Tactile Reasoning and Adaptive Architecture for Intelligence Sense-making

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1 Introduction

Visual analytics is the science of analytical facilitated by interactive visual interfaces [1]. Visual analytics combines automated analysis techniques with interactive visualizations to facilitate reasoning and making sense of large and complex data sets [2]. A key component of visual analytics is information visualisation, which is the communication of abstract data through visual representations that simplify, aggregate and reveal important relationships [3]. However, information visualisation is just one part of the equation that is visual analytics. The ability to manipulate the data directly and to query and initiate analytic processes through that manipulation with the resulting information is the other major component of visual analytics [1]. Together, interaction, visualisation, and analytics, combine to create powerful tools for supporting the analysis and reasoning with large, mix-format, multi-source data sets.

We are interested in the application of tactile reasoning to visual analytics. We define tactile reasoning as an interaction technique that supports the analytical reasoning process by the direct manipulation of information objects in a graphical user interface (GUI). In a study by Maglio et al [4] they found that participants using scrabble pieces (individual alphabets on tiles) generated more words when they were allowed to manipulate the scrabble pieces than when they are not allowed to interact with the pieces. The act of tactile manipulation of the scrabble pieces, i.e. the ability to rearrange them, allowed the participants to form words that they could not form without interaction. Tactile reasoning, we therefore hypothesise, enables individuals to see patterns in visually presented data sets they might otherwise not see through the manipulation, rearrangement and other interaction with the information objects.

In this paper we describe the concept of tactile reasoning in the context of visual analytics, and the adaptive architecture needed to support it during real-time manipulation. We conduct our investigation through a lab prototype – INVISQUE – Interactive Visual Search and Query Environment [4,5]. INVISQUE provides an information visualisation interface coupled with a "reasoning workspace" that facilitates tactile reasoning. INVISQUE was funded by JISC to provide an alternative interface to improve information search and retrieval and sense-making in electronic library resource discovery systems such as the Emerald and ISI electronic journal databases. We have developed an adaptive architecture which underlies INVISQUE and supports the sense-making by providing the system with the capability to rapidly adapt to changing circumstances [6].

Originally intended to support tactile sense-making in the context of information discovery within the digital library space, INVISQUE and its tactile reasoning concepts can be redeployed to other domains that share characteristics such as complex, mixed media, multi-source data. Intelligence analysis is one such domain that in addition to the above, embodies the problem of uncertainty by being incomplete, out of sequence, of dubious reliability and contradictory.

The concept of a reasoning workspace within the domain of intelligence analysis speaks directly to the Pirolli & Card [7] model of intelligence sense-making (see Figure 1). Tactile reasoning techniques can aid in sense-making tasks such as shoeboxing, evidence filing, as well as the higher order abstract tasks of hypotheses formulation by allowing for dynamic manipulation of information to reveal hitherto unknown patterns, relationship between information or by showing a different facet of the information.

