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1 TESLA: An Introduction

1.1 Overview
TESLA is a software tool designed to aid decision makers. It has several purposes:

1. To allow decision makers to assess and record not only evidence that supports or refutes a claim, but also any uncertainties that may exist, for example due to lack of knowledge.
2. To provide a structure for breaking a complex decision down into manageable chunks.
3. To provide a full audit trail of the information that was used to reach a decision.
4. To provide decision makers with tools to analyse their decision, allowing them to effectively target funds and resources at areas that have the most bearing on the overall decision.

The software uses a form of decision theory called Evidence Support Logic (ESL), which is discussed in detail throughout this document.

Importantly, neither TESLA nor ESL takes the place of the decision maker. They are simply tools that are available to support the decision maker when making complex decisions, and to record the details of each decision so that it is robust and defensible.

1.2 About this Document
This document is the user guide for the software. Although it provides an overview of ESL, it does not contain details of best practice or how to interpret results. In addition, as it is intended that the software should be both intuitive and user-friendly, this document does not need to contain details of every menu or button available on the user interface. When describing how to perform an action using the software, generally only one method will be mentioned - however there will often be multiple ways of achieving the same effect (e.g. right-clicking, using a keyboard shortcut etc.) It is suggested that users should explore the software and find the method that best suits them.

As far as possible a consistent terminology has been used throughout this document. Users may wish to refer to the glossary of terms in Appendix B for definitions of the key terms.

1.3 An Introduction to Evidence Support Logic (ESL)

1.3.1 Differences between ESL and MCDA/MADA
You may have heard of multi-criteria decision analysis (MCDA, also known as multi-criteria decision making or multi-attribute decision analysis (MADA)), a common method applied to decisions that involve choosing one option from a number of different options. For example, MCDA could be applied to choose a new car based on which would be most suited to your needs: a Ford Mondeo, a Peugeot 407, a Toyota Avensis etc. Each option (i.e. car) is scored based on how well it meets certain criteria, for example comfort, performance, fuel consumption etc.

In contrast to MCDA, ESL is used to study a single hypothesis (e.g. “this car is comfortable”) in depth. Whereas MCDA aims to answer the question “Which option is best?” ESL aims to
answer the question “How confident can I be that my hypothesis is true?” Since the answer to the question is quantitative, it is possible to compare the results of the same analysis as applied to different scenarios (or cars in this instance). In TESLA this is called a Portfolio Comparison. Portfolio comparisons are described in Section 12.

A second difference between the two methods lies in the evaluation of criteria. In MCDA, each option is usually scored or ranked based on how well it meets the criteria. In ESL, two numbers are entered: the degree of confidence that the hypothesis is true given the evidence supporting it and the degree of confidence that the hypothesis is false given the evidence refuting it. From these a third value can be calculated (the degree of uncommitted belief) which expresses either the degree of uncertainty arising from a lack of evidence and/or confidence in the evidence, or the degree of conflict in the available evidence. Uncertainty arising from lack of evidence could be due to missing research (did you actually try all the seats in the car?) or an inability to collect evidence (e.g. it wasn’t possible to test the effectiveness of the windscreen wipers because it wasn’t raining on the day of the test drive). Accounting for uncertainty in a decision, understanding how it affects the outcome, and planning how to reduce it are some of the most important aspects of ESL.

1.4 Decision Tree Structure and Terminology

A decision is typically informed by determining whether some hypothesis is truthful. For example, consider the decision of whether to take an umbrella with you when you leave the house. This is informed by the truthfulness of the hypothesis “It will rain today” (or equally “It will not rain today”) - if this hypothesis is determined to be true, an umbrella would be a good idea. If it is false, there is probably no need for the umbrella.

Complex decisions are best solved by breaking the main hypothesis down into a number of simpler constituent hypotheses. These can then be broken down further, until a point is reached where some information is known about the lowest level hypotheses. Consider again the problem of deciding whether to take an umbrella with you when you leave the house. In order to determine the truthfulness of the hypothesis "It will rain today" you might do a number of things. First of all, you would look outside to see if it is currently raining. If it is, you will certainly need your umbrella! If it isn’t, you need to consider whether it might rain whilst you are out. You might look at the thickness of the clouds in the sky or look at a forecast given in a newspaper, on the television or radio or via the internet. This simple example shows how information is gathered to answer simpler questions, the answers to which are combined to produce a solution to the overall question. TESLA provides a framework for the propagation of this information; from the points of knowledge through to the solution of the original problem.

This framework is known as a Decision Tree, shown below in Figure 1. Like any other kind of tree, it starts at the roots and grows outwards, branching as it does so, and ending at the leaves. Each point on the tree is called a Node, and these are points of information - each node represents a hypothesis. There are two special kinds of nodes; the Root Node, of which there can only be one, and the Leaf Node, of which there can be many. Since nodes represent hypotheses, these nodes are alternatively referred to as the Root Hypothesis and Leaf Hypothesis respectively.
The Root Node, coloured yellow in the figure, is always positioned at the top left of the tree. It is the only node in the tree not to have a Parent - i.e. it does not originate from any other node. The root node is the ultimate destination of all the information within the tree; it is here that the final solution will be obtained.

The root node will have one or more Children. Child nodes are simply nodes that have a parent, i.e. they originate from another node. They may also be parent nodes themselves, if they in turn have one or more child nodes of their own. Thus the tree branches down and to the right through a succession of nodes. Nodes which share the same parent are called Siblings.

Most nodes will have both a parent and one or more children (coloured orange in the figure). However some have no children; these are the second special type of node, known as Leaf Nodes. Leaf nodes are coloured green on the figure above and are always the final node on a Branch of the tree. These are the points where information is input into the tree by the user; levels of confidence that the hypotheses are true and false based on the available evidence.

The information is then propagated up the tree from the leaves to the root using the algorithms supplied by a Propagation Method. As described above, the propagation method employed by TESLA is Evidence Support Logic or ESL. The details of the algorithm are contained in an appendix to this user guide, but it is not necessary to understand the mathematics to use the software.
2 Installing TESLA

2.1 System Requirements

TESLA runs under 32 bit and 64 bit flavours of Windows XP, Vista and 7. It may run under earlier versions of Windows (e.g. Windows 2000) which have been kept up-to-date, but the software has not been tested in such environments. Any modern PC will meet the hardware requirements of the software.

2.1.1 Microsoft .NET

TESLA requires Microsoft .NET version 2.0 or later. This is simply a library that provides many common pieces of software with the tools they need for drawing windows, manipulating files etc.; it is provided by default with copies of Windows Vista (.NET v3.0) and Windows 7 (.NET v3.5).

If you are using Windows XP (or earlier) you may need to install or update Microsoft .NET before you can begin to use TESLA. If you receive an error message during the installation process, or when trying to launch TESLA, that informs you that the correct version of the .NET framework is not available, you should use Windows Update to download the latest version of .NET. Note that updates to the .NET framework are not usually listed as being ‘Critical’ or ‘High-Priority’, so will not appear if ‘Express’ is selected on the welcome page of Windows Update. Choose ‘Custom’ instead.

2.2 Installation

An installer for TESLA can be downloaded from the Quintessa Online website:

https://www.quintessa-online.com/TESLA/

The software is packaged into a self-extracting installer, which should be saved to a suitable place on the destination computer. Once downloading has completed, double-click on the .msi file to launch the installer which will lead you through the installation process.

Once installed, TESLA can be launched via the shortcut on the desktop or the entry in the Start menu. Until a licence is acquired TESLA will operate in restricted mode, as described below.

2.3 Use of the Unlicensed (Restricted) Version

An unlicensed copy of TESLA is known as the “Restricted” version, since a number of important functions are disabled - for example, decision trees cannot be saved and new trees cannot be constructed with more than 10 nodes.

The Restricted version of TESLA may be freely used for the following:

1. Evaluation of the software, prior to purchase.

2. Viewing (but not altering the structure of) decision trees constructed in a licensed copy of the software.

2.4 Purchasing a Licence for TESLA

To unlock the full functionality of TESLA, a licence must be purchased from Quintessa. Please email
for further details and a quote. If you decide to purchase a licence, you will be sent instructions that will enable you to activate your licence online.

2.4.1 Obtaining Your SID

During the licence activation process, you will be asked for your unique System-Identifier code (SID). To obtain this, launch TESLA on the computer you wish to purchase the licence for. Select ‘Order TESLA’ under the Help menu, to display a window similar to the one shown in Figure 2 below.

![Order TESLA window](image)

**Figure 2:** The System-Identifier code needed to activate a TESLA licence.

The code displayed in the window is unique for each computer. It can be copied to the system clipboard (Ctrl-C) and pasted (Ctrl-V) to the required location.

Once the activation process has been completed, a unique licence code will be emailed to you. Click ‘Enter Licence Code’ under the Help menu in TESLA, and paste the licence code into the box displayed (Figure 3).

After a valid licence has been entered, complete functionality will be unlocked.

The TESLA website (www.quintessa-online.com/TESLA) may also be used to carry out the following operations:

- recover a lost licence code;
- update personal details;
- add a further machine to a licence (e.g. a laptop or home machine belonging to, and for exclusive use by, the licence holder).

![Enter Licence Code window](image)

**Figure 3:** Entering the licence code to unlock TESLA.
3 Building a Decision Tree

The first step in decision-making using TESLA is to construct a hypothesis that represents your decision, as discussed in Section 1.4. The next step is to construct a decision tree, by breaking down your main hypothesis into sub-hypotheses until the lines of reasoning reach a level of detail for which there is supporting or refuting evidence available. This section describes how to go about this process using the TESLA interface.

If at any stage during the tree-building process you are unsure as to what information must be entered in a given field, then a tooltip with guidance can often be produced by hovering over the associated field label with the mouse pointer.

3.1 Creating a New Tree

To create a new tree from scratch, click ‘New Tree’ under the ‘File’ menu (or use the button on the toolbar). A Decision Details form will be shown (this can be retrieved at any point by selecting the menu option in the ‘Tree’ menu), as depicted in Figure 4. Here the user can enter their name and a title and description for the tree. This form is also used to report the tree version number, its current status and to access the change log, all of which will be discussed further later on.

Once the user and tree details have been completed, press OK to close the form and start editing the tree itself.

![Figure 4: The Decision Details form](image-url)
3.2 The Tree View Display

The main view in TESLA is the Tree View display; this is where the decision tree is constructed and tree parameters and confidence values are added by the user. When you first start a new decision tree the display will look like Figure 5, with a single node appearing. This is the root node (see Figure 1) and will always be located at the top left of the tree.

![Tree View Display](image)

Figure 5: The Tree View display, showing a new decision.

It is possible to have a number of trees open in the same instance of TESLA; each is displayed on its own tab, and navigation between them is achieved by clicking the tabs at the top of the Tree View display. Each tab is labelled with a title which is supplied by the user when a new tree is created. Hovering over a tab with the mouse cursor will display the file path of the associated .tes file in a tooltip (provided that the tree has already been saved to file). A ‘#’ symbol in front of the tree name indicates that it contains unsaved changes.

3.2.1 Zooming

The magnification of the Tree View can be altered in a number of ways:

- by using the slider and buttons at the bottom right of the TESLA window, or
- by using the zoom items in the View menu or the associated keyboard shortcuts (Ctrl+Plus or Ctrl+Minus), or
- if a mouse with a scroll wheel is available, then the zoom level can be changed by pressing Ctrl while scrolling the mouse.

