Lecture 5

Metamorphic Testing - III

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Metamorphic Relations

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Metamorphic Relations

Metamorphic relations are necessary properties of the algorithm to be implemented, which involve multiple related inputs and their outputs

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Identification of MRs

- Is it feasible to identify or generate MRs?

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A Simple Approach

- Select an input
- Modify it, hopefully that the relevant change of the output will be somehow predictable.

  If yes, any generalisation?

  If yes, then identify an MR

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Example 1

To find the sum of a series of integers

What are the possible MRs?

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Example 1 (continued)

To find the sum of a series of integers

Suppose the selected input is: [3, 7, 12, 6, 8]

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Example 1 (continued)

To find the sum of a series of integers

Suppose the selected input is: [3, 7, 12, 6, 8]

What are the possible modifications on this input?

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Example 1 (continued)

To find the sum of a series of integers

Suppose the selected input is: [3, 7, 12, 6, 8]

A possible modifications on this input:

- Add “10” to every element of this series of integers
- Is the change of output predictable?

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Example 1 (continued)

To find the sum of a series of integers

Suppose the selected input is: [3, 7, 12, 6, 8]

A possible modifications on this input:

- Add “10” to the first element of this series of integers
- Is the change of output predictable?

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Example 1 (continued)

A possible modifications on this input:

- Add “10” to the first element of this series of integers
- Is the change of output predictable?

Can it be generalised with “10” replaced by any integer “k”?

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Description of MRs

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Notation

- SI, SI-1,SI-2, … denote source inputs
- FI, FI-1, FI-2, …denote follow-up inputs
- SO, SO-1,SO-2, … denote source outputs
- FO, FO-1, FO-2, ..denote follow-up outputs

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Example 1 (continued)

MR:

If FI is constructed from SI by adding an integer value of k to the first element of SI, then FO=(SO + k)

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Example 1 (continued)

To find the sum of a series of integers

Suppose the selected input is: [3, 7, 12, 6, 8]

A possible modifications on this input:

- Add “10” to an element of this series of integers
- Is the change of output predictable?

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Example 1 (continued)

MR:

If FI is constructed from SI by adding an integer value of k to an element of SI, then

FO=(SO + k)

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Example 1 (continued)

To find the sum of a series of integers

Other possible modifications on this input:

- Commutative – permutation
- Duplicate the input
- Split the input
- …….

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Example 1 (continued)

MR (Permutation)

If FI is a permutation of SI, then FO=SO

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Example 1 (continued)

MR (Duplication)

If FI = SI + SI, then FO = 2 * SO.

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Example 1 (continued)

MR (Concatenation)

Given SI-1 and SI-2.
Define FI = SI-1 + SI-2
Then, FO = SO-1 + SO-2

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Example 1 (continued)

MR (Splitting)

Split SI such that SI=S1 + S2.
Define FI-1=S1 and FI-2=S2.
Then, FO-1 + FO-2 = SO.

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Example 1 (continued)

Possible modifications

Type of inputs

List

Possible operations on lists

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Example 2

To find the average of a series of integers

What are the possible MRs?

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Example 2 (continued)

To find the average of a series of integers

Suppose the selected input is: [3, 7, 12, 6, 8]

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Example 2 (continued)

To find the average of a series of integers

Suppose the selected input is: [3, 7, 12, 6, 8]

What are the possible modifications on this input?

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Example 2 (continued)

To find the average of a series of integers

common and similar MRs with

To find the sum of a series of integers

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Example 3

An enquiry or search system

Suppose to find hotels which are:

- Period of staying nights
- Range of room charges per night
- Name of city
- Maximum distance from the relevant city GPO

What are the possible MRs?

