' = \{Y_0, Y_1, \cdots, Y_m\} \wedge Z' = \{Z_0, Z_1, \cdots, Z_m\} \\ & \wedge X'' = \{X_m, X_{m+1}, \cdots, X_{n-1}, X_0\} \wedge Y'' = \{Y_m, Y_{m+1}, \cdots, Y_{n-1}, Y_0\} \\ & \wedge Z'' = \{Z_m, Z_{m+1}, \cdots, Z_{n-1}, Z_0\} \\ & \Rightarrow S(X,Y,Z) = S(X',Y',Z') + S(X'',Y'',Z'')\ (1<m<n) \end{aligned} \tag{7}$$

3.3. Results and Conclusions

Based on the test results of single MR, shown in Table 3, we could generate the failure detection ratios of different MRs, shown in Figure 1. From the Figure, we could get that the failure detection ability of different MRs are not all the same. And not all of them are useful [4]. For example, MR_{1-1}, MR_{1-2} and MR_{2-2} are useless in these five mutant detection, and the failure detection ability of MR_{4-1} for all of these five mutants are obviously higher than others. Moreover, there is an obvious contrast between the failure detection ratios of different mutants for the same MR, such as MR_3. It needs more experiments to validate. Above all, we could get that CMRs could improve the failure detection ability in most cases.

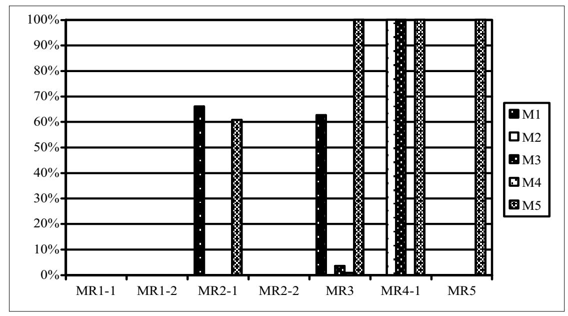

Figure 1. Failure Detection Ratio of Different MRs

4. Summaries and Future Works

In this paper we have analysed the role that the effectiveness of metamorphic relations plays in superficial area calculation program testing. We have empirically shown on several valuable methods constructing MRs. Test Oracle problems that are considered difficult in previous literature become easy to solve. However the testing method proposed needs to be improved. For one thing, the selection of MRs need further more researches. As the empirical results shown, not all the MRs are valuable in failure detection. Therefore, the next issue is to research the MR selection guidelines. For anothor thing, automation of such metamorphic testing procedure is strongly needed for test case generation, execution and results comparison, testing wil be low efficient when the amount of data is large which is quite often in GIS testing.

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