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A Proposal for an Effective Fault Tree Diagram Layout

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Fault Trees (FTs) have proven particularly successful in engineering disciplines to identify and quantify risks for assessment. Due to the only short descriptions, FTs are mainly a visual language and transcends national and language boundaries. To further reduce the risk of misunderstandings with FTs, we have tightened the layout guidelines and adjusted the FT elements accordingly. During our research, we kept the three aspects of efficiency, applicability, and functionality in mind, allowing FTs to communicate as correctly, quickly, and easily as possible to make our societies even safer.

Keywords: Fault Tree Diagrams, Digital Fault Tree, Risk Management, Media, Graphic Design, Gestalt Psychology

1. Introduction

In 1961, H.A. Watson and his team at Bell Laboratories in New Jersey, USA, introduced Fault Tree Analysis, a method that visualizes how failures of a physical system propagate, using a diagram called Fault Tree (FT) (Vesely et al., 1981).

As shown in Figure 1, the diagram begins at the top, where multiple failure paths converge, retroactively explaining how one or more causes lead to the eventual failure.

In practice, risk specialists identify faults within systems, map them into FTs to visualize their causal relationships, and present them to engineers, managers, and other stakeholders. Using FTs, they thoroughly assess the reliability of a product or procedure before approving it for production or implementation (Vesely et al., 1981).

Despite their proven usefulness, FTs often cause significant confusion among non-risk professionals due to their visual complexity. Failure to fully understand the risk analysis can then lead to inaccuracies in product reliability decision-making and procedures.

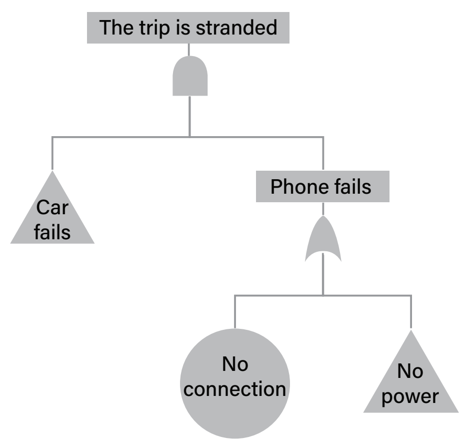

Fig. 1. A fault tree analyzes the root causes of the trip fault, using all symbols from all three major categories.

To support both risk specialists and laypersons in interpreting FTs, this research aims to develop a user-friendly layout that can also be adapted to different media: print and digital.

2. Basic Graphical Syntax of Fault Trees Diagrams

Each FT narrates a cause-and-effect story about how a failure can arise from previous causes. For example, if described only in text, the diagram in Figure 1 would state: "the trip is stranded when both car and phone fail." But instead of relying only on text, an FT also uses the elements nodes and links, together with their spatial placement, to convey its message.

The text, clearly and concisely describes the nature of the failures, see Figure 2. Furthermore, different geometric shapes act as symbols for three types of nodes, namely "events", "transfers" and "gates". Each type has a few variations, see Figure 4. Finally, solid lines between the nodes act as links and can be pronounced "when" when reading an FT. See Figure 3 (Ruijters and Stoelinga (2015); Stamatelatos et al. (2002)).

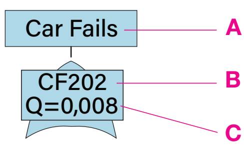

Fig. 2. Text A describes the events and transfers, often abbreviated for space reasons. Large FTs also use codes B for these descriptions, numbers and mathematical symbols C for quantitative information.

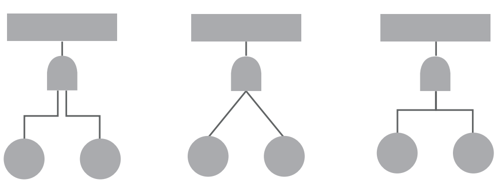

Fig. 3. Three common ways to display links between a gate and basic events below it, with the left one being the most accurate.