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Example 3 (continued)

For source input:

- Dec 15-16, 2020
- [$100, $250]
- Melbourne
- 15 km

SO = {Hotel-A, Hotel-B, Hotel-C}

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Example 3 (continued)

For follow-up input FI:

- Dec 14-16, 2020 //Dec 15-16, 2020
- [$100, $250]
- Melbourne
- 15 km

FO ???? SO={Hotel-A, Hotel-B, Hotel-C}

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Example 3 (continued)

For follow-up input FI:

- Dec 14-15, 2020 //Dec 15-16, 2020
- [$100, $250]
- Melbourne
- 15 km

FO ???? SO={Hotel-A, Hotel-B, Hotel-C}

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Example 3 (continued)

For follow-up input FI:

- Dec 15-16, 2020
- [$100, $300] // [$100, $250]
- Melbourne
- 15 km

FO ???? SO={Hotel-A, Hotel-B, Hotel-C}

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Example 3 (continued)

For follow-up input FI:

- Dec 14-15, 2020
- [$100, $250]
- Sydney //Melbourne
- 15 km

FO ???? SO={Hotel-A, Hotel-B, Hotel-C}

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Example 3 (continued)

For follow-up input FI:

- Dec 15-16, 2020
- [$100, $250]
- Melbourne
- 9 km //15km

FO ???? SO={Hotel-A, Hotel-B, Hotel-C}

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Example 4

To search how many times a non-string (S1) appears in another non-string (S2)

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Example 4 (continued)

To search how many times a non-string (St1) appears in another non-string (St2)

St1: abac

St2: abadcabacddaabcabdcdaabacccdbabaddc

abadcabacddaabcabdcdaabacccdbabaddc

Output: 2

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Example 4 (continued)

Note

St1: aaa

St2: aaaaaabaaddaabcabdcdaabacccdbabaddc

aaaaaabaaddaabcabdcdaabacccdbabaddc

Output: 4

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Example 4 (continued)

To search how many times a non-string (St1) appears in another non-string (St2)

Program

- Accepts two non-strings St1 and St2 as inputs
- Outputs an integer (number of times that St1 appears in St2)

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Example 4 (continued)

To search how many times a non-string (St1) appears in another non-string (St2)

Each input consists of two non-strings:

SI = (SI-St1, SI-St2)

FI = (FI-St1, FI-St2)

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Example 4 (continued)

Given SI = (SI-St1, SI-St2)

Define FI = (FI-St1, FI-St2), such that

- FI-St2=SI-St2, and
- FI-St1 is constructed from SI-St1 by deleting its first element

FO ??? SO

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Example 4 (continued)

Given SI = (SI-St1, SI-St2)

Define FI = (FI-St1, FI-St2), such that

- FI-St2=SI-St2, and
- FI-St1 is constructed from SI-St1 by deleting its last element

FO ??? SO

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Example 4 (continued)

Given SI = (SI-St1, SI-St2)

Define FI = (FI-St1, FI-St2), such that

- FI-St2=SI-St2, and
- FI-St1 is constructed from SI-St1 by deleting one of its elements

FO ??? SO

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Example 4 (continued)

Given SI = (SI-St1, SI-St2)

Define FI = (FI-St1, FI-St2), such that

- FI-St1=SI-St1, and
- FI-St2 = SI-St2 + SI-St2

FO ??? SO

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Example 4 (continued)

Given SI = (SI-St1, SI-St2)

Define FI = (FI-St1, FI-St2), such that

- FI-St1 = reverse of SI-St1, and
- FI-St2 = reverse of SI-St2

FO ??? SO

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Metamorphic Relations

- Some reminders
  - MRs not restricted to identity relations and numeric relations
  - Multiple executions
  - Follow-up test cases may depend on the outputs of the source test cases
  - MT is applicable even if test oracle exists

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Summary

Reference

- F. T. Chan, T. Y. Chen, S. C. Cheung, M. F. Lau and S. M. Yiu, Application of Metamorphic Testing in Numerical Analysis, *Proceedings of the IASTED International Conference on Software Engineering*, 191-197, 1998.
- S. Segura, G. Fraser, A. B. Sanchez and A. Ruiz-Cortes, A Survey on Metamorphic Testing, IEEE Transactions on Software Engineering, Vol. 42(9), 805-924, 2016.