3.3 Editing a Node Name and Summary

The root node should be the hypothesis related to your decision, as discussed in Section 1.4 of the Introduction. For example, if our decision was whether to take an umbrella with us when we leave the house today, a corresponding root hypothesis might be “It will rain today”.

To edit the title of a node, double-click it to bring up the Hypothesis Properties dialog (Figure 6). Enter the hypothesis in the ‘Short Hypothesis’ field, and a more detailed version (if required) in the ‘Detailed Hypothesis’ field. The ‘Explanation’ box can be used to include a further explanation of terms used in the other two fields, or to include extra information about the hypothesis.
Closing the Hypothesis Properties dialog, you will see that the root hypothesis has been updated with the new name. It is also possible to display the hypothesis summaries on the Tree View display; simply select Show Hypothesis Summaries from the View menu (this menu item can be toggled to turn summaries on and off).

3.4 Adding Child Hypotheses

As described in the introduction, decisions are often complex and can be simplified by breaking them down into lines of reasoning, until leaf-level sub-hypotheses are defined with which there is associated evidence. For example, our root hypothesis “It will rain today” could be broken down into the three sub-hypotheses “The weather forecast predicts rain”, “It is cloudy outside” and “It is already raining”. Each of these is easier to establish the truth or falsehood of than the general statement “It will rain today”.

To add a child hypothesis, right-click on the parent and select ‘New Child Hypothesis’ from the pop-up menu. Repeat this process as many times as necessary.
Each of these sub-hypotheses might be broken down further. For example, the hypothesis “The weather forecast predicts rain” could be broken down into the sub-hypotheses “The national TV forecast predicts rain” and “The local newspaper forecast predicts rain”. Hypotheses should be continually simplified in this manner until a point is reached where the final sub-hypotheses (leaf hypotheses) are simple enough that it is easy to judge whether the available evidence supports or refutes them. An example tree with a number of sub-hypotheses is shown in Figure 8.

![Figure 8: A simple example decision tree](image)

### 3.5 Node Numbering

As shown in Figure 8, all nodes (except the root node) are automatically assigned numbers according to their position in the tree. This makes it easy to identify nodes in a complex tree with many branches. However, the numbers can be hidden by selecting ‘Hide Node Numbers’ from the ‘View’ menu. The same menu item is also used to redisplay the node numbers once hidden.

### 3.6 Expanding and Collapsing Nodes

If a node has children (e.g. the root node, or node 1 in Figure 8) a small grey box is shown to the left of the node image. Clicking on this box will show or hide that node’s children.

It is also possible to collapse or expand all nodes at a given level, by right-clicking a node at the desired level and choosing ‘Collapse/Expand Tree at Selection Level’ from the pop-up menu. The ‘Expand All’ item in the main ‘View’ menu expands all collapsed nodes in the tree.
3.7 Editing Trees

3.7.1 Cutting, Copying, Pasting and Deleting Nodes

The 'Edit' menu contains the usual editing controls Cut, Copy, and Paste. These are also available via keyboard shortcuts or right-clicking a node. Nodes or groups of nodes can be cut or copied from a tree and pasted into the same or a different tree as a child node. They can also be pasted into a new tree as a root node. Note that if a node has children, they are also copied, as are the child node’s children, and their children, and so on until a leaf node is reached. In other words, it is the whole tree branch that is copied rather than the single node. It is worth noting that TESLA contains its own ‘clipboard’ to hold a copied section of a tree. This internal clipboard will be lost when the application is closed.

The root hypothesis can never be deleted, as it is an essential part of the tree, but any other node may be freely deleted. Note that if a node has children, they will also be deleted - in fact the whole branch stemming from the selected node will be removed. A second delete option is also found under the ‘Edit’ menu, which is ‘Delete Child Nodes’. This deletes all of the currently selected node’s children (and branches stemming from them).

3.7.2 Reordering Sibling Nodes

Sibling hypotheses can be reordered by first by selecting a node and then shifting it up or down relative to its siblings. This is achieved using the ‘Move Up’ and ‘Move Down’ options from the node's right-click context menu or the associated keyboard shortcuts (Ctrl+Up and Ctrl+Down). Since the node numbering indicates the positions of the nodes in the tree, node numbers are automatically re-calculated.

3.7.3 Altering the Decision Details

The Decision Details form (Figure 4) appears whenever a new tree is started or an old tree opened from file. It can also be viewed, and the information edited, at any point by selecting ‘Decision Details’ from the ‘Tree’ menu.
4  Tree Parameterisation

Before evidence is assessed and confidence values entered into the tree, it needs to be parameterised. This includes specifying the relative importance of each sub-hypothesis, the degree of overlap between sub-hypotheses, and whether any sub-hypothesis could individually be a “show-stopper”.

4.1  Sufficiency

‘Sufficiency for’ and ‘sufficiency against’ parameters must, in general, be specified for each child hypothesis in the tree. (Note that the use of logical operators, described in Sections 4.5 and 4.5, may make certain sufficiency values redundant.) They specify the degree to which proof or disproof of a hypothesis is sufficient to prove or disprove its parent hypothesis on a scale where 0 means totally insufficient and 1 means totally sufficient. In order to determine a sufficiency for or against parameter for a given hypothesis it can be helpful to ask the question: “If the hypothesis were known to be true or false, then how confident would you be that the parent hypothesis is true or false?”

Sufficiency values influence how confidence values are propagated up the tree. Greater sufficiencies will result in confidence values being propagated more strongly up the tree hierarchy.

To input sufficiency values for a node, double-click it to bring up the Hypothesis Properties dialog and select the ‘Parent Hypothesis’ tab. Use the two sliders to input sufficiency for and against values (Figure 9).

![Figure 9: Editing sufficiency values.](image)

Sometimes the sufficiency for and sufficiency against values will be the same. However, perhaps more often and as in our example, they may take different values. Consider the hypothesis “It is already raining”. Clearly, if this is true then the root hypothesis “It will rain today” must also be true. This suggests that the sufficiency of confidence for should be 1. However, if this hypothesis is false (i.e. it is not currently raining) it doesn’t actually tell us much about whether it will rain later or not. Thus the sufficiency of confidence against should be much
lower - here it has been set to 0.2. This low sufficiency value means this hypothesis has a low weighting when considering confidence against.

The sufficiency values of a node are depicted to the left of the node image, as shown in Figure 10. The sufficiency of confidence for is shown at the top, in green, and the sufficiency of confidence against is shown at the bottom, in red.

![Figure 10: The sufficiency values are shown to the left of the node image.](image)

4.2 Dependency

With each set of sibling hypotheses there is a chance that some of the confidence they contribute to the parent hypothesis may arise from common judgements on evidence i.e. overlap in key elements of the evidence base, and the dependency value of the nodes reflects this. The value must lie between 0 (no overlap) and 1 (full overlap). This parameter is used to avoid ‘double-counting’ of evidence when evaluating confidence in a parent.

To edit the dependency between a set of sibling nodes, double-click their parent to bring up the Hypothesis Properties dialog and click the ‘Sub-Hypotheses’ tab. Use the slider at the bottom right to change the dependency value.

![Figure 11: Editing the dependency between a set of sibling hypotheses.](image)

In our example, there is likely to be some dependency between the two sub-hypotheses “The national TV forecast predicts rain” and “The local newspaper forecast predicts rain”, since both will obtain their information from the same source (the Met Office). Each may interpret this data differently though, with the local forecast being at a higher spatial resolution than the national one.

The dependency value assigned to the children of a hypothesis is shown underneath the hypothesis image, as depicted in Figure 12.
4.2.1 Alternative Dependencies

If there are more than two siblings, the level of overlap between each individual node and its siblings may differ. In this case, a separate dependency value can be specified for each possible grouping of sibling nodes. These are referred to as alternative dependencies. To specify alternative dependencies, click the button ‘Specify Alternative Dependencies...’ on the Sub-Hypotheses tab (shown in Figure 11). For the root hypothesis of our example the dialog in Figure 13 will be shown.

![Figure 13: Specifying alternative dependencies between groups of siblings.](image)

On the left is a depiction of all of the sibling nodes, each one of which is assigned a number in brackets. On the right is a list of all possible groupings of the siblings. A separate dependency value can be specified for each group by selecting it from the list and using the slider to enter a value.

Note that the dependency of a group must be less than or equal to the dependency of any subgroup contained within it; for example, the dependency between all the siblings 1, 2 and 3 cannot exceed the dependencies between 1 and 2, 1 and 3 or 2 and 3.

If the children of a node have alternative dependencies specified, an asterisk will be shown next to the value of the dependence underneath the node image.

4.3 Necessity

The success of some nodes may be a necessity for the success of their parent - that is, nodes which, if they fail a ‘confidence test’, will necessarily lead to the node above failing the same test (for example, a site for a new supermarket must have planning permission - if the evidence suggests this will not be achieved, then there is no possibility that the site could be chosen, even if it was perfect in every other sense).
If a node marked as a necessity fails the predefined confidence test, then the confidence values for and against propagated to its parent will be at least as much as the confidence assigned to the failing hypothesis, irrespective of the sufficiency or dependency values specified (“at least as much” because siblings of the failed hypothesis may contribute extra confidence).

To mark a node as being a necessity, double-click it to bring up the Hypothesis Properties dialog and select the ‘Parent Hypothesis’ tab (see Figure 9). Check the box marked ‘Necessity’ at the bottom of the dialog. Hypotheses that are a necessity are indicated on the Tree View display by a grey background to the node image, as shown in Figure 14.

4.3.1 Node Failure
There are two confidence test criteria that can be used to specify whether a node has failed: if the confidence against is greater than 0.5 (the default method); or if the confidence for is less than 0.5. The criterion for determining node failure applies to the entire tree and can be set in the ‘Failure’ tab of the Options dialog, which can be found under the ‘Tree’ menu (Figure 15). This choice only affects nodes that have been marked as a necessity.

4.4 All Sub-Hypotheses Necessary
In many situations, confidence in the parent hypothesis is dependent on achieving confidence in all of the child hypotheses.

This represents a situation where all the child hypotheses are required collectively to ensure the success (or failure) of the parent, but where complete uncertainty about any one child alone would mean complete uncertainty about the parent. This situation is represented by propagating the minimum confidence values from among the child nodes. This form of logic is often (but by no means exclusively) used towards the top levels of a tree, to control integration of confidence arising from various different lines of reasoning. It reflects an assessment that
confidence in the parent can be no better than that for the ‘weakest link’ of the child nodes, and that there is no ‘mutual support’ i.e. confidence in child nodes does not combine in providing confidence in the parent.

In some aspects, this can be thought of as an “AND” operation. In our example, the fact that the sky is covered in cloud is not sufficient on its own to determine whether it is going to rain - we also need to ascertain whether the clouds are rainbearing or not. Similarly if we spot a rainbearing cloud in the distance, but the rest of the sky is blue, it doesn’t necessarily mean that it will rain. If we had no information about either one of these factors, we would be completely uncertain about whether it looks like rain.

To override the propagation algorithm and specify that all sub-hypotheses are required for confidence in the parent, double-click the parent node to bring up the Hypothesis Properties dialog. Click the ‘Sub-Hypotheses’ tab and chose the appropriate radio button (Figure 11) - the propagation method can be overridden for the confidence for and/or the confidence against.

