Chapter 6

ICONIC REASONING ARCHITECTURE FOR ANALYSIS AND DECISION MAKING

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Abstract: This chapter describes an iconic reasoning architecture for analysis and decision-making along with a storytelling iconic reasoning approach. The approach includes providing visuals for task identification, evidences, reasoning rules, links of evidences with pre-hypotheses, evaluation of hypotheses. The iconic storytelling approach is consistent hierarchical reasoning that includes a variety of rules such as visual search-reasoning rules that are tools for finding confirming links. The chapter also provides a review of related work on iconic systems. The review discusses concepts and terminology, controversy in iconic language design, links between iconic reasoning and iconic languages and requirements for an efficient iconic system.

Key words: iconic reasoning architecture, analysis and decision-making, storytelling iconic approach, iconic language.

1. INTRODUCTION

The goal of an iconic evidentiary reasoning (IER) is to convey complex multi-step analytical reasoning and decision making in a more efficient and condensed way than traditional text reasoning. IER is defined as a visual support mechanism for the following general problem-solving steps:

- defining the problem,
- generating initial alternatives for hypotheses that are called pre-hypotheses,
- linking pre-hypotheses with evidences, and
- generating hypotheses by evaluating pre-hypotheses against evidences.
Typically, these steps are repeated several times in the process of refining hypotheses and evidences in scientific research as well as in intelligence analysis, engineering and architectural design, market analysis, health care, and many other areas.

To explain the IER approach we use a modified task of ongoing monitoring of the political situation in some fictitious country. The final reasoning result condenses all of the most important visuals from analytical steps in a single compact picture. This picture combines several types of icons and arrows that indicate a conclusion, its status and a chain of evidences that support the conclusion. For presentation purposes the final part of the reasoning chain can be enlarged and the icons replaced by actual maps, imagery and photographs of people involved.

Major components of the IER architecture are:

- Collecting and annotating analytical reports as inputs using a markup language, e.g., XML, DAML;
- Providing iconic representation for hypotheses, evidences, scenarios, implications, assessments, and interpretations involved in the analytical process;
- Providing iconic representation for confirmations, and beliefs categorized by levels;
- Providing iconic representation for evidentiary reasoning mechanisms (propositional, first-order logic, modal logic, probabilistic and fuzzy logics);
- Providing scenario-based visualization and visual discovery of changing patterns and relationships;
- Providing a condensed version of iconic representation of evidentiary reasoning mechanisms for presentation and reporting.

These components are depicted in Figure 1. The use of iconic visuals permits a user to reach a high condensing ratio level. Experiments reported in Chapter 10 show that iconic sentences can occupy space that is 10 times smaller than space occupied by text, that is a compression factor of 10 is possible. Also people can work with multidimensional icons two times faster than with text [Spence, 2001]. A similar time and space compression is expected to communicate analytical results (including underlying reasoning) to decision-makers and fellow analysts using IER. Moreover, at some moment with such advantages and the ongoing proliferation of visualization technology, iconic reasoning can become a major way of reasoning and communication in general. The visual correlation approach described in chapters 8-10 can be naturally combined with visual reasoning to improve problem solving.
2. STORYTELLING ICONIC REASONING ARCHITECTURE

2.1 Task identification: output characteristics and pre-hypotheses

In this section, we discuss how the process of defining the problem and generating pre-hypotheses can be done visually. The problem is defined as ongoing monitoring of a political situation in some fictitious country [AQUANT, 2002]. This may include identification of the country, and selection of processes to be monitored such demographic, economic, democratic processes, research & development and military activity. Assume that the user selected a task of monitoring democratic processes and identified overall output characteristics to be evaluated as one of the judgments: positive
change, no significant change, negative change, mixed change at this moment. In IER task identification is also done using an iconic user interface where the user picks up the task from the iconic menu of tasks and characteristics as shown in Table 1.

**Table 1. Task identification**

<table>
<thead>
<tr>
<th>Alternative tasks</th>
<th>Select icon</th>
<th>Selected icon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring democratic processes</td>
<td>![icon]</td>
<td>✔️</td>
</tr>
<tr>
<td>Monitoring economic processes</td>
<td>![icon]</td>
<td>☐</td>
</tr>
<tr>
<td>Monitoring military activity</td>
<td>![icon]</td>
<td>☐</td>
</tr>
<tr>
<td>Monitoring research &amp; development processes</td>
<td>![icon]</td>
<td>☐</td>
</tr>
<tr>
<td>Monitoring demographic processes</td>
<td>![icon]</td>
<td>☐</td>
</tr>
</tbody>
</table>

Next the user selects output characteristics to be monitored from the menu provided in Table 2.