Example: The graphical syntax for the road trip example in Figure 1 uses the following nodes. A rectangle for "Trip Failed" and "Phone Failed" as "top" and "intermediate event", respectively. A triangle for "Car Breakdown" and "No Power"

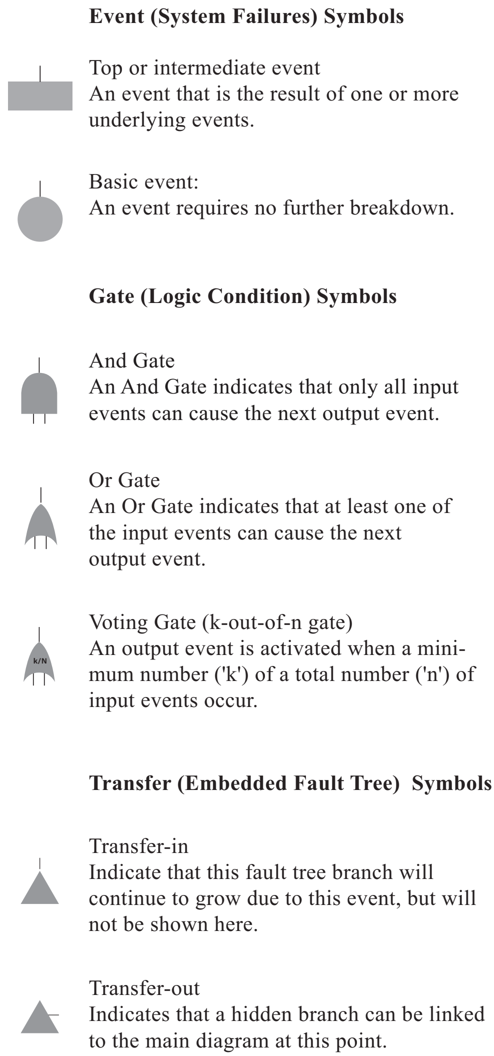

Fig. 4. The nodes in FTs are divided into three categories. First, events that indicate system errors. Second, gates that specify how one or more input events can be combined to cause an output event. And finally, transfers indicate information not shown in the diagram. Each category of nodes contains variants represented by a slight visual difference of the symbol.

is used for the "transfer" node, indicating that further information about this is missing from the diagram. A circle for "No connection", which is a "basic event" and does not require further analysis. Finally, there are the "gates", which act as filters in explaining the failure; a half pill shape

