Analysis and Representation of Changes in Change Detection

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1 Factors leading to changes

Geographic data represents the dynamic surface of the earth. This surface is constantly changing. These changes result from two major aspects: natural forces and human actions. Natural forces generate both abrupt and usually radical changes and slow changes. Human actions also generate abrupt and radical changes, which are mostly caused by the use of explosives. Human actions can cause predictable and unpredictable changes. Table 1 shows the factors leading to changes.

2 Important and ignored changes

The features that change and the magnitude of the above changes are very important in geographic data revision. But it is noted that changes in those features represented in the geographic data in consideration are the only types of changes we are concerned with. That is to say, for different application areas or goals, changes to be detected will be different. If the geographic data in consideration does not include driveways, the construction of ten new driveways in the area will not require detecting and updating the data. Only those features of changes related to research objects will be concerned. For example, for Chinese standard map series, each map defines the detail and magnitude of objects represented in this scale. Out of this framework, it is unnecessary to study them. Of course, the changes of magnitude smaller than given accuracy will also be excluded. One example is that if the relief has changed by less than one-half of the contour interval (contour interval goes from 5 to 20 feet in the 7.5-minute series) there is no need to care about it.
Table 1 Factors leading to changes

| Change factors   | Characteristics | Prediction status | Frequency          | Magnitude                      |
|------------------|-----------------|-------------------|--------------------|-------------------------------|
| Natural forces   | Abrupt          | Hard (or Unpredictable) | Very low           | Very large                    |
|                  | Systematic      | Hard (or Unpredictable) | Constant          | Small in short time, Large in long time |
| Human actions    | Planned         | Predictable       | Very high          | Large                         |
|                  | Other aspects   | Hard (or Unpredictable) | Low               | Large                         |

3 Change type and representation

Assuming that geographic data is composed of objects representing the features and surface of the Earth. Between the epoch difference, \(T_N\) (the epoch of the data for the current times) and \(T_L\) (the epoch of the data used in last revision), four situations are possible for any object of interest at \(T_N\).

An object\(^1\) has four causes:

- \(\bullet\) may no longer be on the ground;
- \(\bullet\) may be changed;
- \(\bullet\) may be unchanged;
- \(\bullet\) may not be represented.

Using the set notation, the vector datasets for times \(T_L, T_N\) and the changed vector datasets can be expressed as:

\[
M_L = \{m_i | m_i\text{ is the vector representation of a terrain or relief object, on a date } T_L, \text{ and at scale } S, \text{ for purpose } L\}\]

\(M_N = \{m_u \text{ | } m_u\text{ is the new vector representation of a terrain or relief objects, on a date } T_N, \text{ and at scale } S, \text{ for purpose } N\}\)

\(M_C = \{m_c \text{ | } m_c\text{ is the changed vector representation of a terrain or relief object between date } T_L \text{ and } T_N\}\)

where \(M_L\) is the out-of-date geographic dataset; \(M_N\) is the up-to-date dataset; and \(M_C\) is the changed vector dataset.

The set \(M_L\), representing the terrain for the date \(T_L\) in the past, can be expressed further as follows:

\[
M_L = \{D, C, U\}\]

where \(D = \{d | d\text{ is the vector representation of an object that no longer exists in the time } T_N\}; C = \{c | c\text{ is the vector representation of an object before change}\}; U = \{u | u\text{ is the vector representation of an unchanged object}\}\).

Here, assuming that:

\(N = \{n | n\text{ is the vector representation of a new object}\}, H = \{h | h\text{ is the new vector representation of an object which has changed}\}.

Then, the changed geographic dataset \(M_C\) may be expressed as:

\[
M_C = \{D, N, H\}\]

Set \(H\) is the formula metamorphosis of \(C\), that is, \(H = f(C)\), so new vector datasets \(M_N\) can be expressed as follows:

\[
M_N = \{N, U, H\}\]

The content of \(H\) can be discussed furthermore. Obviously, \(H\) is the changed objects, it can be divided into three parts: the semantic changes \((H_S)\), the non-semantic changes \((H_N)\), and the combination of them \((H_C)\). Then Eq. (6) can be changed into:

\[
M_N = \{N, U, H_S, H_N, H_C\}\]

Accordingly, Eq. (5) will be changed into:

\[
M_C = \{D, N, H_S, H_N, H_C\}\]

Generally change types can be divided into twelve basic change types. More complex change types can be dissolved into these types in principle. They are:

1) Emergence (Geometric-Thematic). A new object comes into the beginning of its life, as shown in Fig. 1(a).