**Table 2. Defining the output characteristics**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Select icon</th>
<th>Selected icon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description of a new process</td>
<td>![icon]</td>
<td>☐</td>
</tr>
<tr>
<td>Change direction (positive, no change, negative, mixed)</td>
<td>![icon]</td>
<td>✔️</td>
</tr>
<tr>
<td>Rate of change (low, medium, high)</td>
<td>![icon]</td>
<td>☐</td>
</tr>
<tr>
<td>Description of an emerging leader</td>
<td>![icon]</td>
<td>☐</td>
</tr>
</tbody>
</table>

After that the user picks up a pre-hypothesis from the menu for the selected task. The menu contains all logically possible alternatives for changes in country Y in the selected scale shown in Table 3.
Table 3. Pre-hypotheses and their legends. See also color plates.

<table>
<thead>
<tr>
<th>Pre-hypotheses</th>
<th>Legend 1</th>
<th>Legend 2</th>
<th>Selected icon</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_1$  Change is positive in country Y at this time (green shapes)</td>
<td>![Green Icon]</td>
<td>![Green Arrow]</td>
<td>✓</td>
</tr>
<tr>
<td>$H_2$  No significant change in country Y at this time (gray shapes)</td>
<td>![Gray Icon]</td>
<td>![Gray Arrow]</td>
<td></td>
</tr>
<tr>
<td>$H_3$  Change is negative in country Y at this time (orange shapes)</td>
<td>![Orange Icon]</td>
<td>![Orange Arrow]</td>
<td></td>
</tr>
<tr>
<td>$H_4$  Change is mixed in country Y at this time (orange/green shapes)</td>
<td>![Orange and Green Icon]</td>
<td>![Orange and Green Arrow]</td>
<td></td>
</tr>
</tbody>
</table>

Icons in Table 3 show alternative legends for pre-hypotheses. For instance, mixed change alternative ($H_4$) is presented visually in three ways: as a rectangular with orange and green components (green indicates a positive change, and orange indicates a negative change. A two-color flag and two flags express the same idea a little bit differently. Analysts have an option to select an icon legend that best fits her/his preferences and perceptual abilities.

2.2 Visual evidences

In this chapter, we assume that visual evidences are already collected. They also can be already encoded in a predicate form or in XML form that can make automated iconization of them easier. Table 4 presents examples of evidences.

Evidence $E_{11}$ states that a new person that supports democracy is in power. This evidence is depicted by the icon of an official with a positive, green background. A speaker with a neutral, gray background is an icon for evidence $E_{12}$ that there are no new indications of suppressing free speech. Altering the color in the icon for the first evidence produces an icon for evidence $E_{21}$, that there are no indications that new people with alternative views are in power.

Further alternation of the color in the first icon along with two dots produces an icon for evidence $E_{31}$ where orange background is interpreted as negative with icon meaning that several new persons that oppose democracy are in power.
Table 4. Evidence and iconic representations See also color plates.

<table>
<thead>
<tr>
<th>Evidence</th>
<th>Icon description</th>
<th>Icon</th>
</tr>
</thead>
<tbody>
<tr>
<td>E11</td>
<td>A new person that supports democracy is in power</td>
<td>An official with a positive, green background</td>
</tr>
<tr>
<td>E12</td>
<td>No new indications of suppressing free speech</td>
<td>A speaker with a neutral, gray background</td>
</tr>
<tr>
<td>E21</td>
<td>No indication that new people with alternative views are in power</td>
<td>An official with a neutral, gray background</td>
</tr>
<tr>
<td>E31</td>
<td>Several new persons that oppose democracy are in power</td>
<td>An official with negative, orange background for opposition to democracy and two dots for “several” officials</td>
</tr>
<tr>
<td>E32</td>
<td>New indications of suppression of free speech</td>
<td>Orange background encodes negative fact - suppression of free speech</td>
</tr>
<tr>
<td>E41</td>
<td>A new persons that oppose democracy is in power</td>
<td>An official with negative, orange background for opposition to democracy</td>
</tr>
<tr>
<td>E42</td>
<td>New indications of free speech</td>
<td>Green background encodes positive fact - free speech indications</td>
</tr>
</tbody>
</table>

The color language and icon content used for icons in Table 4 is described in Table 5. This language is easy to learn. It had only two iconic elements (iconels) on content (a speaker and an official), three colors and presence and absence of dots for quantity providing total $3^*2^*2=12$ icons.

Table 5. Evidence encoding legend

<table>
<thead>
<tr>
<th>Icon element (iconel)</th>
<th>Semantic indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green background</td>
<td>positive change, positive statement</td>
</tr>
<tr>
<td>Gray background</td>
<td>neutral change, positive statement</td>
</tr>
<tr>
<td>Orange background</td>
<td>negative change, positive statement</td>
</tr>
<tr>
<td>Person sitting at the desk</td>
<td>Official in power</td>
</tr>
<tr>
<td>Person giving a talk</td>
<td>Speech</td>
</tr>
<tr>
<td>Two dots</td>
<td>Several people</td>
</tr>
</tbody>
</table>

2.3 Visual reasoning rules

Evidences provided in section 2.2 can be combined in if-then reasoning rules such as shown in Table 6 in both a natural language and in a formal logic. The first rule “If a new person that supports democracy is in power (E11) and no new indications of suppressing free speech (E12) then positive
change in country Y (H1) is possible (with some confidence)” has its formal equivalent, \( E_{11} \& E_{12} \Rightarrow \text{possible } H_1 \).