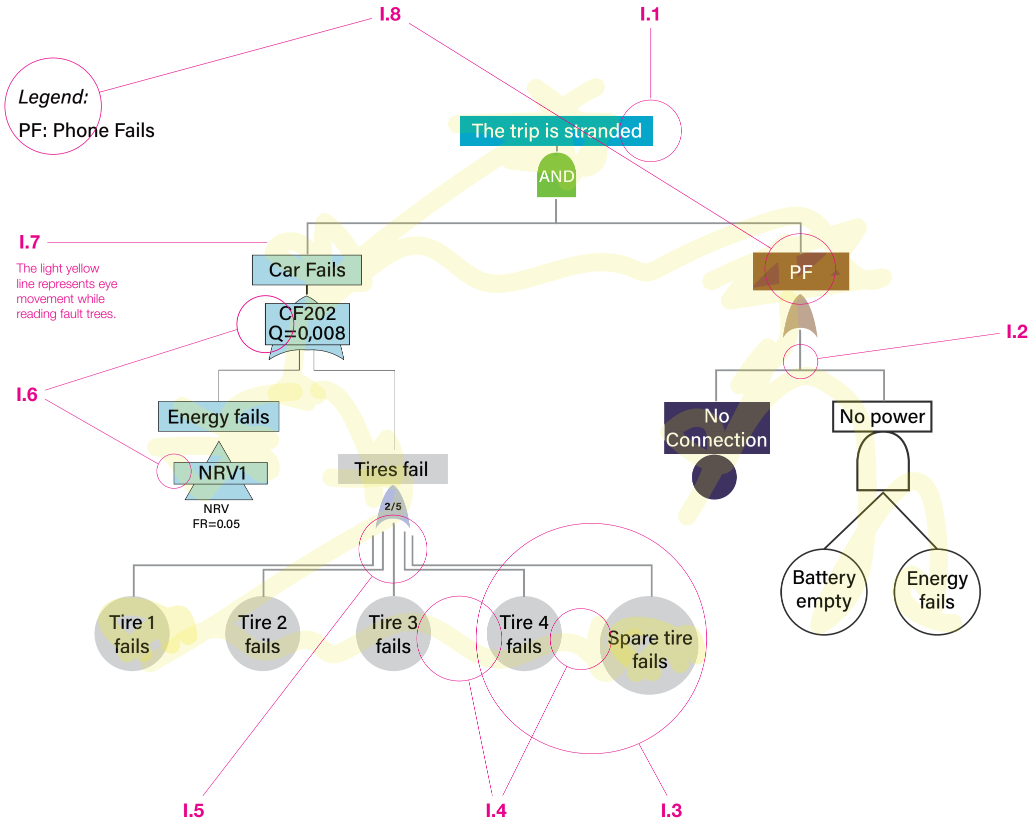

Fig. 5. A compilation of common graphical issues (I) in FTs caused by a lack of graphical guidelines. I.1: No visual correspondence between the symbols and their meaning. I.2: A single link obscures the number of input events. I.3: No uniform dimensions for similar nodes. I.4: No uniform space between similair nodes. I.5: Space under gates too limited with many links. I.6: Incorrect use of event rectangle for transfer node and gate symbol. I.7: Uncomfortable diagonal reading direction. I.8: An unnecessarily large distance between legend and abbreviation.

for an "and gate" if all options are needed to fail, and an arrowhead shape for an "or gate" if one option is already sufficient.

3. Diagnosis

Search the internet for "Fault Tree Diagram" will show a wide variety of differences in shapes, colors, typography, and layout. Figure 5 is composed of the most common graphics solutions offered to engineers and academics by the graphics software used (Isograph, 2024; EdrawSoft, nd; ALD, 2025)

When presenting such Googled FT layouts to users, their general impression was confusion due to visual complexity, followed by discomfort in understanding the diagram (Nguyen, 2025). The underlying issues which contribute to these impressions arise from clutter caused by a lack of graphical guidelines. These issues will be further described in the following two sections and shown in Figure 5.

3.1. *Visual Confusion:*

Issue (I).1: Unlike icons that visually resemble the physical appearance of objects they describe, the shapes of Fault Tree Symbols (FTSs) lack visual resembles to represent their meanings. As a result, beginners and laypersons may need time to understand and remember these shapes.

I.2: When only one line is displayed under a gate symbol, there will be confusion about the number of input events in case more than one is connected to that gate.

I.3: Due to different text lengths, similar FTSs are often given different sizes to accommodate the text. These differences in size suggest an unjustified hierarchy in relation to each other, and visually create an unnecessarily irregular layout.

I.4: The symmetrical structure of the layout creates varying distances between nodes, which falsely suggests a difference in the relationship between the nodes.

I.5: Due to the limited space under a gate symbol, there is not enough room to properly place a larger number of event links.

I.6: In FTs, rectangles are reserved only for the visual coding of top and intermediate events. In case this visual agreement with the users is not respected, confusion will arise.

3.2. *Inefficient Reading Experience*

I.7: Most languages read from left to right, some the other way around, but all from top to bottom. However, the always forced symmetrical structure imposed on the FTs evokes diagonal reading directions that intuitively does not correspond to our already trained way of reading.

I.8: Longer descriptions, especially when displayed in limited space within nodes, require an abbreviation of the text or else the use of reference numbers in combination with a legend. The great distance between them hinders reading and comprehension.

4. Design Principles

The most common issues with FTs, shown in Figure 5, are graphical irregularities usually caused by a lack of interest in paying sufficient attention to the graphical elements and their arrangement. The unnecessary confusion caused by these problems can easily be avoided by following simple guidelines that are mainly based on the already trained reading skills and intuitive ways of our viewing behavior.

When applying the rules of readable typography, including insights from Gestalt psychologists, we always chose logic over beauty (Johnson, 2020; Cairo, 2012). Attractiveness would come naturally if, once our FT setup was working, we carefully visually proportioned all the elements. During our research, we kept three conditions in mind (Reber et al., 2004; Steele and Iliinsky, 2010):

—*Efficiency,* by respecting the natural cognitive limit of short-term memory while making maximum use of it. This is done by simplifying the FT elements, carefully establishing the layout guidelines, and always applying them consistently, without any exceptions.

—*Applicability* by being able to present as many topics as possible, with all kinds of data, in different media with this visual system.

—*Functionality* by combining the previous conditions of efficiency and applicability in a visual system that does not strive for beauty, but for correctly conveying the message to the user as quickly and easily as possible.