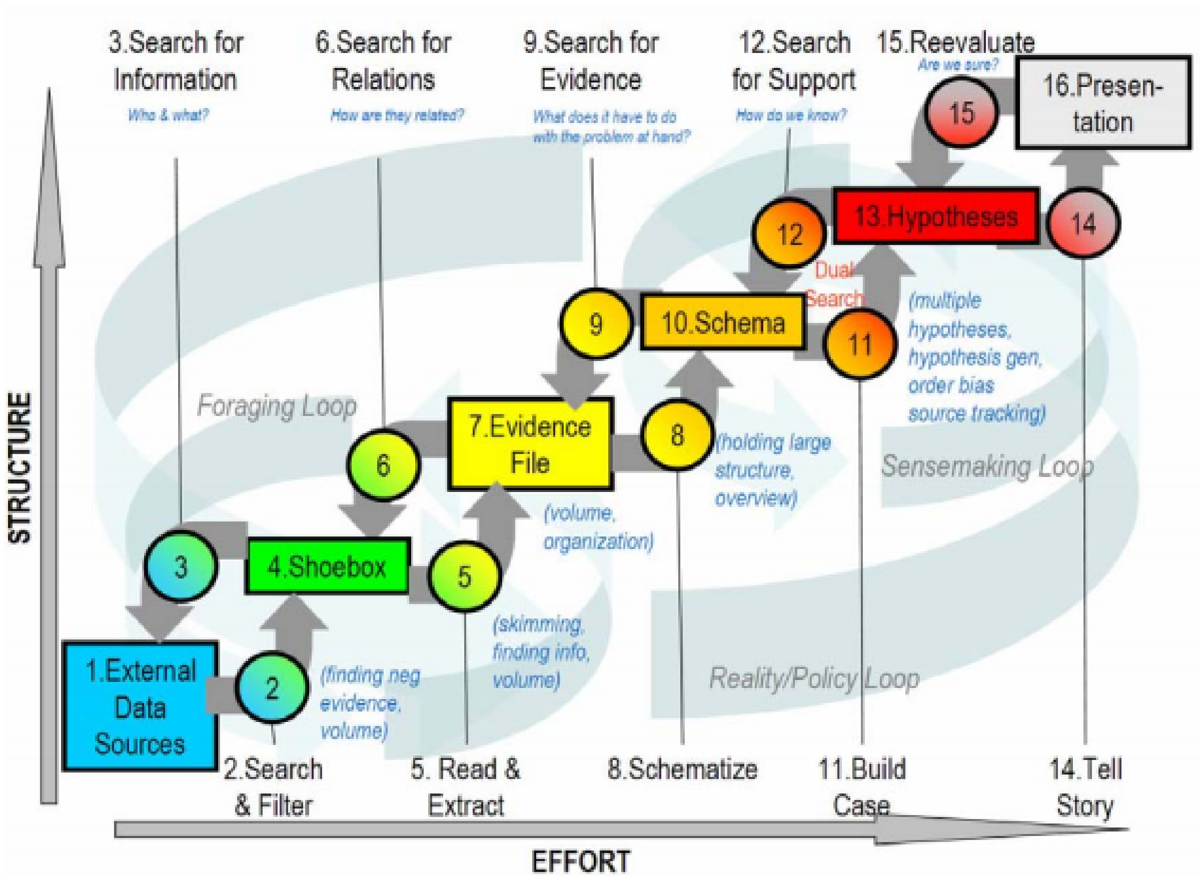

Figure 1: Pirolli & Card Model Of Sense-making [7]

The disruptive technology reported in this paper is the concept of tactile reasoning as we have applied it in the context of visual analytics. Tactile reasoning is best demonstrated though an interface such as INVISQUE as the interface allows the discovery of new patterns of relationship among the information that promotes sense-making. Relating back to the Pirolli & Card model, tactile reasoning has the potential to assist schematisation by assisting in logical reasoning by exposing patterns contains within the information that would not be visible but for manipulation. In other words, the technology and techniques so far has been mainly focused on the foraging loop of the Pirolli & Card model, by embodying the concept of tactile reasoning we are attempting to build technology and develop technique that allow us to support the sensemaking loop of the Pirolli & Card model, as well as the foraging look.

The adaptive software architecture underlying INVISQUE is what allows us to quickly and dynamically adapt INVISQUE to work not only with different datasets but also in different domains. The chief benefits of the architecture is its ability to rapidly adapts to changes in dataset – both type, quantity, as well as incorporate wholly new types of datasets, add new functionality at runtime and also adapt to different requirements for presentation, as an important aspect of visual analytics is the ability to produce, present and disseminate the results of the analysis to communicate the information in the appropriate context to a variety of audiences [1]. As illustrated in Figure 2, in relation to the Pirolli & Card model, the adaptive architecture can strongly support the tasks involving external data sources, shoebox, evidence file and presentation.