**Table 6. Reasoning rules, templates**

<table>
<thead>
<tr>
<th>Natural language rules for the hypotheses ( H_i )</th>
<th>Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R1</strong> If a new person that supports democracy is in power ((E_{11})) and no new indications of suppressing free speech ((E_{12})) then positive change in country Y ((H_1)) is possible (with some confidence).</td>
<td>IF Evidences ( E_{11} ) and ( E_{12} ) take place then ( H_1 ) (positive change) is possible ( E_{11} &amp; E_{12} \Rightarrow \text{possible } H_1 )</td>
</tr>
<tr>
<td><strong>R2</strong> IF Evidences ( E_{12} ) and ( E_{21} ) take place then ( H_2 ) (no significant change) is highly probable</td>
<td>( E_{12} &amp; E_{21} \Rightarrow \text{highly probable } H_2 )</td>
</tr>
<tr>
<td><strong>R3</strong> IF Evidences ( E_{31} ) and ( E_{32} ) take place then ( H_3 ) (negative change) is true</td>
<td>( E_{31} &amp; E_{32} \Rightarrow \text{true } H_3 )</td>
</tr>
<tr>
<td><strong>R4</strong> IF Evidences ( E_{11} ) and ( E_{32} ) take place then ( H_4 ) (mixed change) is true</td>
<td>( E_{11} &amp; E_{32} \Rightarrow \text{possible } H_4 )</td>
</tr>
</tbody>
</table>

These rules can be visualized in different visual forms. Figure 2 shows visualization of rule R1 in two graphical forms. The first line shows the rule in an **abstract block diagram paradigm**. The significant difference from the classical formal logic here is in the use of the colors to indicate positive (green) meaning of the terms \( E_{11} \) and \( H_1 \) and neutral (gray) meaning of the term \( E_{12} \). The second line presents the **iconic storytelling paradigm** where terms \( E_{11} \) and \( E_{12} \) are presented as icons with the same green and gray backgrounds. In both forms an arrow indicates inference, where \( P \) stands for possible (modal logic operator). The iconic form reveals more information than abstract one and it is more appealing perceptually.

![Figure 2](image-url)
gray line indicates a neutral line of reasoning and conclusion. A mixed color line indicates a mixed conclusion. Similarly to Figure 2 this figure illustrates that the iconic form conveys more information, is more appealing and permits to convey a reasoning statement easier.

Figure 3. Traditional and iconic visualizations of rules. See also color plates.

Table 7 presents some arrow icons used in IER. Arrow icons have a hierarchy, that is if we want only to encode that fact that the result is possible we can use the first icon in Table 7, but if we want to encode the possibility more specifically we can use text markers such as HP and LP for highly possible and low level of possibility. Another option is use of partially filled arrows to identify the level of conclusion certainty as shown in Table 7.

Table 7. IER selected arrow icons

<table>
<thead>
<tr>
<th>Icon</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Icon P" /></td>
<td>P - Possible conclusion</td>
</tr>
<tr>
<td><img src="image2" alt="Icon HP" /></td>
<td>HP - Highly possible conclusion</td>
</tr>
<tr>
<td><img src="image3" alt="Icon Sure" /></td>
<td>Sure conclusion (classical logic true)</td>
</tr>
<tr>
<td><img src="image4" alt="Icon 50:50" /></td>
<td>Conclusion with 50:50 chances</td>
</tr>
<tr>
<td><img src="image5" alt="Icon Search" /></td>
<td>A search which may yield nothing, a correct result or an incorrect result</td>
</tr>
<tr>
<td><img src="image6" alt="Icon Device" /></td>
<td>Conclusion based on the use of a Device</td>
</tr>
<tr>
<td><img src="image7" alt="Icon Human" /></td>
<td>Conclusion based on a Human judgment</td>
</tr>
</tbody>
</table>
2.4 Linking evidence and pre-hypotheses using reasoning rules

Next we link available evidences and a pre-hypothesis using reasoning rules as matching templates. This is a first step for evaluating pre-hypotheses and finding plausible hypotheses. If a pre-hypothesis $H_1$ is selected and evidences listed in table 4 are available, then we look through rules listed in Table 6 to see if some of them match hypothesis $H_1$ with at least some of available evidences. Rule $R_1$ is such a rule, since it matches $H_1$ with $E_{11}$ and $E_{12}$:

$$E_{11} \& E_{12} \Rightarrow \text{possible } H_1.$$

To find matching rule $R_1$ we can compare texts in Tables 3 and 4 or icons in Figure 2, Tables 3 and 4. Comparing icons has some advantages because they contain more information than symbols $E_{11}$ and $E_{12}$ and represent their meaning more directly.