5. Methodology

To identify areas for improvement for FTs, several examples of existing fault tree layouts were collected from online sources like Google Images and Pinterest. Inspired by this, the authors of this article discuss ideas for solutions during weekly meetings that were also sketched out on paper.

The most promising plans were then executed in detail using design tools Adobe Illustrator and Adobe XD. A selection of these high-fidelity visualizations was tested with an initial investigation of eight FT experts through semi-structured interviews.

6. Towards a Solution

Section 2 explained the function of the FT elements, such as the various nodes, text, and links. Section 3 explained the problems encountered. This section shows how we solved these problems, by mainly coming up with layout instructions for all graphic elements involved.

6.1. *Text, Events, and Layering*

Instead of adjusting the dimensions of FTSs to accommodate the explanatory texts, we keep all symbols uniform in size. This approach eliminates the visual hierarchy created by differences in symbol size while also making the layout more rhythmic and, therefore, calmer. Here, the Gestalt principle of similarity emerges.

Because the explanatory texts almost always extend beyond the right edge of the orange symbols, it appears as if their typography hovers above them. See Figure 6 and 7. This effect is created partly by the difference in light intensity because the dark, black text on a bright background is perceived as closer, while lighter, orange-colored symbols appear further away, resulting in a visual depth of two layers. This approach optimizes the use of space, allowing more information per surface. The text overlaying the symbols is associated with each other via the Gestalt principle of proximity.

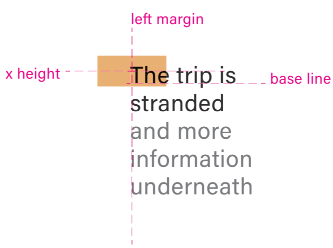

Fig. 6. The margin of the top or intermediate event description is aligned with the vertical center of the colored symbol. Its horizontal center is aligned with the x-height of the first line. These two symmetrical axes, therefore, determine the position of the text. The bottom of this symbol, and all other symbol shapes, never coincide with the baseline. This to express the symbol outline, and at the same time not reduce legibility and create a sense of spaciousness.

6.2. *Links, Lines, and Layering*

Instead of drawing all the links as uniform, straight lines, introducing variations in their design can convey additional information. To name the most important:

—The short vertical line segment directly below a gate is doubled in thickness to indicate when two input events converge. See Figure 8. With an increasing number of input events, the thickening

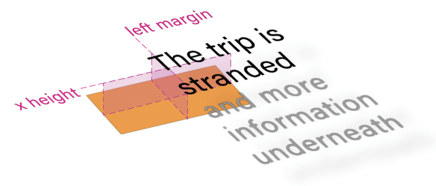

Fig. 7. This 3D view shows the imagined space between the text and the symbols by always having the black text run over the colored shapes.

would transform the lines into a rectangle shape, eliminating the impression of a vertical slim appearance. Therefore, a number paired with the word "events" is introduced to indicate the amount of input if there are more than two.

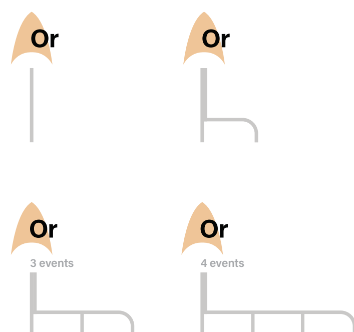

Fig. 8. A thicker line indicates two and more input events connecting to an or gate. This visual code is also applied to "and" and "vot" gates

—The corner of the rightmost line is rounded to indicate that no further input events will connect to the gate.

—Making the lines light gray makes them appear further into the background than the orange symbols due to the difference in light intensity. Also, the lighter orange version of the gates evokes greater depth, while the typography is foregrounded as it is black and placed over the symbols. The FT suggests multiple visual levels.

—By never connecting the lines with nodes or typography, this separation allows the lines to connect to different visual levels simultaneously. See Figures 8, 9, and 10. First, they align with the text margins; this via the Gestalt principle of continuation. Second, the lines connect to nodes by pointing to their center; this via the Gestalt principle of symmetry. Finally, the lines always connect to all other lines by being aligned with each other; the Gestalt principle of continuation.