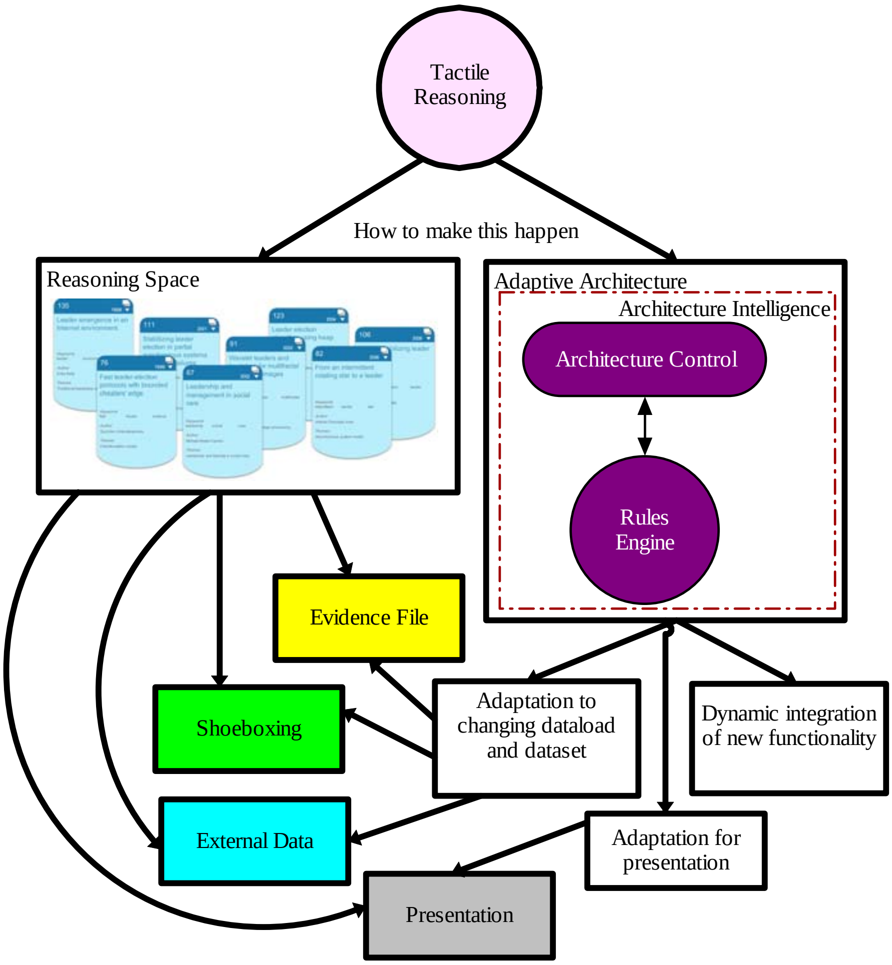

Figure 2: How The Architecture Supports Sense-making

The application of INVISQUE to other domains, including intelligence, is still at its infancy. Therefore, in this paper, we will focus on the application of INVISQUE in the domain of digital libraries.

2 The State of the Art

There are a number of information visualisation and visual analytics tools available today that aim to help users make sense of data. Commercially, companies such as **I2** [8], **Distillery** [9] provide analysis tools **Analysts Notebook** and **Analysts Desktop** respectively, aimed squarely at the intelligence analysis. Other companies such as **Tableau** with **Tableau** [10], **Visikio** with **Omniscope** [11] and **LiquiLight** with **LiquiMap** [12] provide tools for information visualisation so new insights can be gained from altered perspectives for a more general audience such as retailers and even the general public. In addition, from academia come **Georgia Institute of Technology's JIGSAW** investigative support visual analysis tool [13] and the **Open University's Cohere** visualisation tool [14].

The software's provided by these companies and institutions have two parts to them. The main emphasis for these tools is at the interface level where the information visualisation takes place and which allows users to interact with said visualisation to perform analytics. The second part is the architecture underlying the system that connects the usually self-contained, monolithic, information visualisation and analysis interface with data sources that supply the information for visualisation and analysis. The concentration of intelligence is also mainly at the interface level. All these tools have different visualisation and analysis interfaces, with each having their own advantages and disadvantages that cannot be readily compared without a proper study. However, the architecture of underlying these systems is much more easily explored.

The majority of existing software use the standard client-server architecture, which is a tiered architecture with a client (interface) and server (backend) [15]. The server side of the architecture can be further sub-divided and usually is to create n-tier applications [16]. Example of the use of client-server architecture include **I2's Analysts Notebook** [8] when combined with **I2**'s **iBridge** or **iBase** data connectivity modules [17], **LiquiLight's LiquiMap** [12] and **Tableau** [18].