If the propagation algorithm has been overridden in this fashion, the sufficiency value in the node image is replaced by “ALL” in the Tree View display, as shown in Figure 16.

![Diagram]

**Figure 16:** If all sub-hypotheses are necessary, the sufficiency values of the siblings are replaced by “ALL” in the Tree View display.

### 4.5 Any Sub-Hypothesis Sufficient

In many situations, any and every single child hypothesis is sufficient on its own to ensure the success (or failure) of a given parent hypothesis, and each child is independent of the others. That is, if any one of the children is true, then the parent must also be, but confidence in the children does not combine to produce overall higher confidence in the parent than that for the node that represents the ‘strongest link’; the latter aspect is important to identifying if ANY should be employed rather than just employing a sufficiency value of 1 for all of the group of sibling nodes. This is modelled by direct propagation of the maximum confidence value from among the child nodes. As for the ‘ALL’ operator, this form of logic is often (but by no means exclusively) used towards the top levels of a tree, to control integration of confidence arising from various different lines of reasoning.

In some aspects, this can be thought of as an “OR” operation - in our example, if we look outside through the window we know it is raining if either we spot some people sheltering under umbrellas OR we can actually see the raindrops splashing onto the ground. Both of these hypotheses are sufficient on their own to have confidence in the statement that it is already raining. However, the overall judgement of the truthfulness of the parent uses these different kinds of evidence independently; you would not be more likely to take an umbrella if you...
observed raindrops splashing on the ground AND observed people sheltering under umbrellas, than if you saw ONLY raindrops splashing OR people sheltering (but no raindrops).

To override the propagation algorithm and specify that any sub-hypothesis is sufficient for confidence in the parent, and that the confidence across the group does not combine when providing confidence to the parent, double-click the parent node to bring up the Hypothesis Properties dialog. Click the ‘Sub-Hypotheses’ tab and choose the appropriate radio button (Figure 11) - the propagation method can be overridden for the confidence for and/or the confidence against.

If the propagation algorithm has been overridden in this fashion, the sufficiency value in the node image is replaced by “ANY” in the Tree View display, as shown in Figure 17.

![Figure 17: If any sub-hypothesis is sufficient on its own, the sufficiency values of the siblings are replaced by "ANY" in the Tree View display.](image)

### 4.6 Recording Tree Parameterisation Choices

TESLA aims to provide the capabilities necessary to record a complete audit trail for the decision. This includes not only the sources of the evidence values that are entered, but also the rationale behind the tree structure. The box labelled ‘Rationale’ on the ‘Notes’ tab of the Hypothesis Properties dialog is provided for this purpose (Figure 18).

![Figure 18: Entering a rationale for the tree parameterisation.](image)
5 Entering Confidence Values

Once the tree structure is complete, it is time to start collecting together sources of evidence and entering confidence values at the leaf nodes.

5.1 About Confidence Values

Confidence values can only be entered directly at a leaf node (a node with no children). Confidence values for all other nodes in the tree will be automatically calculated using the ESL propagation algorithm, described in Appendix A.

Two confidence values must be entered for each hypothesis; confidence that the hypothesis is true given the available supporting evidence ("confidence for") and confidence that the hypothesis is false given the available refuting evidence ("confidence against"). These are quantified by selecting a number between 0 (no confidence; the evidence says nothing about the truth or falsehood of the hypothesis) and 1 (total confidence that the evidence supports or refutes the hypothesis).

From these two confidence values an additional quantity can be calculated which will be referred to as the uncommitted belief which can vary from -1 to 1.

\[(\text{Confidence For}) + (\text{Uncommitted Belief}) + (\text{Confidence Against}) = 1\]

The uncommitted belief reflects the degree of uncertainty due to a lack of evidence or confidence in the evidence when positive and the degree of conflict due to overconfidence or inconsistent evidence when negative. In order to help draw clearer conclusions evidence of sufficient quality and confidence should be gathered to reduce the uncommitted belief as close as possible towards zero.

5.2 Assessing and Improving Confidence

In an ideal world the evidence in support of or against each hypothesis would be such that it was conclusive, making it easier for decision makers to justify their decisions. This is indicated in TESLA by strong confidence for or against the hypothesis being true. See Figure 20, cases a) and b).

However, the reality is often much less clear cut than that. In the extreme case, there may simply be no evidence on which to make any judgement, so that the confidence for and against are both zero. In this case the uncommitted belief is unity. See Figure 20, case c).

The amount of whitespace (positive uncommitted belief), is a measure of uncertainty related to a lack of evidence or a lack of confidence in the available evidence. This could result from basic lack of information or from inaccuracies in experimental data etc. Confidence can generally be improved by obtaining more evidence or improving the quality of evidence. Reducing the white space on a leaf hypothesis will generally improve the levels of confidence up the tree towards the root hypothesis.

After obtaining evidence and improving confidence it may still be the case that the evidence is inconclusive. See Figure 19, case d). When, as in this example, there is no white space at all (zero uncommitted belief), the flag can be thought of as indicating the odds that the hypothesis is true or false given the available evidence. In some cases it may be possible to undertake new investigations or obtain new evidence that will shift the balance of confidence towards an assessment that the hypothesis is true or false. Undertaking such actions to obtain further evidence can aid decision making.
Sometimes there may be a conflict in the confidence levels, identified by a negative uncommitted belief (over-committed belief) or a yellow overlap region in the flag. See Figure 19, case e). This may arise due to poor or inaccurate evidence or overconfidence in some or all of the evidence. In this case action should be taken to identify and address the conflict†.

<table>
<thead>
<tr>
<th>a)</th>
<th>Complete confidence that the hypothesis is true</th>
</tr>
</thead>
<tbody>
<tr>
<td>b)</td>
<td>Complete confidence that the hypothesis is false</td>
</tr>
<tr>
<td>c)</td>
<td>No confidence, implying that there is no evidence on which to make any judgement for or against the hypothesis. The uncommitted belief is unity.</td>
</tr>
<tr>
<td>d)</td>
<td>There is not a lack of evidence. (The uncommitted belief is zero.) However, the evidence that is available is not conclusive. In this case, based on the available evidence it can be stated that there is a 50% chance that the hypothesis is true or false.</td>
</tr>
<tr>
<td>e)</td>
<td>The evidence is conflicting. (The uncommitted belief is negative.) Efforts could be undertaken to identify and eliminate the cause of the conflict. The conflict could arise from over-confidence in the available evidence, or from poor quality or incorrect evidence, for example.</td>
</tr>
</tbody>
</table>

Figure 19: Examples of flags indicating different confidence levels

5.3 Inputting Confidence Values

To input confidence for and against values, double-click a leaf hypothesis to bring up the Hypothesis Properties dialog then select the ‘Evidence’ tab. Use the sliders to enter values between 0 and 1, as shown in Figure 20. As you move the sliders the green and red bars in the graphic will increase or decrease in size accordingly; the green portion represents the confidence for and the red portion the confidence against. The white section is the uncommitted belief. Should the confidence values overlap (i.e. sum to more than 1), the overlap will be coloured yellow indicating conflict.

In our example, for the hypothesis “The clouds are rainbearing” we have assigned a confidence for of 0.7, because about 70% of the clouds look like they contain rain; and we have assigned a confidence against of 0.1, because about 10% of the clouds look like they do not. The remaining 0.2 is then the uncertainty arising from a lack of evidence or lack of confidence in the evidence, which could occur not only because we are not experts at identifying cloud types but also, for example, because some of the sky is obscured by buildings and trees around us.

† As discussed in Appendix A, ESL is founded on Probability Interval Theory and in this regard the uncommitted belief is equivalent to the uncertainty in the probability that the hypothesis is true or false. Therefore a negative value for the uncommitted belief is not consistent with a valid probability range.
Figure 20: Entering confidence values at a leaf node.

In the Tree View display, the confidence values assigned to a hypothesis are displayed graphically in the node image, again using a horizontal green bar to show the proportion of confidence for, and a horizontal red bar to show the proportion of confidence against (Figure 21). The section between is coloured white to indicate the uncommitted belief, or coloured yellow when there is overlap in the case of conflict. Due to its appearance, this image is sometimes referred to as an 'Italian flag'.
5.3.1 Linguistic Mappings

Defining Mappings

Sometimes, particularly when working with a group of experts in a workshop setting, it is preferable to use linguistic terms rather than numbers to indicate the confidence in the evidence that supports or refutes a hypothesis. TESLA provides a mechanism for inputting confidence values linguistically.

First of all, you should decide on a set of terms to represent the degrees of confidence in the evidence supporting or refuting a hypothesis. The default set of terms in TESLA are “Very good”, “Good”, “Average”, “Poor”, “Very poor” and “None”. You should then assign numerical confidence values to each of these, ranging from 0 to 1. The default mappings used in TESLA are shown in Table 1. The set of experts from whom you are eliciting confidence values should then be encouraged to use the linguistic terms, rather than numerical values, when describing their level of confidence in the evidence.
Table 1: The default linguistic mappings employed by TESLA.

<table>
<thead>
<tr>
<th>Linguistic Term</th>
<th>Mapped Confidence Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>0.9</td>
</tr>
<tr>
<td>Good</td>
<td>0.7</td>
</tr>
<tr>
<td>Average</td>
<td>0.5</td>
</tr>
<tr>
<td>Poor</td>
<td>0.3</td>
</tr>
<tr>
<td>Very poor</td>
<td>0.1</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

To set up linguistic mappings in TESLA, double-click a leaf node to bring up the Hypothesis Properties dialog. Click the ‘Linguistic Mappings’ tab and select the ‘Linguistic Mappings’ radio button on the left (Figure 22).

![Figure 22: Specifying linguistic mappings to use for inputting confidence values.](image)

The default mappings are shown on the right. These can be edited by selecting a term from the list then using the controls on the right to change the linguistic term and the mapping value. Press ‘Update’ when finished to commit any changes.

If desired different linguistic mappings can be applied to confidence for or confidence against, using the check boxes above the slider control. Also each leaf node can in principle be assigned its own set of linguistic mappings; however it is more likely that the same set will be used across all leaf nodes. If that is the case, check the box ‘Use this method for all hypotheses in the tree’ on the left to apply the linguistic mappings entered here to all other leaf hypotheses.

It is important to note that if the input mode is changed to linguistic after confidence values have been entered using the standard method with sliders (or a linguistic scheme is edited after confidence values have been entered), the existing confidence values will be altered by TESLA so that they are consistent with the new scheme. So, for example, if a value of 0.95 had been entered and the default linguistic mapping scheme was then adopted, this value would be changed to 0.9 (corresponding to “Very Good”) since it is the nearest compliant value to the original. Changing back to numerical confidence value input will not retrieve the original value of 0.95 so care must be taken when using this option.

Entering Confidence Values

Once the linguistic mappings have been set, click the ‘Evidence’ tab to start inputting confidence values. You will notice that the confidence sliders have been replaced by drop-down lists containing the linguistic terms defined on the ‘Linguistic Mappings’ tab (Figure 23). To input confidence values simply select the relevant term from the drop-down boxes.
5.3.2 Advanced Controls

When assessing the level of confidence that can be had in the truth or falsehood of a hypothesis given the available evidence for or against, there are sometimes several factors that may influence the judgement, such as:

- the quality of the evidence,
- the quantity of evidence or evidence coverage; and
- the face value of the evidence, i.e. of the evidence that is available, whether it supports or refutes the hypothesis.

