A Template-Based Approach to Describing Metamorphic Relations

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Problem

Number of Metamorphic Relations (MRs) presented in research papers
Problem

Lack of standards to describe MRs

- Most MRs are described informally using natural language.
- Key information about the MRs is sometimes omitted.
- Great variability in the way MRs are described.

Let’s use tables!
<table>
<thead>
<tr>
<th>Name</th>
<th>Online search engines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Online search engines</td>
</tr>
<tr>
<td>Version</td>
<td>1</td>
</tr>
<tr>
<td>License</td>
<td></td>
</tr>
<tr>
<td>URL</td>
<td></td>
</tr>
</tbody>
</table>

**Inputs**

<table>
<thead>
<tr>
<th>Name</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>String</td>
</tr>
<tr>
<td>Description</td>
<td>Search query</td>
</tr>
<tr>
<td>Mandatory</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>String</td>
</tr>
<tr>
<td>Description</td>
<td>Site domain filter (introduced as a part of the query)</td>
</tr>
<tr>
<td>Mandatory</td>
<td>No</td>
</tr>
</tbody>
</table>

**Outputs**

<table>
<thead>
<tr>
<th>Name</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>List</td>
</tr>
<tr>
<td>Description</td>
<td>List of search results</td>
</tr>
</tbody>
</table>

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**Context ID**

D - OSE

**Description**

Test search engine’s reliability when retrieving Web pages that contain an exact word or phrase.

**Source test case**

**Inputs**

- Q

**Outputs**

- P

**Follow-up test case**

**Inputs**

- Q, D

**Outputs**

- P

**Preconditions**

\[1 < |P_A| ≤ 20 \text{ and } 1 < |P_B| ≤ 20\]

**Input relation**

\[Q_B = Q_A \text{ and } D_B = d_i \text{ being } d_i \text{ the domain of } P_{A}[i] \text{ with } 1 ≤ i ≤ |P_A|\]

**Output relation**

\[P_{B}[j] \in P_{B}\]

**Example**

For example, let us test Google by issuing the following source query:

"side effect of antibiotics in babies" ...
Related templates
User story

As a <role>,
I want <goal/desire>
so that <benefit>

Example:
As a user,
I want to indicate folders not to backup
so that my backup drive isn't filled up with things I don't need.

Related templates
Goal Question Metric (GQM)

Goal: <purpose, issue, object, viewpoint>,
Question: <question(s)>
Metric: <metric(s)>

Example:
Goal: Improve the timeliness of change request processing from the project manager's viewpoint.
Question: What is the current change request processing speed?
Metric: Average cycle time.
Analyze <Object(s) of study>,
for the purpose of <Purpose>
with respect to <Quality focus>
from the point of view of <Perspective>
in the context of <Context>

Example:

Analyze the practice of mindfulness,
for the purpose of evaluating its effects
with respect to the performance of students in conceptual modelling
from the point of view of the experimenters
in the context of second-year students in the Degree in SE.

These templates have something **in common**...
Simplicity

Flexibility

Problem
Related templates
Template
Conclusions
In the domain of <application domain>,
[where <context definition>]
[assuming that <constraints>]
the following metamorphic relation(s) should hold
  • <metamorphic relation name_1>:
    if <relation among inputs/outputs>
    then <relation among inputs/outputs>
  • <metamorphic relation name_n>:
    if <relation among inputs/outputs>
    then <relation among inputs/outputs>

Let’s see some examples
**Template Examples**

In the domain of cybersecurity (code obfuscators) the following metamorphic relation(s) should hold:

- MR1:
  
  - if two different source programs, \( P_1 \) and \( P_2 \), are functionally equivalent
  
  - then their obfuscated versions, \( O(P_1) \) and \( O(P_2) \), should also be functionally equivalent and, therefore, the compiled obfuscated executables programs, \( C(O(P_1)) \) and \( C(O(P_2)) \), should have equivalent behavior, i.e. the same outputs for the same inputs.

In the domain of cybersecurity (code obfuscators) where:

- \( p, p_1 \), and \( p_2 \) are computer programs.
- \( \Omega \) is a program obfuscation function.
- \( \Omega(p) @ \{t\} \) is the obfuscation of \( p \) at a given time \( t \).
- \( \equiv \) is the program functional equivalence relation.

the following metamorphic relation(s) should hold:

- MR1:
  
  - if \( p_1 \equiv p_2 \), i.e. \( p_1 \) and \( p_2 \) are functionally equivalent
  
  - then \( \Omega(p_1) \equiv \Omega(p_2) \), i.e. the obfuscations of \( p_1 \) and \( p_2 \) are also functionally equivalent.

- MR2:
  
  - if \( \{ t_1, ..., t_n \} \) are different times
  
  - then \( \forall t \in [1, n] - 1 \) \( \Omega(p) @ \{t\} \equiv \Omega(p) @ \{t+1\} \), i.e. the obfuscation process does not depend on the obfuscator environment (time of execution in this case).

