The Utility of Neural Network Test Coverage Measures

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Traditional safety-related software development

Neural network coverage measures

Towards traditional coverage for neural networks

Utility of neural network coverage measures

Conclusions
Traditional Safety-Related Software Development
We want assurance that the software behaviour is fully described by the requirements.

We use the Requirements to derive Test Cases, which are executed dynamically.

We measure both the result of each test and how the collection of all tests covers the software structure.

- For example: Statement, Branch, Modified Condition / Decision Coverage [1]

Incomplete code causes test failure; incomplete requirements may not be detected.

If tests pass, but do not achieve full coverage then, either:

- Software behaviour is correct, requirements are incomplete
- Requirements are correct, software includes additional unnecessary behaviour
- Software behaviour and requirements are both correct, test set is incomplete
100% Requirements-Based Testing (RBT) for traditional software is based on:

- A complete set of requirements, which are (for example) accurate, consistent, unambiguous and verifiable
- Which can be decomposed in a hierarchical, traceable manner, so that low-level test results can confidently aggregate to high-level software behaviour
- To “units”, where behaviour is closely linked to code structure, behaviour that is strongly data-dependent should be captured as a specific requirement

The combination of RBT and structural test coverage provides confidence that the requirements suitably describe the software's behaviour, both what it does and what it does not do

- Note: 100% RBT and full structural coverage does not guarantee error free code
Neural Network Coverage Measures
• Typical neural network coverage measures are related to neuron activations

• Historically, there has been a progression:
  – From measures that consider neurons in isolation [2]
  – Through measures that consider neurons within each layer [3], [4]
  – To measures that consider how neurons in one layer affect neurons in the subsequent layer [5]

• These approaches are reminiscent of traditional software coverage measures, with the neuron as the “low-level behavioural unit”
Towards Traditional Coverage for Neural Networks
Traditional Software -vs- Neural Networks

<table>
<thead>
<tr>
<th>Traditional Software Aspects</th>
<th>Neural Network Context</th>
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<tbody>
<tr>
<td>There is a complete set of requirements</td>
<td>Neural networks solve “open” problems; there is not a set of requirements that is accurate, complete, unambiguous and verifiable</td>
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<tr>
<td>Requirements can be hierarchically decomposed</td>
<td>Some level of decomposition may be possible, but requirements are not decomposed to a level that can directly be coded against</td>
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<tr>
<td>Behaviour is closely linked to code structure</td>
<td>The link between structure (i.e. neuron activation) and behaviour is indirect and not well-understood</td>
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<td>Coverage can be measured efficiently</td>
<td>Information on individual neuron activations may not be readily available from highly optimised hardware</td>
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None of the aspects that make test coverage “work” for traditional software apply to neural networks
Software satisfies requirements:

- Robustness to adversarial examples [6]
- Disciplined approach to requirements specification [7]
- Transformation of abstract domains through typical activation functions [8]
- Encoding logic constraints as part of the network training process [9]

Requirements cover behaviour:

- Tests cover input, operational, failure and adversarial domain spaces [10]
- Detection and mitigation of backdoor attacks [11]
- Automatic (formal) inference of network properties [12]

Current techniques allow the two main aims of requirements-based test coverage to be partially met for neural networks
Utility of Neural Network Coverage Measures
Neural network coverage measures provide additional utility, beyond the aims of requirements-based test coverage for traditional software:

- They could be used to **optimise training data** (e.g. whether there is value in collecting additional training data)
- They could be used to **compare training and (independent) verification data sets**, specifically from the network’s perspective
- They could be used to **generate additional inputs**, which could meaningfully extend the training data set
- They could be used to **choose between different neural networks**, for similar levels of performance, select the better covered network
- They could be used to **monitor runtime behaviour** (e.g. by benchmarking activation patterns)
Conclusions
Current neural network test coverage measures cannot provide the same level of confidence as requirements-based test coverage does for traditional software.

But, there are some approaches that can partially meet the aims of traditional coverage in the context of neural networks.

And, the neural network test coverage measures are valuable in other ways.
References