On the other hand, **Distillery Software's Analysts Desktop** uses an enterprise webservice model, i.e. a Service Oriented Architecture, for their forensic analysis tools [9]. Service Oriented Architecture (SOA) is a software architecture where functionality is grouped around business processes and packaged as interoperable services [19]. Variation of the SOA model includes Semantic-enabled SOA, which combines SOA with semantic technology such as ontology and proposition logic [20]. **Open University's Cohere** visualisation tool has Semantic-enable SOA augmentation [21].

Unlikely the others, **JIGSAW** is built on the Model-View Controller (MVC) architecture [13]. MVC separates the model of business from the "view", i.e. the interface, and the controller that allows that manipulation of the "view" [22]. As such, the underlying paradigm of the MVC architecture is idea that "model" has a longer life-span then the interface that is used to interact with the model [22]. As a result, separating the model from the view and then using the controller to manipulate the view enables the view, aka the interface, to be more easily altered and upgraded [22].

Client-server, SOA and MVC architectures are all modular architectures with SOA being a distributed architecture that strings together functionality from diverse sources. However, they are also static architectures. Even MVC largely only promotes the changing of the "view", i.e. the interface, and that cannot be done at runtime. The approach being proposed in this paper differs from existing tools in being supported by an adaptive architecture. An Adaptive Software Architecture is an architecture that changes its structure based on use and demand [6]. Adaptive Software

Architecture from the basis of self-adaptive software [6]. Advocates of the architecture propose adaptive software based on adaptive software architecture to be the key to achieving the goal of retaining full application plasticity throughout the software's lifecycle and that are as easy to modify on the field as they are on the drawing board [6]. This allows for the overall system, and not just the interface, to be intelligent and support the user in their sense-making process.

3 Tactile Reasoning & Reasoning Space

Tactile reasoning is a term that we coined to embody the concept of supporting analytical reasoning through tactile manipulation of information objects in a GUI. As stated in the introduction, past research with scrabble pieces has shown that tactile manipulation can lead to better sense making and reasoning [23]. Significantly, the findings of previous scrabble experiments indicate that manipulation assists in greater word generation in sets that are marked *low frequency* [23]. To generalise this finding, manipulation assists in finding patterns among information in situation where the patterns are not obvious. In other words, tactile reasoning and interaction offer a visual context for triggering associations based on ones frame of reference [24], "Frame" - a data-structure for representing a stereotyped situation that is stored in the users memory [25], as well as the users mental model [26] and perceptions based on said mental model [27]. However, tactile reasoning requires a "reasoning workspace" on which the pieces of information that are being used for reasoning can be interacted with. For example, a table top on which rests the pieces of the jigsaw puzzle the person is trying to solve. Shown in Figure 3, our tactile reasoning space is INVISQUE.

Figure 3: INVISQUE Interface With One Information Cluster

As mentioned in the introduction, while applicable to different domains, the current domain of application for INVISQUE is the digital library domain. Within this domain, INVISQUE represents a departure from traditional methods of displaying retrieved information from simple keyword search and an equally radically different method of interpreting, exploring and making sense of the returned result set to discover the required piece of information.

Within the scenario of a library, the required piece of information would be one or more information resources such as journal articles and books, with the purpose of the search being to discover relevant information that is not mere recall and retrieval, as characterized with knowing that a paper exist and simply locating it, but the more complex task of information discovery with an imperfect or no understanding of what is available [28]. There is an added caveat that while the information seeker is not aware of what is available, they do have a perspective [27] and frame of reference [24] which informs their information seeking. They are, in other words, looking for particular pieces of information and will not accept just any piece of information. It is because of this latter situation where the tactile reasoning space provided by INVISQUE is of paramount importance.

Currently, the result of information searches in both the library space is presented as a list on which the only manipulation possible is sorting. INVISQUE departs from the status quo of information retrieval interfaces by displaying the "list" of returned results as a series of cards that at a glance present a highlight of relevant information. The cards can be rearranged spatio-temporally along X-Y axis (with the Z axis to come), dragged and dropped to be rearranged in new groups or clusters, they can even be removed from the screen entirely if deemed irrelevant or marked as being highly relevant. All these manipulation assists the user the in the sense making process and facilitate information discovery in the digital library domain with the underlying architecture coming into play to make the overall INVISQUE system more dynamic and adaptive to changes.