For example, a single piece of supporting experimental evidence may, if taken at face value, indicate that a hypothesis is true. However, there may be doubts over technique or its accuracy, lowering confidence that the hypothesis is true. On the other hand, several independent research groups may have independently verified the experiment - and this may act to increase confidence in the hypothesis being true. In such situations it can sometimes be difficult to decide on an appropriate confidence value. The advanced controls on the ‘Evidence’ tab of the Hypothesis Properties dialog can help to break down the assessment of confidence into component parts (quality, coverage and face value), thus making the judgments about the roles of the component parts more transparent.

The advanced controls are disabled by default. To enable them select the ‘Enable’ radio button, as shown in Figure 24. To use the advanced controls the user will typically independently evaluate the quality, coverage and face value of the evidence in terms of provision of confidence in the parent. Sliders are available to input the relevant values for each. The final confidence values, indicated in the flag, are calculated as

\[
(\text{confidence for/against}) = (\text{face value of evidence for/against}) \times (\text{quality for/against}) \times (\text{evidence coverage})
\]

Note that as uncertainty in evidence coverage and quality are covered by specific parameters, the face values can be thought of as providing a best estimate for the odds that the hypothesis is true or false given the available evidence, and the ‘face value of evidence against’ will generally be related to the evidence ‘for’ as follows:
This is because the primary sources of uncertainty are covered in the other sliders, and all that typically remains is to identify whether the evidence sources support the hypothesis or not.

Figure 24: The advanced slider controls can be used to assess the impact of evidence quality and coverage on the judgement of confidence values.

5.4 Recording Reasons for Selecting Confidence Values

To provide a full audit trail of the decision, reasons for selecting particular confidence values should be recorded within TESLA. To input this information, click the ‘Show Audit Trail’ button on the ‘Evidence’ tab of the Hypothesis Properties dialog. The audit trail pane will appear on the left (Figure 25).

Figure 25: Clicking *Show Audit Trail* on the *Evidence* tab will open the confidence details pane on the left of the dialog. Here reasons for selecting confidence values can be entered.
There are two sections of the ‘Reasons’ tab in the evidence details pane; one for entering reasons for choosing the confidence for value, and one for entering reasons for choosing the confidence against value. Both work in the same way. To add a new reason, click ‘Add...’ underneath the relevant section. In the dialog that appears enter a short title for the reason and, if required, a longer description, as shown in Figure 26. You should also enter a name against the reason (this may be the name of the person editing the tree or, in a group workshop situation, the name of the expert who specifies the reason).

When the reason is committed by pressing OK, its title will be shown in the relevant section of the audit trail pane. To view reason descriptions directly from the audit trail pane, simply hover the mouse over the reason title and the description will appear in a tooltip. To edit an existing reason, select it and click ‘Edit’.

Note that the reason title text box uses text completion to allow users to quickly input reasons (which may be applicable to multiple nodes in the tree). Use the mouse, arrow keys or tab key to select the relevant reason from the list of possibilities - or keep typing to enter a new reason. If an existing reason is chosen, the description box will be filled in automatically.

![Figure 26: Adding a reason for selecting confidence values.](image)

5.4.1 Reference Files

Often there will be files that back up confidence values, for example a spreadsheet which contains the output from a numerical simulation, a report describing experimental data etc. TESLA allows the decision maker to link such files directly to the tree.

To add a reference file to a node, double-click the node to bring up the Hypothesis Properties dialog and select the ‘Reference Files’ tab. A list of all reference files currently linked to the node will be displayed (Figure 27); click ‘Import’ to add another. Select an existing report from the tree library or add a new one from the library on the local computer (see Section 8 for details).
Figure 27: Adding reference files to a node.

Once a reference file has been linked to a node, it can be viewed by selecting it from the list of reference files and clicking ‘Open’. This will launch the default application for the file type (e.g. MS Word for .doc files, Adobe Reader for .pdf files etc.) with the selected file opened for inspection.

Nodes that have linked reference files are indicated in the Tree View display by a paperclip icon next to the node image, as shown in Figure 28.

Figure 28: A paperclip icon indicates that a node has linked reference files.

5.4.2 Links

Supporting documentation for confidence values may often originate from a website. The ‘Links’ tab on the Hypothesis Properties dialog (Figure 29) allows the user to link website URLs to a node; simply enter the website address in the ‘Link’ box and press ‘Add’. Once a website has been added in this manner, it can be double-clicked to launch the default web browser and load the website.

The Links tab could also be used to link to a file, if that file is not required to be embedded in the tree itself - for example, some organisations have central filesystems where documents relevant to all employees are stored. A link to a file can be added by prepending the file name by file://, e.g.: 

file:///C:\Users\Default\Documents\myDocument.pdf

This should only be used in preference to the ‘Reference Files’ tab for adding links to files if the file that is being linked to is available to everyone that might want to work on or view the decision tree, using the same path.
5.5 Recording Outstanding Actions

Once confidence values have been entered against hypothesis, it can also be useful for decision makers to consider classes of actions that could be taken to strengthen what can be said about the truth or falsehood of the hypothesis. Here are two examples of ways in which a hypothesis can be strengthened to make it more conclusive:

- **Reduce Uncommitted Belief**: Improvements can be made by reducing the uncommitted belief towards zero. This can be achieved by obtaining further evidence so to address uncertainty due to lack of evidence or by addressing conflict of evidence. For example, to improve confidence in our judgement for the “The clouds are rainbearing” we could get a book from the library about cloud forms, or gather a group of independent meteorological experts to provide their judgements too.

- **Improve the Balance of Confidence**: Conclusiveness can be improved by obtaining further evidence or undertaking new studies that are designed to shift the balance of confidence towards full support for the hypothesis being true or false. For example, if the hypothesis related to the performance characteristics of an underground gas storage system, then we may be able to improve conclusiveness of the hypothesis by adopting different engineering practices that are known to provide a better final injection well seal.

Note that some evidence gathering actions will affect or improve both to some degree. TESLA provides a mechanism whereby users inputting confidence values can list actions that could be undertaken to strengthen the conclusiveness of the hypothesis.

To enter such actions double-click the relevant leaf node and select the ‘Evidence’ tab from the Hypothesis Properties dialog. Click ‘Show Audit Trail’ to show the audit trail pane on the left (if not already visible). Within the pane itself, click the ‘Actions’ tab. This tab is split into two sections; one for entering actions to improve confidence and one for entering actions to improve conclusiveness (see Figure 30). These sections behave similarly to the sections on the ‘Reasons’ tab (see Section 5.4 for details) and actions are entered in the same manner.
Figure 30: Clicking 'Show Audit Trail' on the 'Evidence' tab will open the audit trail pane on the left of the dialog. Here actions for improving confidence and conclusiveness can be entered.
Analysing the Decision

Once a tree has been parameterised and populated with confidence values it can be used to inform decisions and to identify areas where efforts could be focussed in order to improve the conclusiveness of the root hypothesis. TESLA includes a number of graphical tools that can be used for such purposes:

- **Uniform Confidence** (Section 6.1) plots can be used to check that the parameterisation of the tree is plausible and that it does not preclude a positive or negative outcome.

- Decision makers often are concerned by the question “How confident can we be that the root hypothesis is true or false given the available evidence?” If the confidence values propagated to the root node, as shown in the Tree Plot, are sufficiently conclusive then it may be that no further action needs to be taken. (See Section 6.2.) However, the user may want to analyse the sensitivity of the outcome to changes in confidence in the leaf nodes. (Section 6.4)

- If the root hypothesis is not conclusive then the decision maker will typically wish to identify why not. There may be areas were evidence is lacking or where it is in conflict leading to ambiguity. The Ratio Plot (Section 6.3) helps decision makers to identify hypotheses on which to focus effort in order to improve the conclusiveness of the root hypothesis.

- **Tornado Plots** (Section 6.4) help answer the question “Which hypotheses have the greatest impact on confidence in the root hypothesis?” This can also help the decision maker to decide which hypotheses to focus effort on in order to most effectively improve the conclusiveness of the root hypothesis.

### 6.1 Uniform Confidence Plots

It is important to test the tree structure during the decision making process to ensure that the values chosen for sufficiency, dependency etc. lead to expected results. For this purpose, a tool to produce Uniform Confidence plots is provided. This tool allows the user to temporarily assign the same confidence value to all leaf nodes in the tree, thus determining if confidence is propagated through the tree as intended. The most useful confidence values to apply to the leaf nodes are confidences for and against of 1, though any values can be chosen.

To produce a Uniform Confidence plot, select the menu item from the ‘Plots’ menu in the main TESLA window. A dialog will appear (Figure 31), into which the confidence value to be assigned to leaf nodes can be selected using the two sliders.
Figure 31: The Uniform Confidence plot dialog. On the left, the root node for the plot should be selected. On the right, the level at which to apply the uniform confidence should be selected. The confidence to apply is specified using the sliders at the bottom of the dialog.

At the top are two panels, each showing a summary of the decision tree. In the left panel the root node for the plot should be selected - this does not have to be the root node of the whole decision tree. On the right, the level at which the uniform confidence should be applied should be selected - again, this does not have to correspond to leaf nodes in the decision tree, uniform confidence can be applied at any level. All nodes at which the confidence will be applied are highlighted in light blue. These are nodes at the same level as the selection, or any leaf nodes higher than the selection (but in the same branch, i.e. underneath the selected root node). Press 'OK' to display the plot.

The Uniform Confidence plot is similar to the Tree View display, but only the nodes between the selected root node and the selected leaf nodes are displayed. An example plot is shown in Figure 32; here the uniform confidence was applied at the first level in the tree. This plot shows that our choices of tree parameters will allow a conclusive answer to be calculated for the root hypothesis "It will rain today"; this may not always be the case, depending on the values chosen for sufficiency etc. Usually the parameterisation of trees that do not produce a conclusive result should be reconsidered.
By selecting alternative root nodes it is possible to concentrate on branches of a tree rather than the whole decision; for example, a Uniform Confidence plot for the “Weather forecast” branch of our tree is shown in Figure 33. Here the parameterisation of the tree (specifically the dependency coupled with the sufficiency values) means that the confidence in support of the hypothesis “The weather forecast predicts rain” could never actually reach a value of 1. This may indicate that the tree parameters need to be altered.

![Figure 32: A Uniform Confidence plot for the first level in the tree.](image)

![Figure 33: A Uniform Confidence plot for the “Weather forecast” branch.](image)

6.2 Tree Plot

The Tree Plot is the standard TESLA view of the hierarchy of hypotheses. Using flags, it shows how confidence in the leaf hypotheses propagates to the root hypothesis, as well as indicating how the tree has been parameterised. By looking at the root hypothesis the decision maker can judge whether, given the confidence values assigned to the leaf hypotheses and the tree parameterisation, the root hypothesis is sufficiently conclusive. See Section 5.2.

6.3 Ratio Plots

A Ratio Plot is used to analyse a decision once confidence values have been input. It summarises graphically the confidence values for all selected hypotheses. It is structured to enable identification of hypotheses for which the balance of confidence is weak (neither strongly supporting or refuting the hypothesis), and those for which there is a lack of, or conflict in
confidence (large uncommitted or over-committed belief). To produce a Ratio plot, simply select the menu item from the ‘Plots’ menu in the main TESLA window.