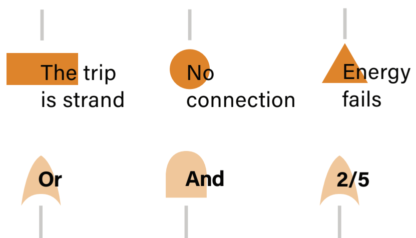

Fig. 9. The now smaller event and transfer symbols maintain their visibility by coloring them with bright, saturated orange. To draw less attention to the gate symbols, their saturation is less.

6.3. *An Option for Adding Symbol Descriptions*

Instead of assuming that everyone is familiar with FT and all their symbols, additional information could be provided for training purposes. For gate symbols, “or” and “and” in regular black typography are placed on top. To ensure that the symbol descriptions of other nodes do not stand out too much, the typography has been kept small, left aligned on the margin above the nodes, and executed in the same orange color. See Figure 10. Now, the symbol description and its corresponding symbol are visually connected through the two principles of Gestalt psychology: that of similarity and that of symmetry.

6.4. *The Logical Layout of Fault Trees*

Rather than always squeezing the FT into a standard cone-shaped layout, we prefer it to find its unique shape based on its own content. See Figure 12. While many find the symmetrical balance visually appealing, we propose that the number of input events and their order determine the layout, following logic-based guidelines. These instructions make each FT easier to build, easier to read, and easier to recognize by its unique shape. To name the most important guidelines:

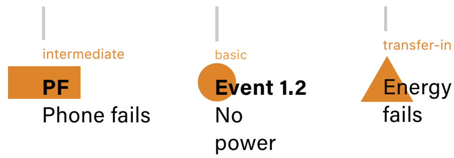

Fig. 10. Adding a symbol type name is optional, done in orange and aligned with the black typography. The gray links correspond to both texts and emphasize the vertical axis. Like letters in words, all FT forms are separate, yet connected by the Gestalt principle of continuation and proximity.

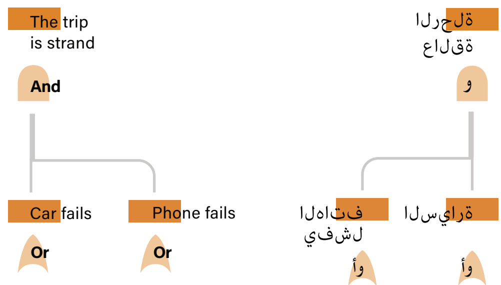

Fig. 11. The two different reading directions can easily be accommodated in this layout system. This is done by always centering the text margin on the center of the symbols. Then, the typography reverses the entire layout by the reading direction.

—Because the symbols, links, and texts are never connected or enclosing each other, they present themselves as explicitly as possible by being visually separated from each other.

—Each type of symbol always has the same size and color and is placed beneath its explanatory text. Because the symbols can never enclose their words due to their small size, both suggest visual depth. See section 6.1 and Figure 7.

—The typography is always asymmetrical, left or right aligned for different languages. When the reading direction reverses, the text margin remains exactly the same centered position relative to the underlying symbols. By mirroring the typography, the entire layout reflects and maintains the same ease of reading for that language. See Figure 11.

—The text margin is always aligned with the vertical links; this is to guide the eye via the Gestalt principle of continuation.