2.5 Pre-hypotheses evaluation against evidence using visual rules

Any logically possible alternative is a pre-hypothesis but only some of them are meaningful hypotheses (or hypothesis for short). We assume that meaningful hypotheses are those pre-hypotheses that (i) have some confirmation by evidences and opinions or (ii) it is expected that such confirmation by evidences or opinions can be found. Thus, we differentiate pre-hypotheses and hypotheses conceptually.

In the example above, rule $R_1$ matched pre-hypothesis $H_1$ and available evidences. This match happened to be complete, that is every term in the if-part of the rule $R_1$ has been found in the database (Table 4). This creates the base for evaluation of the pre-hypothesis $H_1$ as “possible” according to the description of rule $R_1$ presented above. It is easy to see that here we followed a rule-based approach typical in knowledge-based reasoning systems. The significant difference is that we can accomplish this reasoning by iconic means by human and automatic iconic search.

3. HIERARCHICAL ICONIC REASONING

In the previous consideration, we assumed that evidences listed in Table 4 are already given, but in fact, they often need to be established. Let us consider evidence $E_{11}$ = “a new person that supports democracy is in power” as a candidate evidence. Actually, this statement is a new hypothesis $H_{11}$ of
lower level 2. To confirm or refute it we introduce and visually represent using icons two new evidences \(E_{111}\) and \(E_{112}\) shown in Table 8. These evidences are of the next level 2. Reasoning rules for evidences of this level are shown in Table 9. Rule \(R_{13}\) is a conjunction of two rules \(R_{11}\) and \(R_{12}\).

### Table 8. Hypotheses and their legends. See also color plates.

<table>
<thead>
<tr>
<th>Evidences (level 2 hypotheses)</th>
<th>Icon</th>
</tr>
</thead>
<tbody>
<tr>
<td>(E_{111}) a new pro-democracy person X stands next to the president in a recent photograph (partial green background encodes positive change)</td>
<td><img src="https://example.com/icon111.png" alt="Icon" /></td>
</tr>
<tr>
<td>(E_{112}) A new pro-democracy person X is appointed to the cabinet as the national security advisor (green background and arrow up encode positive change and high rise)</td>
<td><img src="https://example.com/icon112.png" alt="Icon" /></td>
</tr>
</tbody>
</table>

### Table 9. Reasoning rules, templates

<table>
<thead>
<tr>
<th>Natural language rules for the hypotheses (H_i)</th>
<th>Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_{11}) A new pro-democracy person X stands next to the president in a recent official photograph</td>
<td>(E_{111} \rightarrow H_{11})</td>
</tr>
<tr>
<td>(R_{12}) A new pro-democracy person X is appointed to the cabinet as the national security advisor</td>
<td>(E_{112} \rightarrow H_{11})</td>
</tr>
<tr>
<td>(R_{13}) A new pro-democracy person X stands next to the president in a recent official photograph and a new pro-democracy person X is appointed to the cabinet as the national security advisor</td>
<td>(E_{111} &amp; E_{112} \rightarrow H_{11})</td>
</tr>
</tbody>
</table>

A new level 2 reasoning rule \(R_{13}\) (If \(E_{111} \& E_{112}\) then \(H_{11}\)) is shown visually in Figure 4. Now keeping in mind that \(H_{11}=E_{11}\) we can visually combine reasoning steps from Figures 2 and 4 to produce a reasoning chain (see Figure 5).

![Figure 4. Comparison of two visual reasoning alternatives. See also color plates.](https://example.com/figure4.png)
In this figure, the first line shows the match found between \( H_{11} \) and \( E_{11} \) in rules visualized by partial overlapping the blocks for \( H_{11} \) and \( E_{11} \). Similarly, the second line matches icons for \( H_{11} \) and \( E_{11} \) by overlapping them. The third line shows a completed match with a full overlapping of matched \( H_{11} \) and \( E_{11} \) icons. A user can do this visually by dragging one icon over another one and animate the process and the result.

Dragging is an additional intuitive element of visual reasoning. It is also possible in abstract reasoning (first line in Figure 5), but it requires remembering that \( H_{11} \) and \( E_{11} \) are the same. In contrast icons reveal similarity of these concepts instantly. Figure 5 makes the reasoning chain evident and easy to communicate. The first step of reasoning is firm (black arrow), but the second one is only possible (arrow with letter P). Having a longer reasoning chain or a tree an analyst and a decision maker can quickly see the most questionable reasoning steps that may need more attention.