The horizontal axis of the Ratio plot indicates the percentage uncommitted belief, with an increasing negative value representing increasing conflict.

The vertical axis indicates the ratio of confidence for to confidence against. To avoid division by zero in this calculation, all confidence values are moved into the range [0.01, 1] (confidence values lying below this range are set to the bottom boundary value). This results in a possible ratio between 0.01 and 100. The calculated values are then plotted using a logarithmic scale.

The background of the plot is shaded to indicate areas where confidence values are greater than or less than 0.5. Along with the two axes, this splits the plot up into eight distinct regions, summarised in Figure 34. The user may also define their own ratio plot regions, as described below in Section 6.3.1. Points that lie in the dark green or dark red areas indicate more conclusive levels of confidence, i.e. the confidence for (or against, in the red region) is greater than 0.5 and the confidence against (or for, in the red region) is less than 0.5. The nearer to the top or bottom of the vertical axis the point lies, the confidence there is that the hypothesis is true or false.

A Ratio plot for the example we have been following is shown in Figure 35. Most of the hypotheses, including the root hypothesis (labelled 1 in the Ratio plot) lie in either the dark green or dark red areas, indicating that there is strong confidence that they are either true or false. The point labelled 6 on the plot (corresponding to “People outside have umbrellas up” lies in the lighter red region, indicating that there is a lack of confidence about the truth or falsehood of this hypothesis. This may lead us to do some more research in that area (spending longer looking out of the window for example, to see more people go by).
Figure 35: Ratio plot for the umbrella example. Each numbered circle represents a hypothesis, as indicated in the legend. The root hypothesis (1) lies within the dark green area indicating that there is strong confidence that the hypothesis is true.

6.3.1 User-Defined Ratio Plot Regions

As depicted in Figure 34 and described above, the coloured regions of the Ratio plot indicate areas where there is stronger and weaker confidence that hypotheses are true and false. By default, the ratio plot is split into 4 distinct regions based on the values of confidence for and against. The user can specify their own regions on the Ratio plot by selecting ‘Options...’ from the ‘Tree’ menu in the main TESLA window, and clicking the ‘Ratio Plots’ tab (Figure 36).

Select the ‘User Defined’ radio button to activate the user-defined regions. TESLA provides some suggestions but these can be altered as desired; a maximum of 5 regions can be specified. Enter the region names and confidence ranges as required, and press ‘OK’ to commit the changes.

The Ratio plot for our example with user-defined regions is shown in Figure 37. With this greater refinement of regions on the plot, the root hypothesis lies in the “Significant Doubt” band indicating that whilst the balance of confidence is in favour of the hypothesis being true, there is a sufficient lack of confidence and sufficient confidence that the hypothesis is false to cast doubt on the outcome.
Figure 36: User-defined regions for the Ratio plot can be specified in the Options dialog (located under the Tree menu).

Figure 37: A Ratio plot with user-defined regions.
6.4 Tornado Plots

Like Ratio plots, Tornado plots are designed to analyse trees that have been populated with confidence values. The aim of the Tornado plot is to calculate the impact that the confidence values of each leaf hypothesis have upon the overall decision; that is, how sensitive the root hypothesis confidence values are to small changes in the confidence values of the leaf hypotheses. This can aid the decision maker by identifying areas where extra research to improve confidence is valuable, and areas where it would have little or no effect.

This is essentially a differential calculation, and is implemented in TESLA by temporarily incrementing by a marginal amount the confidence values of each leaf hypothesis in turn, noting the change in confidence values of the root hypothesis. The sensitivity of the confidence values at the root node will depend upon the confidence values that have been assigned to the leaf nodes and on the manner in which the tree has been parameterised.

The impact, calculated separately for confidence for and confidence against, is defined to as:

\[
\text{impact} = \frac{\text{change in confidence value of the root hypothesis}}{\text{change in confidence value of the leaf hypothesis}}
\]

The calculated impact for each type of confidence is converted to a percentage, and plotted as a horizontal bar on the Tornado plot. This bar is coloured green to indicate sensitivity to confidence for and coloured red to indicate sensitivity to confidence against.

The nodes are plotted in descending order of total impact, thereby giving the whole plot its tornado-like appearance from which it takes its name. The hypotheses are listed in a legend underneath the plot, in ranked order.

To generate a Tornado plot, simply choose the menu item from the Plots menu in the main TESLA window. A plot generated for our example tree is shown in Figure 38.

Here we see that the top-ranked hypothesis is “The local newspaper forecast predicts rain”. This means that if a small change is made to the confidence for value of this node, there would be a (relatively) large change to the confidence for value of the root node. Thus it might be a good idea to try to reduce the amount of uncertainty here by conducting some more research.
Figure 38: A Tornado plot generated for the umbrella example.

Note that empty tornado plots may be produced if some nodes are necessary and always result in the failure of the root node. This is because TESLA is correctly showing that small perturbations to the leaf nodes have no effect in this case as the confidence from the necessary nodes is propagated favourably instead. If the necessary node does not, by itself, cause the failure of its parent then the tornado plot will not be empty.

A similar effect is also seen if the propagation method has been overridden by specifying that all sub-hypotheses are necessary for a particular parent hypothesis. This is the case for our example tree where the sibling hypotheses “The clouds are rainbearing” and “At least 80% of the sky is covered in cloud” are both marked with “ALL”. As seen in Figure 38, the impact of “The clouds are rainbearing” on the root hypothesis is shown to be zero, since it is always the minimum confidence value from the pair that is propagated (and thus changing the value of one may not affect the value of the parent).

An important point to note is that as Tornado plots consider the sensitivity of the tree to small variations in leaf level confidence values, they do not always capture the overall sensitivity of the tree to larger changes in such values, which might ‘trip’ certain logical criteria and lead to markedly different overall outcomes. Changes in success/failure of ‘necessary’ nodes, and of the ‘weakest’ or ‘strongest links’ from groups of nodes whose confidence propagation is controlled by ALL or ANY logical constructs are examples of this. Thus, the Tornado plot, although a very powerful analysis tool, needs to be carefully used with these factors in mind.
7 Outputs

TESLA provides a variety of methods for outputting information about a decision, all of which are summarised in this section.

7.1 Tree Plots

One of the most important outputs from TESLA is the decision tree itself. Whilst screenshots of the Tree View display can be taken for inclusion in reports etc., the Tree plot produces a copy of the Tree View and can be used to display both the whole tree and branches of a tree.

To draw a Tree plot, select the menu item from the ‘Plots’ menu in the main TESLA window. If a plot of a branch is required, rather than the entire tree, select the desired root node in the Tree View display first. Once a Tree plot has been drawn, it can be printed or saved as an image for inclusion into a report via the options on the File menu. Figure 39 shows a Tree plot of a branch of the example tree.

![Tree plot](image)

Figure 39: A Tree plot of a portion of the example decision.

7.2 Decision Summary Reports

TESLA can automatically produce summaries containing information about all aspects of the decision. These summaries can be produced as Word or PDF documents, and can either be in Report format (portrait, comprehensive information, can be used as a standalone document or as part of a larger report) or Presentation format (landscape, larger fonts and contain just the most important points about the decision).

To produce a summary report, choose ‘Create Report...’ from the ‘Reports’ menu in the main TESLA window. A dialog similar to the one shown in Figure 40 will be displayed. From here the report type and format can be selected. As well as Word and PDF formats, reports can be displayed on-screen in the Report Viewer tool - reports viewed in this fashion can also be exported directly from the Report Viewer tool to Word or PDF format.

Some elements of the report are optional, for example tables of reasons for selecting confidence values, lists of linked reference files and the various plots. Use the check boxes to select which elements to include in the report (note that some elements are not available in Presentation reports).
Figure 40: The Report Choices dialog (select ‘Create Report’ from the ‘Reports’ menu). From here the report type, format, elements and level of detail can be specified.

In addition, the level of detail to include in the report can be chosen from the Report Choices dialog using the radio buttons at the bottom. The choices are as follows:

1. Whole Tree. Information about the entire tree is included in the report, from root to leaf nodes.

2. Root Hypothesis + Children. Only information about the root hypothesis and its immediate children are included.

3. Truncated Tree at... Use the drop-down box to select the level at which to truncate the tree. Level 0 represents the root node; Level 1 is the children of the root; Level 2 is their children etc. Thus selecting Level 1 here would be equivalent to selecting “Root Hypothesis + Children”.

4. From Hypothesis... This option allows you to report on a single branch of the tree. Use the first drop-down to select the root node for the tree, and the second to select the level at which to truncate the tree. As described above, Level 0 is the root node; Level 1 is the children of the root; Level 2 is their children, etc.

Once the report options have been chosen, click OK to generate the report. If Word or PDF formats have been chosen you will be asked to provide a filename for the report. The report will then be created, and displayed in the default application for that format (e.g. Word or Adobe Reader). A section of a summary report (in Report format) is shown in Figure 41.
7.3 Leaf Reason and Action Summary File

In addition to the summary reports described in Section 7.2 above, a CSV (comma separated value) file can be produced by TESLA summarising all the reasons entered against leaf nodes for selecting confidence values, and all outstanding actions to reduce the uncommitted belief and to improve the balance of confidence.

To produce a leaf summary file, select ‘Create Leaf Summary CSV File...’ from the ‘Reports’ menu in the main TESLA window. An excerpt of a file is shown in Figure 42. As this is a CSV file there is no formatting, but formatting can be applied manually later using Microsoft Excel (or another spreadsheet tool that reads .csv files).

If a hypothesis has multiple reasons or actions entered against it, it will have multiple lines in the file (e.g. hypothesis 2.2 “The clouds are rainbearing” in the example shown in Figure 42, which has two actions to reduce uncommitted beliefs entered against it).
8 Managing the File Library

As described in Section 5.4.1, TESLA allows the user to link reference files to particular nodes. The Library is used to manage these files, and is described in detail in this section.

8.1 The Tree Library

The Tree Library contains all of the reference files that have been linked to the current tree (this includes files that may have been linked to previous versions of the tree but may no longer be required). Whenever a new file is attached to a node, it will be added to the Tree Library.

To view or edit the Tree Library, select ‘Manage Reference Files...’ from the Tree menu in the main TESLA window. The Reference Document Manager dialog will appear, as shown in Figure 43. All of the files currently used in the tree are listed here. The ‘Description’ field can be edited to provide information about what the file contains. The ‘Status’ field indicates whether the file is embedded in the tree file (“Embedded”), not embedded but available locally (“In Library”), or could not be found (“Missing from Library”).

![Reference Document Manager dialog](image)

Figure 43: The Reference Document Manager dialog. This lists all the documents that have been referenced in the current tree.

Reference files can either be linked or embedded. An embedded file is literally embedded in the tree, and is saved (in binary format) within the decision file itself. Although this can lead to bulky files, it allows the user to easily share their trees and reference files with others without having to worry about manually collecting together all the reference files.

A linked file is simply stored locally on the user’s computer as a separate file and is accessed when required. When the tree is saved, options will be provided to either embed linked files or leave them as separate entities (see Section 8.3 for details).

To embed a single file, right-click on it in the Reference Document Manager dialog and select ‘Embed...’ from the pop-up menu. To embed all files in the library, click the ‘Embed All’ button. Similarly embedded files can be detached by right-clicking and selecting ‘Detach...’ or clicking the ‘Detach All’ button. To view a file, right-click on it and select ‘Launch...’. It will be launched in read-only mode using the default application.