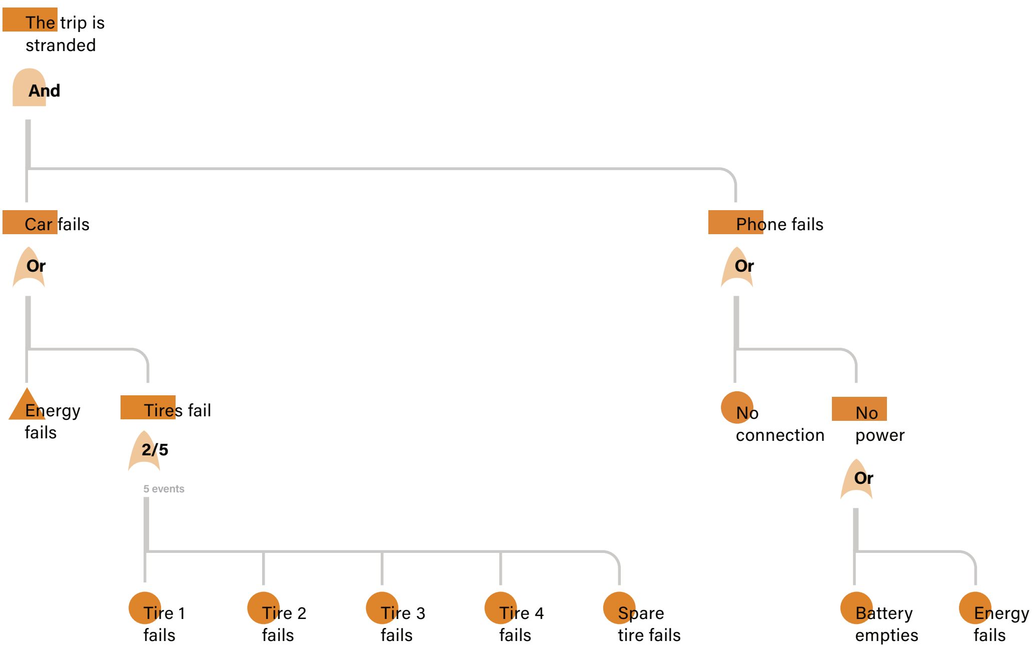

Fig. 12. The end result was created by combining various sub-researches. As in the graphic elements, such as shapes and colors. As the FT components that are constructed with this, such as the form of the events. As in the graphic spatial relationships of the events, the layout. The latter is always determined by the content and is always asymmetrical due to the reading direction of the language used. To use the surface more efficiently, the impression of visual depth is created.

—All FTS are vertically centered on the text margin, which ensures that all symbols visually connect with the typography. This is done via the Gestalt principle of symmetry.

—In addition to the vertical alignment, all event icons are also aligned horizontally, resulting in a structured layout that is grid-like and, therefore, rhythmic, providing a quick overview and good accessibility. All these qualities were appreciated by the interviewed experts.

6.5. *Digital* FT *Version*

Instead of focussing on print only, this FT layout system can, with some adjustments, be applied to the screen and made suitable for smaller mobile devices with further adjustments. Digital platforms then make FTs more adaptable, even moving, and accessible anywhere and anytime, for example on the work floor. See Figure 13.

7. Conclusion

More than sixty years after H.A. Watson, fault trees have proven their success, especially in technical disciplines, by providing a common language for identifying, quantifying, and then assessing risks. As a “Lingua Franca” that crosses borders, FTs are vital for making our increasingly complex world a safer place.

However, even experts who work with FTs can still be confused by graphical inaccuracies and, therefore, have difficulty assessing risks. Little research has been done to prevent this, and this article of just eight pages is a brief account of our long-term research into graphical guidelines for more effective visual grammar.

Imagine this FT system as a graphical building block box that together forms the lexicon and grammar of the language it speaks. Its lexicon only speaks clearly if the building rules for the

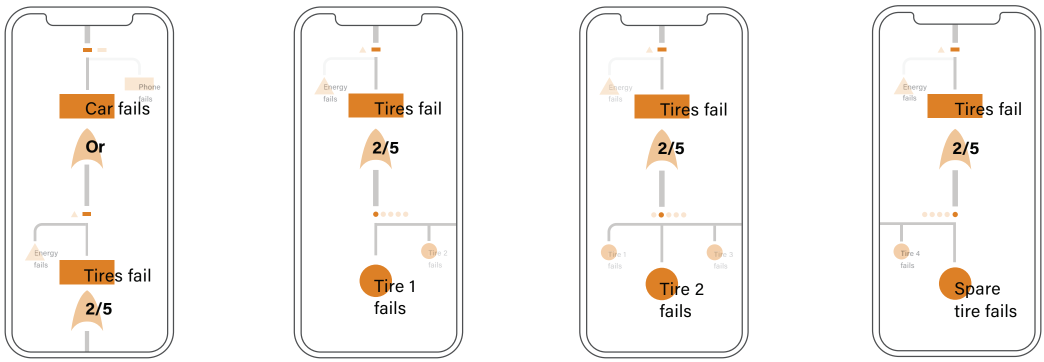

Fig. 13. The adaptation of the FT formatting system to allow display on a small phone screen. For readability, the size of the graphic elements has been kept large, so not all information can be shown and will become visible by swiping. The verticality of the tree branch is emphasized by placing the axis in the symmetrical center and by reducing the peripheral elements in size and color saturation.

bricks are strictly followed. To avoid any confusion in this graphic language for risk management, we sowed the graphic seeds by slightly modifying the bricks and tightening the building rules to make the world even safer.

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