4. **CONSISTENT COMBINED ICONIC REASONING**

In this section we elaborate the process of combining iconic rules in more detail. As we can see, iconic rules combine evidences and hypotheses uniformly. We start from visualizing reasoning that combines two visual rules to produce a new rule as shown in line 1 in Figure 6.

The first rule is “If a new person that supports democracy is in power (\( E_{11} \)) then positive change in country Y (\( H_{1} \)) is possible”. The second rule is “If there are new indications of free of speech (\( E_{42} \)) then positive change in country Y (\( H_{1} \)) is possible”. The produced rule on the right is “If a new person that supports democracy is in power (\( E_{11} \)) and there are new indications of free of speech (\( E_{42} \)) then positive change in country Y (\( H_{1} \)) is possible”.

![Figure 5. Reasoning chains. See also color plates.](image)
This is a rule $R_1$ from Table 6. Such conjunction is generic for combing any rules and we will call it a **conjunction metarule**.

We can also generate another compact visual reasoning rule shown in line 2 in Figure 6. This visual rule shows that if a mixture of “gray” and “green” properties implies a positive change then a consistent analyst should accept that two “greens” also should imply a positive change. This rule is based on principle of **monotonicity**. The storytelling visual rule is much *shorter and intuitively clearer than text* of this rule:

```
IF (If a new person that supports democracy is in power ($E_{11}$) and no new indications of suppressing free speech ($E_{42}$) then positive change in country $Y$ is possible)

Then (If a new person that supports democracy is in power ($E_{11}$) and there are new indications of free speech ($E_{12}$) then positive change in country $Y$ is possible)
```

The importance of this monotonicity rule is in the fact that we do not need to write this rule in advance. We can generate a specific form of this rule automatically using the principle of monotonicity. This metarule (rule applied to rules) will be called **monotonicity metarule**.

In the same way another short visual rule is generated in line 3 of Figure 6. It can represent analyst’s opinion: "If a positive change is possible because of a pro democracy person is in power then positive change is possible even if there is no progress in free speech". A visual presentation of this statement reveals its structure clearly and is shorter. This rule also has its metarule counterpart – **neutral metarule** – adding a neutral statement (with & operator) does not change reasoning result.
4.1 Visual search-reasoning rules

The process of searching for other candidate evidences can bring us to the lower level hypotheses similarly to the discussion above. In this process, candidate evidences are considered as pre-hypotheses and new evidence candidates for them are generated and visualized on the next third level. We are making search an explicit part of the reasoning process by introducing search rules such as rule R_{111} shown in line 2, Figure 7:

If the name of X is known then search in the list of foreign chiefs for this name and if found retrieve the post occupied.

Thus, this approach visualizes integration of declarative and operational knowledge, where search rules represent an operational knowledge. Let us assume that search produced the following result -- Mr. X is a national security advisor in country Y. The line of reasoning that produced this result can be expressed visually by rule R_{111} shown in the second line in Figure 7.

The textured arrow indicates that the search result can be incorrect or not guaranteed. For instance, the name may not be in the search list or the list contains the name, but it is another person with the same name.

Let us assume that (1) we have a candidate evidence E_{111} = "A new pro-democracy person X stands next to the president in the recent official picture"; (2) the analyst has found a photograph with a new person that stands next to the president during a recent visit to a foreign country, and (3) the analyst does not know who is Mr. X.

If the name is not known we need a reasoning rule of the next forth level. For instance, we may have rule R_{1111}:

If name is not known then run face recognition software (FRS) of the selected face against all annotated images available from country Y.

Figure 7 provides visuals for this reasoning by depicting rules R_{1111} and R_{111} used sequentially.
4.2 Search for confirming links

Now we need to check that Mr. X is pro democracy as stated in evidence E_{111}, his name should be in Dem.Name file from an independent source. This request is presented as a visual rule in the line 1 in Figure 8. We may also have a negative rule R_{1112} depicted in line 1 in Figure 8:

If searching for political opinion of an official in non-democratic country Y then do not rely on local official media, search independent data.

The crossed search arrow in line 2 indicates the negative rule, not to search using local media.

Now if the independent database is not available we apply another level 4 rule R_{1113}:

If searching for political opinion of an official in non-democratic country Y then search for confirming links of Mr. X.

This rule is depicted in line 3 in Figure 8 as a green "link" block that requires running interactive link analysis software. The search is indicated by the search arrow. Link analysis software found a telephone call from country Y to Mr. X's home in 1998. A caller (Mr. W) confirms that Mr. X is pro democracy ("yes" callout in visual representation). This rule is shown in Figure 9, where letter “H” in the arrow indicates a confirmation from a human.
Mr. W is a trusted source (green block "trust"). To make this conclusion we use a lower level rule such as rule R111211:

If Mr. W was tested using a polygraph successfully before then X can be trusted.

Figure 10 shows this as a visual reasoning rule, where “D” in the arrow means “confirmed” by a device. Thus, Figures 8-10 visualize logic of search.