8.2 The Local Library

The Local Library is a repository on your computer for all the files that have been linked to TESLA decision trees. It enables you to quickly and easily locate reference files that are used regularly in your decisions, and as it is a central repository containing copies of the files it guards against accidental deletion or the moving of important files.
Any reference file added to the Tree Library must also be added to the Local Library. To manage the Local Library, select 'Manage Local Library' from the 'File' menu in the main TESLA window to bring up the Library Manager (Figure 44).

![Library Manager](image)

**Figure 44:** The Local Library Manager dialog. This displays the contents of your TESLA file repository, covering all decision trees that have been created.

The Library Manager shows the file details, including a description which can be edited by clicking twice in the cell. The “Status” column indicates whether the file is “Available” or “Missing” - missing files may have been deleted accidentally from the central repository outside TESLA. It is not recommended that the library should be edited in any manner other than via the Library Manager within TESLA. The “TESLA Files” column lists the filenames of decision trees on the local computer to which the file is known to have been linked.

To add a new file to your library, click the “Import” button and browse for the file. To delete a file, select it from the list and click “Delete”.

### 8.3 Saving Trees with Linked Files

There are 3 options available when saving a decision tree file containing linked reference files:

1. **Embed.** The files can be embedded as binary objects in the tree file itself. This means that the files and the tree are intrinsically linked and eliminates problems of missing reference files. It allows users to share trees easily. However it can lead to bulky decision tree files. Choose this option if you want to share your tree and only have a few linked reference files.

2. **Archive.** The files can be collected together into a TESLA document archive (.tda file), which can be distributed independently from the tree but ensures that the reference documents are held together in a single location and clearly marked as being part of a TESLA tree. The TESLA document archive file is saved in the same folder as the TESLA tree file (.tes). When loading a TESLA tree file, if a corresponding document archive is present in the same folder, TESLA will read the documents from the archive file and add them to the local library if necessary. Choose this option if you want to share your tree and have a large number of linked reference files.

3. **Omit.** The files can be omitted from the tree file but retained locally. This means that other users you share your tree with will not be able to view the linked files, but the decision tree file will be small. Choose this option if you do not need to share your tree or if the linked files are not important when sharing.
Figure 45: This dialog appears when a decision tree containing linked files is saved. It allows the user to embed, archive or omit the linked files.
9 Working with Sub-Trees

Decision trees created with TESLA can often be complex, with many nodes and levels. Often it helps to work on individual parts of the tree and focus on the issues involved there rather than in the context of the whole decision. TESLA allows the user to identify a branch of the tree to work on, break it off from the main tree, alter parameters and values without affecting the main tree, and then subsume the changes back into the main tree (or cancel).

![Working on a Sub-Tree](image)

To start working on a sub-tree, in the Tree View display select the node that will be the root of the branch to be worked on. Right-click and select ‘Work on Sub-Tree’ from the pop-up menu. A new tab will be opened containing the selected branch as a separate tree. See Figure 46 for an example, which shows a Sub-Tree for the hypothesis “The weather forecast predicts rain” of the Umbrella decision. Make all the changes necessary here - the main tree will be unaffected - and when ready, click the ‘Apply’ button at the bottom of the window to subsume the changes back into the main tree. Click ‘Cancel’ to return to the main tree without accepting the changes.

Sub-Trees are useful both when parameterising the tree (to study the behaviour of the branch in detail) and when entering confidence values (particularly in a group workshop; by breaking off a Sub-Tree, it helps to focus the group on the particular branch in question).
10 Version Control

TESLA includes built-in version control that records the history of changes made to a decision tree.

10.1 Tree Versions

A new tree version is created whenever a tree is closed and re-opened (saving does not create a new version), or when a tree is reviewed or approved (see Sections 10.3 and 10.4). Versions are stored in the Change Log and can be viewed at any time. The current version number of a tree is shown on the Decision Details dialog and in brackets after the tree title on the tab label of the Tree View display.

10.2 Change Log

All versions and a list of the changes they include are recorded in the Change Log, which can be accessed either from the Decision Details dialog or the ‘Tree’ menu. The Change Log dialog is shown in Figure 47.

![Figure 47: The Change Log dialog.](image)

The Change Log shows each version number, the date it was modified and the user who modified it (as entered in the Decision Details dialog when a tree is opened). By clicking the plus sign next to an individual version, it can be expanded to show full details of the changes included in that version.

10.2.1 Viewing an Old Version

Every version of a tree is stored and can be viewed at any point by selecting it from the Change Log and clicking ‘View’. The old version will be opened in a new tab in the main TESLA window, and all the information in it can be viewed but not edited.

10.2.2 Rolling Back

It is possible to “roll back” to an old version of a tree, losing all changes that were made to the tree after that version. To roll back, simply select the tree version in the Change Log and click ‘Roll back’. The tree will be replaced in the main TESLA window by the selected version.

It is not possible to roll back past a reviewed or approved version of a tree (see below).
10.2.3 Exporting an Old Version

Rather than rolling back to an old version, you may wish to edit an old tree without losing the changes made to the current version. In this case, the old tree should be exported, i.e. saved as a separate tree file, which can then be edited whilst retaining the original tree.

To export an old version, select the version in the Change Log and click ‘Export…’. This will open the old version of the tree in a new tab, from where it can then be edited and saved under a different filename.

10.2.4 Labelling Versions

In order to allow the user to quickly identify versions in the Change Log, it is possible to label specific versions. To label a version, select it in the Change Log window and click ‘Label…’. Enter a label for the version in the box that appears (Figure 48), or select an existing one from the drop-down list, and press ‘OK’ to apply the label.

![Figure 48: Labelling a version in the Change Log.](image)

Version labels are shown in brackets in the Change Log after the version number, as shown in Figure 49. Versions that have no label applied are marked as “Unlabelled”. The check box ‘Only Show Labelled Versions’ can be used to restrict the view in the Change Log window to just those versions which have a label applied.

![Figure 49: A Change Log dialog showing labelled versions.](image)

10.3 Reviewing a Tree

Once a tree has been completed it might be peer reviewed. TESLA allows trees to be marked as “Reviewed”, recording the date of the review and the name of the reviewer. To mark a tree as having been reviewed, select ‘Actions’ and then ‘Review’ from the ‘Tree Specific Actions’ in the ‘Tree’ menu. Enter the name of the reviewer in the dialog that appears and press ‘OK’. You will then be asked to provide a label for the reviewed version; the default is “Reviewed” but you may choose any label you wish.

Reviewing a tree will cause the tree version number to be incremented. The reviewed version will be visible in the Change Log both by its label and “REVIEWED” following the name of the last editor of the tree (Figure 50).
Once a tree has been reviewed, it is not possible to roll back to versions prior to the reviewed version. However it is possible to edit the current tree. Trees that have been reviewed and subsequently edited are indicated as such on their Decision Details dialogs.

A tree may be reviewed any number of times, and each review version is clearly marked in the Change Log.

10.4 Approving a Tree

A tree can only be approved once it has been reviewed. To mark a tree as having been approved, select ‘Actions’ and then ‘Approve’ from the ‘Tree Specific Options’ in the Tree menu. Enter the name of the approver in the dialog that appears and press ‘OK’. You will then be asked to provide a label for the approved version; the default is “Approved” but you may choose any label you wish.

Approving a tree will cause the tree version number to be incremented. The approved version will be visible in the Change Log by its label, “APPROVED” following the name of the last editor of the tree, and the entry being in a bold typeface (see Figure 51). The check box ‘Only Show Approved Versions’ can be used to restrict the Change Log view to only approved versions.

Once a tree has been approved, it is not possible to roll back to versions prior to the approved version. However it is possible to continue editing the current tree (the approved version will be retained in the Change Log and can be viewed at any time). Edited trees are marked as unreviewed and unapproved in the Decision Details dialog.

A tree may be approved any number of times, though it may only be re-approved after it has been re-reviewed. The review/approval cycle is summarised in Figure 52.
Figure 52: The review and approval cycle.
11 Designing and Exporting Templates

In some situations it can be useful to use the same hierarchy of hypotheses to assess multiple options or even projects. For example, when choosing a site for a new supermarket, the same factors may be assessed for each candidate site to enable them to be readily compared. TESLA allows users to design and export template trees which can then be used across multiple options or projects, ensuring that the same tree structure is used in each case. In addition, TESLA allows the creators of the template trees to embed guidance that can be accessed by the people populating those trees. This section describes how to create a template tree and how to generate new trees based on an existing template.

Once multiple trees based on the same template have been populated then, provided the structure of these trees has not been changed, they can be compared in TESLA using the portfolio tool. This is described in Section 12.

11.1 Designing a Template

A template tree starts off life as a normal tree. It is only at the final stage of creation when it becomes a template. To create a template, start a new tree or open an existing tree as normal. You should ensure that the tree structure is logically arranged and well explained, and that any linguistic mappings (Section 5.3.1) or user-defined ratio plot regions (Section 6.3.1) have been set up.

11.1.1 Entering Template Guidance

Guidance can be provided by the template designer that will subsequently be made available to users of trees derived from the template when they input confidence values. This guidance can include guideline confidence values (for example, to delimit expected attainable values), sources of evidence, discussions of how to map evidence to numerical values etc.

Template guidance can be added to any tree that has not been based on an existing template. To add template guidance to a hypothesis, double-click the node to bring up the Hypothesis Properties dialog and select the “Template Guidance” tab (note that this tab only appears for leaf hypotheses).

Figure 53: The Work Elements tab.
Use the sliders to input guideline confidence values that you wish users of your template to see. An explanation, or any other notes, can be entered into the “Explanation” box. Again, this will also be visible by users of your template. It is also possible to link supporting documentation to the Template Guidance tab, using the controls on the right - this feature works in a similar manner to the reference files described in Section 5.4.1. Within the ‘Add Document’ dialog, it is also possible to specify a relevant page within the document. If the document is a PDF, then when the template user views the file it will automatically open at the right page. If the document is not a PDF the page number simply acts as a guide to the user who will have to navigate to the correct page manually.

11.1.2 Pre-Defined Version Labels

As a template designer, you may wish to specify a set of version labels that users of your template can apply to their trees at various stages of the tree development process. To do so, open the Change Log (via the Tree menu or Decision Details dialog) and click the ‘Pre-defined Labels...’ button. The dialog that appears (Figure 54) lists all of the labels currently used in the tree; new ones can be added by typing the label text in the box at the bottom and clicking “Add”. Labels created via the Change Log, using the method described in Section 10.2.4, will automatically be added to the list.

Any labels added to the list of pre-defined labels will be available from the drop-down box that appears when a user labels a version in the Change Log (see Section 10.2.4 for details).

![Figure 54: The pre-defined labels dialog.](image)

11.1.3 Exporting the Template

To create a template tree, select ‘Export as Template...’ from the File menu. Your tree will be saved with the .tem file ending, instead of the usual .tes ending. If you wish, you may enter a password to protect the tree structure. If you choose not to specify a password then users of trees derived from the template will be able to change its parameterisation and structure (adding/removing nodes) freely. If a password is applied, then users will only be able to enter confidence values, add to the audit trail and produce plots and reports freely. All other features will be restricted by the password.

The .tem file can then be distributed to users who are working on individual projects. Note that the .tem file cannot be opened directly like a tree. It can only be used to generate new trees that
derived from that template. Therefore, if after creating a template further updates need to be made, these should be made to the original .tes file. A new template can then be exported.