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**Template Examples**

In the domain of Google search assuming that:

- the number of results of the source search query is greater than zero and less than or equal to 20 in order to avoid inaccuracy caused by empty and large result sets

the following metamorphic relation(s) should hold:

- MPR\(_{reverseID}\):
  
  - if the search terms of the given query are set in reverse order
  
  - then the result of the new query must be similar to the results of the former one applying Jaccard similarity.

In the domain of Google search where:

- site: is a Google search operator that specifies domains, e.g. site:windo.com.
- \( q_1 \) and \( q_2 \) are queries represented as sequences of conjunctive search criteria, i.e. \( q = (q_1)_1 .. m \)
- an exact word or phrase is a search criterion, e.g. "side effect of antibiotics in babies".
- \( site: \) is also a search criterion.
- \( R(q) \) is the result set of web pages returned by a given query \( q \), i.e. \( R(q)=\{p_1\}_{i=1..n} \)
- \( \#R(q) \) is the size of \( R(q) \).
- \( \equiv \) is the sequence concatenation operator.
- \( rev \) is the reverse sequence function, i.e. \( q = (q_1)_1 .. m \Rightarrow rev(q) = (q_m ... q_1) \)
- \( 9 < \#R(q) \leq 20 \)

assuming that:

- \( 0 < \#R(q) \leq 20 \)

the following metamorphic relation(s) should hold:

- MPR\(_{site}\):
  
  - if \( q_2 = q_1 \setminus site: d \) where \( d \) is the domain of one of the web pages in \( R(q_1) \)
  
  - then \( R(q_2) \subseteq R(q_1) \), i.e. the results of \( q_2 \) must be a subset of the results of \( q_1 \).

- MPR\(_{reverseID}\):
  
  - if \( q_2 = rev(q_1) \), i.e. \( q_2 \) is the reverse of \( q_1 \)
  
  - then \( R(q_2) \approx R(q_1) \), i.e. the results of \( q_2 \) are similar to the results of \( q_1 \), applying Jaccard similarity.

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### Template

#### Validation

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Title</th>
<th>Domain</th>
<th>#MRs</th>
</tr>
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<tbody>
<tr>
<td>2002</td>
<td>T.Y. Chen et al.</td>
<td>Metamorphic Testing of Programs on Partial Differential Equations: a Case Study</td>
<td>Numerical programs</td>
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<td>2004</td>
<td>T.H. Tse et al.</td>
<td>Testing Context-Sensitive Middleware-Based Software Applications</td>
<td>Embedded systems</td>
<td>1</td>
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<tr>
<td>2009</td>
<td>W.K. Chan et al</td>
<td>Finding failures from passed test cases: improving the pattern classification approach to the testing of mesh amplification programs</td>
<td>Computer graphics</td>
<td>3</td>
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<tr>
<td>2010</td>
<td>X. Xie et al</td>
<td>Testing and validating machine-learning classifiers by metamorphic testing</td>
<td>Machine learning</td>
<td>2</td>
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<tr>
<td>2011</td>
<td>F.-C. Kuo et al</td>
<td>Testing Embedded Software by Metamorphic Testing: a Wireless Metering System Case Study</td>
<td>Embedded software</td>
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<tr>
<td>2014</td>
<td>S. Segura et al</td>
<td>Automated metamorphic testing of variability analysis tools</td>
<td>Software variability</td>
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<td>2016</td>
<td>T.Y. Chen et al</td>
<td>Metamorphic Testing for Cybersecurity</td>
<td>Cybersecurity</td>
<td>2</td>
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<tr>
<td>2016</td>
<td>M. Lindvall et al</td>
<td>Agile Metamorphic Model-based Testing</td>
<td>Search database</td>
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</tr>
</tbody>
</table>

**Total** 17
Template specification

In the domain of \(<application\ domain>\) where \(<context\ definition>\)
assuming that \(<constraint(s)>\) the following metamorphic relation(s) should hold:

- \(<metamorphic\ relation\ name_1>:\)
  \[ \text{if } <relation\ among\ inputs/outputs> \quad \text{then } <relation\ among\ inputs/outputs> \]
  \[ \ldots \]
- \(<metamorphic\ relation\ name_n>:\)
  \[ \text{if } <relation\ among\ inputs/outputs> \quad \text{then } <relation\ among\ inputs/outputs> \]

Versioned technical report

LaTeX template

Problem

Related templates

Template

Conclusions
Conclusions

Problem

- Lack of standards to describe MRs
  - Most MRs are described informally using natural language.
  - Key information about the MRs is often omitted.
  - Great variability in the way MRs are described.

Template

In the domain of realization, domain, (where xcontext definition)
[assuming that $constraint(s)$]
the following metamorphic relation(s) should hold
- $relation among inputs/outputs$
  - $relation among inputs/outputs$
  - $relation among inputs/outputs$

Template validation

<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
<th>Authors</th>
<th>Journal</th>
<th>Page</th>
</tr>
</thead>
</table>

Template specification

Versioned technical report
LaTeX template

Thanks!

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