4.3 Integrating visual reasoning components

Now successful reasoning steps can be combined into a single visual evidentiary reasoning scheme (Figure 11). This single picture shows all eight reasoning steps, levels of fidelity of conclusions, and points of linking of individual reasoning steps. For instance, it shows that only three steps out of eight steps are firm in final conclusion about positive change in country Y.

Three conclusions have no guarantee in conclusion (they came from search). One conclusion came from a device and one came from a human.

This picture can also be augmented with more elaborated levels of confidence of conclusions, their contradiction and quality of the source.

The example shows tight integration of three stages: Storytelling Iconographic Visualization, Collecting Information, and Evaluating Hypotheses. An analyst is able to see from visualizations similar to shown in Figure 11 a current status of the analysis, which can show that only few hypotheses have been tested and tested against only a small number of evidences included in
reasoning rules. An appropriate part of this visualization can be converted into a visual report to decision makers.

More complex hypotheses require more complex and dynamic icon development. Ideally, iconic representation should be automated. This subject is discussed in Chapter 10.

4.4 Visual reasoning for handling signal uncertainty

Similarly visual evidentiary reasoning can be applied to improve handling signal uncertainty in identifying location of a signal source using visualization combined with probabilistic and fuzzy logics. A sketch on Figure 12 illustrates a type of visual reasoning and presentation that is applicable here.

A traditional approach uses ellipses to convey uncertainty of location based on radar information [Mikulin, Elsaesser, 1995] with simple ellipses. A more elaborated visual representation provides additional information: probabilistic distribution of individual fixes (see Figure 13).

A visual reasoning technique conveys additional information: probabilistic distribution of individual fixes and their mixtures. Areas with higher values of a distribution function have more points rendered.

Figure 12 shows other alternatives to visualize uncertainty of location using iconic approach. It permits to convey visually, in a condensed way and quickly the differences between alternative combinations of fixes, where lines 2 and 3 visualize the traditional ellipsoid approach.

This visualization also permits naturally convey a mixture of distributions as shown on the line 4 in Figure 13. Ellipses from Figure 12 also can be used in such visual reasoning.

Similarly this approach can accommodate in visual reasoning new developments in reasoning about radar emitters such as “what-and-where” fusion for recognition and tracking of multiple radar emitters based on a neural network learning technique [Granger, Rubin & Grossberg, 2001].
5. RELATED WORK

5.1 Concepts and terminology

Data representations are characterized by several dimensions [Sloman, 1995]. Two dimensions are important in the context of visual reasoning: formal-natural and verbal-visual [Nadin, Küpper, 2003]. Frixione et al. [1997] discuss the role of image-like representations in the computational modeling of mental processes in Artificial Intelligence and Cognitive Sciences. Authors trace earlier research starting from the theorem proving machine [Gelerntner, 1959], the use of diagrammatic representations in problem solving proposed by Funt [1980], accounts of mental imagery in terms of pictorial representations [Kosslyn, 1980], and “opposition” between image-like representations and more linguistically oriented approaches [Block, 1981]. Later revival studies moved to blending features of images, diagrams, and propositional systems, e.g., [Chandrasekaran, Simon, 1992; Gardin, Meltzer, 1989; Kulpa, 1994]. Iconic reasoning is a term actively used now, e.g., [Frixione at al., 1997]. This subject is also presented in Chapter 3. Often tasks are very different and the term is interpreted differently. Iconic communication is another umbrella term [King, 1999; Yazdani, Barker, 2000] with focus on developing iconic languages for human communication. From our viewpoint the major difference between iconic communication and iconic reasoning is not in the subject (icons) but in the application area: problem solving (e.g., robot navigation) for iconic reasoning and human
conversation for iconic communication. Note the term “iconic communication” itself is more general than its scope in current research. Thus, we suggest using this term as an umbrella term for both areas. A variety of icons are developed for both purposes [Dreyfuss, 1972, 1984].

The term an iconic language is another term with different meanings. Valiant et al. [1995, 1997] define an iconic language as a language with absence of a specified syntax. In contrast, iconic programming languages are defined with a specified syntax.

Pierce categorized the patterns of meaning in visual signs as iconic, symbolic and indexical as shown in Table 10 based on [Moriarty, 1995; Nadin, Küpper, 2003].

Table 10. Peirce’s sign categories

<table>
<thead>
<tr>
<th>Sign</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>iconic sign</td>
<td>looks like, resembles what it represents</td>
<td>picture of a dog; garbage can icon</td>
</tr>
<tr>
<td>indexical</td>
<td>a clue that links or connects things in nature;</td>
<td>smoke as a sign of fire; icicles as a sign of cold; fingerprint, wind arrow as marks left by an object</td>
</tr>
<tr>
<td>sign</td>
<td>the marks left by an object</td>
<td></td>
</tr>
<tr>
<td>symbol</td>
<td>meaning is determined by convention</td>
<td>the US flag; the Statue of Liberty; Roman and Hindi-Arabic numbers</td>
</tr>
</tbody>
</table>

More terms based on [King, 1999; Valiant, 1997] are described in Table 11.