Note that any confidence values and reference documents attached to nodes in the tree will be removed from the exported template file, leaving just the tree structure, parameters and supporting guidance documents. Users of a template are expected to fill in their own confidence values.

11.2 Deriving a Tree from a Template

If you have been provided with a template file (ending in .tem), start a new tree based upon it by launching TESLA and selecting ‘New from Template...’ from the ‘File’ menu. Select the template file (.tem) from the file browser. The derived tree will open in a new tab, and can be worked upon and saved in the usual manner.

If the template designer has locked the tree structure with a password, you will be prompted for this password if you try to make any modifications other than those related to the input of confidence values. If you have been supplied with the password then you only need enter it once per session to unlock the tree structure.

11.2.1 Viewing Template Guidance

The ‘Template Guidance’ tab described in Section 11.1.1 is not available in trees that are derived from a template, but any information entered in this tab by the template designer is visible instead on the ‘Evidence’ tab. Guideline confidence values are shown as washed-out green and red bars in the Italian flag as shown in Figure 55. Click the ‘Show Guidance’ button to slide out the Template Guidance pane on the right of the dialog; here the explanation for the guideline values is shown in the ‘Explanation’ tab; the ‘Supporting Documentation’ tab shows a list of documents added by the template designer. Double-click a document (or select and press ‘View’) to open it in the default application for that document format.

Figure 55: The Template Guidance pane on the ‘Evidence’ tab displays any guideline information entered by the template designer.
12 Comparing a Portfolio of Trees

ESL allows the decision maker to study one hypothesis in detail. There are occasions when it is desirable to compare multiple trees (e.g. if each tree represents a different option), or multiple versions of the same tree (e.g. to view how confidence has varied over time). TESLA provides a portfolio tool for this purpose, which is explained in this section.

12.1 Comparable Trees

TESLA’s portfolio tool allows multiple trees to be compared. Those trees may be in separate files (see Section 12.2) or may be multiple versions of a single file (see Section 12.3). In order to compare the trees TESLA checks that they represent the same hierarchy of hypotheses, as defined by the hypothesis titles. So, starting from the root hypothesis, the hypothesis titles must match, the titles of their children must match and so on. For a given parent, it does not matter if the child hypotheses are ordered differently across the different trees however.

When launching a portfolio TESLA will establish what differences in parameterisation there are between the trees, such as changes in logic, sufficiency, dependency, or simply in hypothesis descriptions and will warn the user about them on launch. See Figure 56 for an example.

![Figure 56: A warning about differences in the parameterisation of trees in a portfolio](image)

12.2 Multiple Files

It is possible to compare multiple trees, stored in multiple .tes files, using the portfolio tool provided:

- that every tree was based on the same template file, or on no template file; and
- that every tree has the same structure as defined in Section 12.1.

To open a portfolio of decision tree files, launch TESLA and select ‘Open Portfolio’ and then ‘From Files...’ from the File menu. You will then be asked to select the files you wish to open. These files must all be located in the same directory on the computer. Multiple files can be selected simultaneously by holding down the Ctrl key whilst clicking.

If there are differences in parameterisation between the trees, a summary of the changes will be provided first. (See Section 12.1.) You will then be presented with a dialog (Figure 57) asking the order in which to display the trees in the portfolio tool. Arrange the trees in the order you require by selecting each decision in turn and using the ‘Move Up’ and ‘Move Down’ buttons to re-order them. When finished, press ‘OK’.
Figure 57: Selecting the order of the trees in the portfolio.

The portfolio tool will then open, as shown in Figure 58. Here we have compared multiple trees, each one representing a judgement on the weather conditions on a different day of the week. We can only say whether it is cloudy or raining for the current day (Monday), thus there is much uncertainty in the lower half of the tree.

Each tree in the portfolio is represented by a small, vertically-orientated “Italian flag” image. The number above the image can be used in conjunction with the legend to determine which tree is which. The order of the trees can be changed at any time via the ‘Options’ item in the ‘Tree’ menu. Double-click any tree in the legend to open it up in a separate tab - however please note that any changes made to a tree will not be reflected in the portfolio tool, unless it is closed and re-opened.
12.3 Multiple Versions

The portfolio tool can also be used to view multiple versions of a single decision tree (see Section 10 for a discussion of version control). To open a set of versions from a single file, launch TESLA and select ‘Open Portfolio’ and then ‘From Single File...’ from the ‘File’ menu. You will then be asked to select the file you wish to open the versions from. TESLA will compare all historic versions of the tree that have a hypothesis structure that is comparable with the most recent version. (See Section 12.1.)

Once the file is selected, a list of versions found within that file will be displayed. Select the versions you wish to include in the portfolio and press ‘OK’. If there are differences in parameterisation between the chosen trees, a summary of the changes will be provided. Finally you will be asked to select the order of the versions in the portfolio, as shown in Figure 57. This can be changed at any point from the ‘Options’ item in the ‘Tree’ menu.

A portfolio of versions behaves in a similar fashion to a portfolio of multiple trees (Section 12.2).
12.4 Plots

12.4.1 Tree Plot
The tree plot for the portfolio behaves as described in Section 7.1 for standard trees.

12.4.2 Single-Hypothesis Ratio Plot
The Single-Hypothesis Ratio plot is similar to the standard Ratio plot (see Section 6.3) but only includes a single hypothesis, and displays that hypothesis for each of the trees/versions in the portfolio on the same plot. For example, Figure 59 shows a Single-Hypothesis Ratio plot for the root hypotheses of the portfolio of trees shown in Figure 58.

To draw a Single-Hypothesis Ratio plot, select the node to plot in the Tree View display and select 'Single-Hypothesis Ratio Plot' from the 'Plots' menu in the main TESLA window.

![Single-Hypothesis Ratio Plot]

Figure 59: A single-node ratio plot, generated by the portfolio tool. This shows a single selected node for each tree/version in the portfolio.

12.4.3 Ratio Plots for All Trees/Versions
Ratio plots can also be produced for all trees/versions in the portfolio, as shown in Figure 60. A single Ratio plot is shown for each tree/version and displayed in a grid; each Ratio plot shares the same legend. This enables the user to easily compare Ratio plots across all trees/versions in the portfolio.

To draw Ratio plots for all trees/versions in the portfolio, select 'Ratio Plots for all Trees' from the 'Plots' menu.
12.4.4 Tornado Plots for All Trees/Versions

Similarly Tornado plots (see Section 6.4) can be produced for each tree/version in the portfolio. The Tornado plots are displayed in a grid (Figure 61) and share a single legend, which is shown at the bottom. Note that in order for the trees to share a single legend, the nodes are not ordered by rank (since this may change between trees/versions) but by position in the tree, using the same numbers as the ratio plots. Numbering starts at 2 rather than 1 since 1 represents the root node, which is only displayed on a Ratio plot.

To draw Tornado plots for all trees/versions in the portfolio, select ‘Tornado Plots for all Trees’ from the ‘Plots’ menu.
Summary Reports can be generated from a portfolio in the same manner as described in Section 7.2 for standard trees. Two options are available; a single report summarising the portfolio as a whole (choose ‘Create Report’ from the ‘Reports’ menu), or multiple reports, one for each tree in the portfolio (choose ‘Create Reports for All Trees in Portfolio’ from the ‘Reports’ menu). This latter option will produce a report that is identical to the standard report for an individual tree.
Appendix A: The ESL Propagation Algorithm

Introduction

ESL is an information propagation calculus (Davis & Hall, 2003) developed from Interval Probability Theory (Cui & Blockley, 1990). It considers an open world view, in which information can be incomplete or even contradictory. Classical probability theory considers two-value logic, whereby the probability of a hypothesis being true or false is known with certainty. Associating a user’s confidence in the hypothesis being true with the probability of it being true gives a closed world perspective, with confidence for and confidence against being complementary concepts (i.e. confidence for + confidence against = 1).

ESL extends this to allow for a user’s uncommitted belief, which can be identified with the uncertainty in the probability that the hypothesis is true or false (i.e. confidence for + uncommitted belief + confidence against = 1). In this case the probability that the hypothesis is true is modelled as being bound by the range

\[(\text{confidence for}) < \text{probability} < 1 - (\text{confidence against})\]

with the confidence for and against being used to define the lower and upper bounds of the probability range.

Confidence for and confidence against are defined independently, each ranging from 0 to 1, with uncommitted belief thus taking a value from -1 to 1. An uncommitted belief of 1 implies that there is no confidence that the hypothesis is true or false - or that the probability of the hypothesis being true is completely uncertain. A negative value indicates confidence for and against totalling more than 1 - which is not compatible with a physical range of probabilities. i.e. there is a conflict in confidence values.

The three values of confidence for, uncommitted belief and confidence against are often represented in the form

\[
[ \text{confidence for}, \text{uncommitted belief}, \text{confidence against} ]
\]

for example \([ 0.34, 0.45, 0.21 ]\).

Derivation of the Propagation Algorithm

The ESL algorithm propagates the probability range for each hypothesis up the hierarchy of hypotheses. Cui and Blockley (1990) showed that the upper and lower bounds of the range of probabilities for each hypothesis can be treated independently as a point probability. Therefore, in the following we consider the propagation of a single probability, while understanding that this is applied to both the lower and upper bound of the probability range for each hypothesis.

Consider a parent hypothesis, \(H\), with two child hypotheses labelled \(C_1\) and \(C_2\). The relationship between the parent and its children is demonstrated with a Venn diagram in Figure 62. Here the space where each hypothesis is true is depicted by a differently coloured circle. The probability that the parent hypothesis is true, \(P(H)\), is calculated from the probabilities of its children being true, and is represented by the degree of overlap with \(H\), outlined in red in the figure.
Using the Venn diagram it is easy to write down an expression for \( P(H) \) in terms of intersections:

\[
P(H) = (P(H) \cap P(C_1)) + (P(H) \cap P(C_2)) - (P(H) \cap (P(C_1) \cap P(C_2)))
\]  

(A1)

Note that, since we are dealing with probabilities, the areas outside a circle are areas where the probability of that hypothesis being true is zero. The overlap that occurs when the probabilities of \( C_1 \) and \( C_2 \) being true are both non-zero is accounted for in the third term of the above equation.

Cui & Blockley (1990) define the degree of dependency between two sets \( A \) and \( B \) as:

\[
\rho = \frac{A \cap B}{\min(A, B)},
\]

(A2)

i.e. the fraction of the smaller of the two sets which overlaps with the other set. There are three special values of the degree of dependency that concern us:

\[
\begin{align*}
\rho &= 0 \quad \text{A and B are mutually exclusive, i.e. } A \cap B = 0. \\
\rho &= 1 \quad \text{A and B are totally dependent, i.e. } A \subseteq B \text{ or } B \subseteq A. \\
\rho &= \max(A, B) \quad \text{A and B are statistically independent, i.e. } P(A \mid B) = P(A) \text{ where } P(A \mid B) \text{ is the probability of } A \text{ given that } B \text{ has already occurred (a conditional probability).}
\end{align*}
\]

If \( \rho = 0 \) (mutual exclusivity), this means that \( P(C_1) \) and \( P(C_2) \) cannot overlap and thus a situation cannot arise where both have non-zero probabilities of being true - a situation we should discount. The minimum value of \( \rho \) that we can accept is \( \max(P(C_1), P(C_2)) \), corresponding to statistical independence; the probability of \( C_2 \) being true has no bearing on the probability of \( C_1 \) being true.