2) Disappearance (Geometric-Thematic). An object comes to the end of its life, as shown in Fig. 1(b).

3) Regular geometric transformation (Geometry). This includes those changes demonstrated by some simple and regular geometric functions, such as scale, shift, rotation and so on. Corresponding examples are given in Fig. 1(c), 1(d), 1(e).

4) Irregular geometric transformation (Geometry). This includes those changes which are not described by simple geometric functions, such as
shape changed by adding vertex, moving vertex and so on. An example is given in Fig. 1(f).

5) Mergence (Geometry). Several old objects are merged into a new object, as shown in Fig. 1(g).

6) Splitting (Geometry). An old object is split into several new objects, as shown in Fig. 1(h).

7) Splitting-mergence (Geometry). More than two objects are merged into and split into several objects, as shown in Fig. 1(i).

8) Thematic. Some thematic attributes of an object are changed. For instance, a building or a piece of land gets its new owner, as shown in Fig. 1(j).

9) Mergence (Thematic). Some attributes of an object are merged into other attributes, as shown in Fig. 1(k).

10) Splitting (Thematic). Some attributes of an object are split into other attributes, as shown in Fig. 1(l).

11) Splitting-Mergence (Thematic). Splitting and merging happen together for an object, as shown in Fig. 1(m).

12) Splitting-Mergence (Geometric-Thematic). This is one combination change of geometric and thematic, as shown in Fig. 1(n).

In fact, these change types can be generalized into seven classes:

1) Emergence of a new object, including change type 1),
2) Disappearance of an old object, including change type 2),
3) Geometric transformation of a single geo-object, including change types 3), 4),
4) Thematic transformation of a single geo-object, including change type 5),
5) Geometric transformation of two or more geo-objects, including change types 5), 6), 7),
6) Thematic transformation of two or more geo-objects, including change types 9), 10), 11),
7) Combination of geometric and thematic transformation of a single or more geo-objects, including change type 12).

Another problem worth discussing is the change of relation. Although relation change hides inside the change of geometry and/or thematic change, it must be considered separately because it contains too much information and always affects behaviors of the next process. Again assuming that $R_S$ represents spatial relation and $R_N$ represents non-spatial relation, then Eqs. (7) and (8) can be turned into:

$$M_N = \{N, U, H_S, H_N, H_C, R_S, R_N\} \quad (9)$$

$$M_C = \{N, D, H_S, H_N, H_C, R_S, R_N\} \quad (10)$$

Obviously, $M_N = (M_C - D) \cup U$ \quad (11)

4 Relation about changes between geo-objects and pixels in images

In change detection using remotely sensed data, it should be noted that changes of geo-objects and that of pixels are not all corresponding to each other[3]. The reason lies in some external factors such as effects of atmosphere, different sun angle, image noise and so on. That is to say, changes can be divided into two parts: true change (TC) which is caused by actual geo-objects' change and false change (FC) which is not caused by geo-objects' change but other factors. In fact, an $m:n$ relationship exists between change/no-change of a geo-object and the pixel value. This can be formalized into four categories:

1) Change to change: the change is the thematic content of the object which is large enough to lead to a change in image pixel values.
2) Change to no-change: either the change is not large enough to lead to a spectral change, or the spectral change has been weakened by unexpected noise.
3) No-change to change: the terrain object is in a normal condition but the image pixel value has changed because of external factors.
4) No-change to no-change: if there is no external noise, no change in pixel values is expected for a stable object.

So these factors cause the difficulty of accurate and robust change detection techniques. For robust change detection techniques, TC and FC should be recognized and discriminated.

5 Conclusion

This paper discusses the factors which lead to
changes, change representation, change types and relation between geo-objects' change and pixel’s change and so on. And these aspects are the firstly concerned with content change detection. Obviously this forms a very firm basis of change detection techniques for analyzing and developing. The future work is to investigate how to design an accurate, prompt, robust and automated change detection system by analyzing actual changes.

References

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