Table 11. Sign terminology

<table>
<thead>
<tr>
<th>Sign</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>natural sign</td>
<td>a universally intelligible iconic or indexical</td>
<td>a picture of a dog; icicles as a sign of cold</td>
</tr>
<tr>
<td></td>
<td>sign</td>
<td></td>
</tr>
<tr>
<td>abstract sign</td>
<td>a symbol, conventional sign that have to be learned</td>
<td>Hindi-Arabic numbers</td>
</tr>
<tr>
<td>ideogram</td>
<td>an icon that encodes an idea/concept</td>
<td>Bliss alphabet [Bliss, 1965]</td>
</tr>
<tr>
<td>figurative icon/picture</td>
<td>a metaphorical icon /sign</td>
<td>the Statue of Liberty</td>
</tr>
<tr>
<td>semem</td>
<td>a traditional text message made up of linguistic entities in a natural language</td>
<td>any text in English</td>
</tr>
</tbody>
</table>

This is not a complete set of the iconic terms used. For instance, semiom is defined as a message composed with icons which do not necessarily match up to linguistic entities. Icons that express predicates are called predicative icons. Single word icons can be expressed with a single word in a natural language and multiple word icons correspond to more than one word in a natural language.
5.2 Controversy in iconic language design

Blissymbolics [Bliss, 1965] is an example of a sign system that was driven by comprehensibility of signs; semantics of signs intends to capture a deep meaning of a concept depicted in the icon. A roman number system is another attempt to create a comprehensible sign system. Compare Roman numbers three (III) and eight (VIII) with the same Hindu-Arabic numbers 3 and 8. The first two are more “natural” (III directly shows three units “I”) and last two (3 and 8) are abstract, conventional signs without a direct link between their appearance and contents. History made its choice for Hindu-Arabic numbers, in spite of the fact that they are not “natural”, but they have advantages indicated in [King, 1999]:

- encode a complex concept in a simple sign (8 is simpler than VIII),
- support arithmetic simpler than Roman numbers,
- can be easily learned and distributed (compare 1999 and its Roman equivalent),
- supported by billions of users around the Globe.

Two related extreme claims are listed in [King, 1999]: (1) all sign systems and methods of representation are inherently arbitrary and (2) pursuing intrinsic comprehensibility of a sign is a chimera.

Cruickshank and Barfiel [2000] develop an approach that augments textual communication with user-created icons. The authors argue that this approach can overcome difficulties of alternatives such as Bliss symbology intended to replace textual communication by using a fixed iconic vocabulary.

“Bliss faltered and ultimately failed because people are generally not prepared to learn and communicate with a rigid new language, syntax and grammar; the required investment in time and understanding outweighs the potential benefits” [Cruickshank, Barfiel, 2000].

It is suggested that a modern symbol system must be able to grow. This is especially useful for attempts to create a universal iconic language that can augment text in many possible situations of human communications (e.g., e-mail). However, this ambitious goal is not necessarily the goal of every problem solving iconic communication. For instance, a music symbolic language, digital logic, military and traffic symbologies are sophisticated iconic languages but are not intended to be universal and hardly can be produced quickly in the course of communication itself. Such languages should be consistent and have relatively lower ambiguity in contrast with a language for an unrestricted domain. These examples also illustrate the difference between two research focuses: problem solving and conversation between people.
5.3 Iconic reasoning and languages

Typically visual reasoning models belong to one of two categories: logic-based “analogical” models and hybrid models [Frixione et al., 1997]:

- Logic-based “analogical” models use visual representations isomorphic to their logical models [Levesque 1988; Johnson-Laird 1983, Fauconnier 1985], and

Often these reasoning models have computational advantages over reasoning models based solely on propositional representations without visual components. Sometimes these models also are more expressive.

The mathematical base of visual reasoning comes from classical logic, probabilistic reasoning, fuzzy logic, possibilistic logic. Recently description logic (terminological logic) with fuzzy logic components was added [Lutz, 2003; Straccia, 2001].

Modern approaches in iconic languages start from Isotype [Neurath, 1978] and Semantography [Bliss, 1965] developed in 1920-1940s. A recent related bibliography is presented in [Camhy, Stubenrauch, 2003].

Below we comment on a few recent iconic languages. Computer Assisted Iconic Language System, CAILS [Champoux, 2001] produces “iconic message objects”. It deals with visual/spatial concept representation with specific syntax. Visual references or “words” are classified in the following categories: Hands, Movements, Expression, and Pictures. CAILS’s grammar contains six conjunctions: standard complementizer (that), implicative (if), antecessive (because), concessive (but) and connectives (and / with) shown in Figure 14.