Therefore a new parameter, \( D \), is introduced (e.g. Bowden, 2004) which is simply known as the dependency. This is related to the degree of dependency \( \rho \) by the expression

\[
\rho = D + \rho_{\text{eq}} (1-D),
\]

(A3)
where $\rho_{\text{ND}}$ is the value that $\rho$ takes when the overlapping sets are statistically independent. By restricting $D$ to values between 0 and 1, $\rho$ is restricted to values between $\rho_{\text{ND}}$ (statistical independence) and 1 (total dependence). The value of $D$ is set by the user in TESLA.

Using the expression (A2) for the degree of dependency, (A1) can be written as

$$P(H) = (P(H) \cap P(C_1)) + (P(H) \cap P(C_2)) - \rho \min(P(H) \cap P(C_1), P(H) \cap P(C_2)),$$

where $\rho$ is given by

$$\rho = \frac{(P(H) \cap P(C_1)) \cap (P(H) \cap P(C_2))}{\min( P(H) \cap P(C_1), P(H) \cap P(C_2))}$$

$$= D + (1 - D) \max( P(H) \cap P(C_1), P(H) \cap P(C_2))$$

(A5)

Here we have used equation (A3) and the definition of a conditional probability to obtain the last line:

$$P(A|B) = \frac{P(A) \cap P(B)}{P(B)} \quad \text{(statistical independence)}$$

$$= P(A)$$

(A6)

The intersects $P(H) \cap P(C_1)$ and $P(H) \cap P(C_2)$ are simply equal to some fraction of $P(C_1)$ and $P(C_2)$ respectively (as shown in Figure 62). If these fractions are denoted by $w_1$ and $w_2$ then equation (A4) can be written as:

$$P(H) = w_1 P(C_1) + w_2 P(C_2) - \rho \min(w_1 P(C_1), w_2 P(C_2)).$$

(A7)

In ESL, the fractions or weightings $w_i$ are known as the sufficiency - a fully sufficient hypothesis has a weighting of one. The values of the weightings are set by the user, guided by expert judgement.

The degree of dependency, $\rho$, (as given by equation (A5)) can also be written using the sufficiency:

$$\rho = D + (1 - D) \rho_{\text{ND}}$$

$$= D + (1 - D) \frac{(w_1 P(C_1) \cap w_2 P(C_2))}{\min( w_1 P(C_1), w_2 P(C_2))}$$

$$= D + (1 - D) \frac{w_1 w_2 P(C_1 | C_2) P(C_2)}{\min( w_1 P(C_1), w_2 P(C_2))}$$

$$= D + (1 - D) \frac{w_1 P(C_1) w_2 P(C_2)}{\min( w_1 P(C_1), w_2 P(C_2))}$$

(A8)

In the final step of (A8), we have used the fact that $P(C_1|C_2) = P(C_1)$ if $C_1$ and $C_2$ are statistically independent. Note that, when integrated into equation (A7), the denominator of the term on the

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$^+$ In actual fact, these weightings are conditional probabilities, as can be seen from equation (A6).
right of the sufficiency cancels, avoiding the singularity that might otherwise occur when the minimum of \( P(C_1) \) and \( P(C_2) \) is zero.

The derivation above can readily be extended to \( n \) child hypotheses; in that case equations (A7) and (A8) can be generalised to:

\[
P(H) = \sum_{i=1}^{n} w_i P(C_i) - \sum_{i,j=1}^{n} \rho_{ij} \min \left( w_i P(C_i), w_j P(C_j) \right) \\
+ \sum_{i,j,k=1}^{n} \rho_{ijk} \min \left( w_i P(C_i), w_j P(C_j), w_k P(C_k) \right) \\
+ \ldots + (-1)^{n-1} \rho \min \left( w_1 P(C_1), \ldots, w_n P(C_n) \right),
\]

where, if \( S = \{i, j, \ldots\} \),

\[
\rho_S = D + \frac{(1 - D) \prod_{a \in S} w_a P(E_a)}{\min_{a \in S} \left( w_a P(E_a) \right)},
\]

**The Necessity Heuristic**

The necessity is taken into account via a heuristic that governs the whole propagation process. The idea of this heuristic is to make sure that if any necessary nodes 'fail' then the failure gets reflected upon the parent node. In general, the confidence values (both for and against) are propagated directly from the failing node. However, if the confidence values calculated from the propagation algorithm above result in the parent node failing anyway, then these values are used instead provided that the confidence for is greater than that of all the failing necessary child nodes.

Thus, firstly the confidences for and against are calculated for a node using the propagation algorithm described above. Then the following rules are applied:
If, for any necessary node, the node fails

{ if the parent’s calculated confidence against is even greater than the largest
of these for all necessary child nodes
{ propagate confidences for and against as calculated
}
else
{ propagate the confidence values of the necessary child node with the
largest confidence against (if more than one necessary child nodes
have the same value of confidence against, propagate the values of
the node with the smallest value of confidence for)
}
} else
{ propagate confidences for and against as calculated
}

Advanced Evidence Support Logic (AESL)
The propagation method employed by TESLA is a direct extension of ESL (described in the
preceding section), called Advanced Evidence Support Logic. See Bowden (2004) for full
details.

Evidence Coverage and Quality of Evidence
As well as being able to specify the confidence values directly for an AESL leaf node, the user
may wish to break the confidence values down into component the parts: Face Value of
evidence, Evidence Coverage and Quality of Evidence. These are multiplied to give the overall
confidence. That is,

$$E_i = k_i q_i a_i,$$

where $k_i$, $q_i$ and $a_i$ are the Evidence Coverage, Quality of Evidence and Face Value of evidence
respectively for hypothesis $i$, each taking a value between 0 and 1. The confidence $E_i$ is then
used in all further calculations.

Any Sub-Hypothesis Sufficient
This represents a situation where any and every single child node is sufficient to ensure success
(or failure) of a given node, but with no mutual support from confidence arising from other child
nodes (as distinct from applying sufficiencies of ‘1’ for each sibling). This is modelled by direct
propagation of the maximum confidence values from among the $n$ child nodes, i.e.

$$E_H = \max(E_1, \ldots, E_n)$$

All Sub-Hypotheses Necessary
This represents a situation where all the child nodes are required in unison to ensure success
(or failure) of the parent. This is achieved by propagating the minimum confidence values from
among the $n$ child nodes, with no mutual support from confidence arising from other child nodes, i.e.

$$E_{ii} = \min(E_i, ..., E_n)$$

Therefore, if these alternative propagation procedures are used for both types of confidence then any dependence value(s) for that node will become redundant, along with any sufficiency/necessity values for its child nodes.
### Appendix B: Glossary of Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AESL</td>
<td>Advanced Evidence Support Logic, a method of propagation and an extension of ESL.</td>
</tr>
<tr>
<td>Branch</td>
<td>A section of the tree, running from a given node to all leaf nodes connected below it.</td>
</tr>
<tr>
<td>Confidence For</td>
<td>A measure of the confidence in a hypothesis being true, based on the available evidence. This is measured on a scale from 0 to 1 where 0 represents no confidence in support of the hypothesis being true and 1 represents complete confidence that the hypothesis is true.</td>
</tr>
<tr>
<td>Confidence Against</td>
<td>A measure of the confidence in a hypothesis being false, based on the available evidence. This is measured on a scale from 0 to 1 where 0 represents no confidence in support of the hypothesis being false and 1 represents complete confidence that the hypothesis is false.</td>
</tr>
<tr>
<td>Face Value of Evidence For</td>
<td>This field only becomes available when using the advanced evidence input controls. It can be considered a &quot;best estimate&quot; for whether the hypothesis is true, and should be set such that the face values of evidence for and against sum to unity. The evidence coverage and quality fields can then be used to express the uncommitted belief for the chosen face value.</td>
</tr>
<tr>
<td>Face Value of Evidence Against</td>
<td>This field only becomes available when using the advanced evidence input controls. It can be considered a &quot;best estimate&quot; for whether the hypothesis is false, and should be set such that the face values of evidence for and against sum to unity. The evidence coverage and quality fields can then be used to express the uncommitted belief for the chosen face value.</td>
</tr>
<tr>
<td>Child</td>
<td>A node that has a parent (i.e. any but the root node).</td>
</tr>
<tr>
<td>Conflict</td>
<td>Conflict occurs if confidence for + confidence against &gt; 1 and indicates that there is definitely over-confidence in the available evidence. Action should be taken to determine why there is conflict between the confidence in the evidence for and against. It may indicate that some of the evidence is not as sound as previously thought.</td>
</tr>
<tr>
<td>Dependency</td>
<td>A value between 0 and 1 related to the amount of overlapping evidence between two or more sibling hypotheses.</td>
</tr>
<tr>
<td>Failure</td>
<td>Failure of a node is determined by its confidence values; depending on the failure definition, a failed node has either confidence against &gt; 0.5 or confidence for &lt; 0.5.</td>
</tr>
<tr>
<td>Hypothesis</td>
<td>A statement to be tested; linked to a node in a decision tree.</td>
</tr>
<tr>
<td>Leaf</td>
<td>A node in the tree with no children; leaf hypotheses are the only hypotheses in the tree where evidence can be input by the user.</td>
</tr>
<tr>
<td>Necessity</td>
<td>If a node is a necessity, the success of its parent depends on the success of the node.</td>
</tr>
<tr>
<td>Node</td>
<td>Nodes in the decision tree represent a hypotheses.</td>
</tr>
<tr>
<td>Parent</td>
<td>A node with one or more children (i.e. any but a leaf node).</td>
</tr>
<tr>
<td>Propagation</td>
<td>Movement of information (i.e. confidence in the available evidence) through the tree from the leaves to the root.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>Root</td>
<td>A <strong>node</strong> with no <strong>parent</strong>. After <strong>propagation</strong> the root node provides a gives the confidence and uncertainty in the main <strong>hypothesis</strong> associated with the decision.</td>
</tr>
<tr>
<td>Siblings</td>
<td><strong>Nodes</strong> that share the same <strong>parent</strong>.</td>
</tr>
<tr>
<td>Success</td>
<td>Success of a <strong>node</strong> is determined by its confidence values; depending on the failure definition, a successful node has either <strong>confidence against</strong> $&lt; 0.5$ or <strong>confidence for</strong> $&gt; 0.5$.</td>
</tr>
<tr>
<td>Sufficiency</td>
<td>A value between 0 and 1 indicating the weight that should be given to the <strong>confidence</strong> associated with a <strong>hypothesis</strong> when propagating the values up the <strong>tree</strong>.</td>
</tr>
<tr>
<td>Tree</td>
<td>A collection of <strong>hypothesis nodes</strong> representing a decision.</td>
</tr>
<tr>
<td>Uncommitted belief</td>
<td>Uncommitted belief can be expressed numerically as:</td>
</tr>
<tr>
<td></td>
<td>$1 - \text{confidence for} \cdot \text{confidence against}$</td>
</tr>
<tr>
<td></td>
<td>and takes values in the range 0 to 1. When positive it represents uncertainty arising from lack of evidence or from lack of confidence in the available evidence. If the uncertainty is negative then this corresponds instead to a <strong>conflict</strong> of evidence.</td>
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</table>
References