![Figure 14. CAILS’s conjunctions symbols](Champoux, Fujisawa, Inoue, Iwadate, 2000)

A system based upon a set of dynamic visuals with qualitative reasoning about information displayed within a document is known as Context Transport Mark up Language, CTML [Tonfoni, 1996,1998-2001].

An iconic communication system to assist a user to construct sentences, without typing them in words, i.e. solely relying on icons is called Visual Inter Language, VIL [Becker, 2000]. The goal of VIL is to make the system language independent so that it can be used universally.
5.4 Requirements for an efficient iconic system

It is widely believed that an iconic language (IL) and an iconic system can be successful if:

- IL is a specialized language for specific domain (such as music, math, traffic control, military, digital logic) with a built-in iconic reasoning mechanism.
- IL is a language naturally growing in communications of people who use and spread it (e.g., growth of natural spoken and hieroglyphic languages). This approach is advocated by Cruickshank and Barfiel [2000].
- Efficient learning procedures are established for IL (e.g., start from a small subset).
- IL is a small language with a very few graphical elements/icons with multiple meanings depending on their location relative to other icons.

For instance, in mathematics, line above word \( \lim \) has one meaning and line below \( \lim \) has another meaning. This polysemantic contextual approach is called semantic compaction in [Cruickshank & Barfiel, 2000].

Other requirements identified are [King, 1999]: (1) typographic convenience, (2) ability to draw attention and interaction to a point, (3) ability to encapsulate a complex meaning in a simple and “on the spot” message, and (4) ability to support creation of a community of effective sign-users.

Comprehensibility icons are still actively discussed, it is obviously desirable but often is not considered as a necessity. If other icons that are less comprehensible can be simple manipulated, then such icons can survive. The history of mathematics provides many examples in support of this point.

6. CONCLUSION

This chapter presented the iconic evidentiary reasoning (IER) architecture with iconic storytelling visualization and an overview of the related work. IER intends to convey complex multi-step analytical reasoning and decision making in a more efficient and condensed way than a traditional text is able. IER is defined as a visual support mechanism for the following general problem-solving step: defining the problem, generating initial alternatives for hypotheses that are called pre-hypotheses, linking pre-hypotheses with evidences, and generating hypotheses by evaluating pre-hypotheses against evidences.

The architecture is applicable for intelligence analysis, engineering and architectural design, market analysis, health care, and many other areas. IER approach was presented using an example of ongoing monitoring of the political situation in some fictitious country. As a result, a compact single pic-
ture condenses all reasoning steps. This iconic picture combines indicates a conclusion, its status and a chain of evidences that support the conclusion. For presentation purposes the final part of the reasoning chain can be enlarged and icons can be replaced by actual maps, imagery and photographs of people involved.

Major components of IER architecture are: (1) Collecting and annotating analytical reports as inputs using a markup language, e.g., XML, DAML; (2) Providing iconic representation for hypotheses, evidences, scenarios, implications, assessments, and interpretations involved in analytical process; (3) Providing iconic representation for confirmations, and beliefs categorized by levels; (4) Providing iconic representation for evidentiary reasoning mechanisms (propositional, first-order logic, modal logic, probabilistic and fuzzy logics); (5) Providing scenario-based visualization and visual discovery of changing patterns and relationships and (6) Providing a condensed version of iconic representation of evidentiary reasoning mechanisms for presentation and reporting.

Iconic reasoning is much shorter and perceptually appearing than text. This is important for communicating analytical results (including underlying reasoning) to decision-makers and fellow analysts. With these advantages at some moment iconic reasoning can become a major way of reasoning and communication in general. In this chapter, the overview of iconic studies contrasted iconic reasoning and iconic communication. The application area for iconic reasoning is problem solving and the application area for iconic communication is unrestricted human communication. The chapter provided a short overview of iconic terminology started by Charles Pierce. It is also discussed comprehensibility of icons along with the user-created icons vs. a fixed iconic vocabulary. The overview indicated that visual reasoning models that use visual representations isomorphic to their logical models and hybrid models that combine visuals with logical representation often have computational advantages over reasoning models based solely on propositional representations without visual components. The overview also briefly presented a history of iconic languages and ideas of more recent iconic languages.

7. **EXERCISES AND PROBLEMS**

1. Develop visual reasoning rules similar to those presented in Figure 6. Tip: use OR and negation operations.

2. Build visual search-reasoning rules similar to those shown in section 1.8.
6. Iconic reasoning architecture for analysis and decision making

3. Develop your own integrated visual evidentiary reasoning description similar to the scheme presented in Figure 11. Tip: Select a text from a recent mass media report and attempt to present it as a visual reasoning.

4. Discuss requirements for an efficient iconic reasoning system based on considerations presented in section 3.4.

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