4 The Adaptive Architecture

The key component of the INVISQUE Adaptive Architecture is the *Architecture Control* and the *Rules Engine* that dictates the behaviour of the *Architecture Control*. This is what gives the architecture its intelligence. The system dynamically changes structure by the *Architecture Control* selecting needed modules from the module repository and orchestrating them either on the *Data Visualization and Analysis Layer* - to provide information visualization and analysis capability, or the *Data Connectivity Layer* - to provide access to a required data silo. The two layers are linked by the *Transient Homogeneous Data Pool*, which frees the *Data Visualization and Analysis Layer* and the *Sense Making Space* from having to concern themselves with the structure (or lack thereof) of the data as it sits within its native data silo. However, the data pool connecting the two layers is "transient" and is designed to be able to give direct access to the data in its native form, as it sits within its native silo, should it be required to do so for any reason. The INVISQUE architecture is illustrated in Figure 3

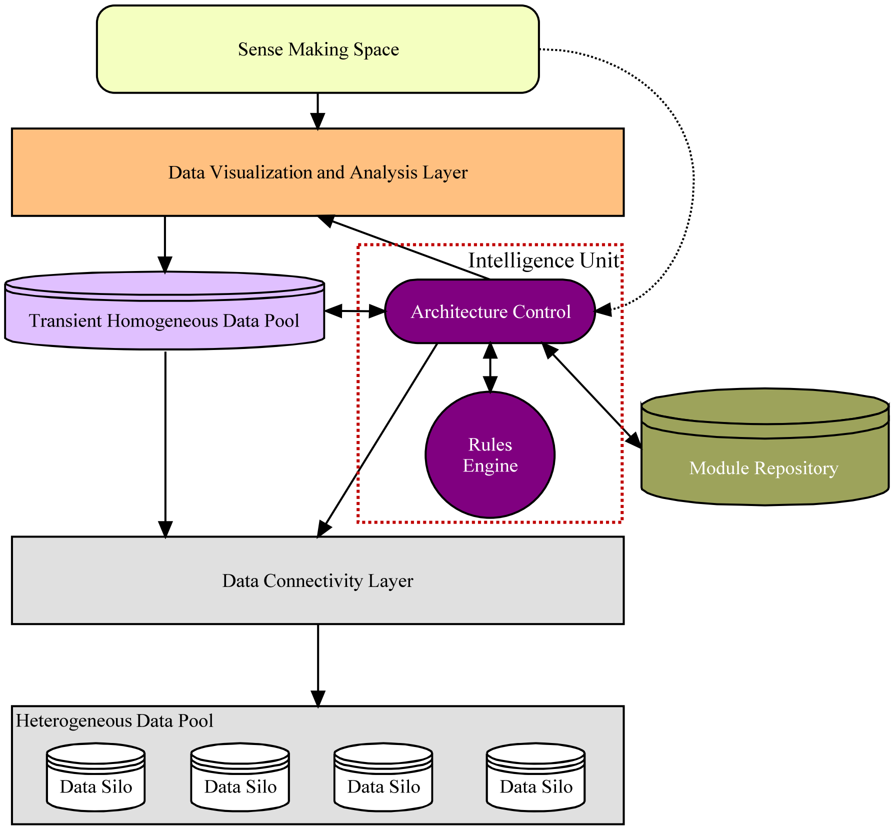

Figure 4: INVISQUE 's Adaptive Architecture

This adaptive structure makes the system dynamically scalable and gives the overall system the ability to adapt to changes in data load, data characteristics and most importantly, dynamically adapt to incorporate new functionality such as the ability to read new types of datasets and present the results of analysis in novel manners that may be required by new demands being placed on the presentation of the result of the sense-making process.

In addition, the embedded intelligence has the potential to track conclusion pathways, paths taken to arrive at the conclusion as well as the path that lead to dead-end. The system can track and compile provenance information that can be used to create the 'conclusion pathways' that trace the way information is used in the evidential reasoning process and in each conclusion. These conclusion pathways are audit trails based on provenance information, and will be able to provide answers to the question "How did we get here?" by re-tracing or re-playing the steps in the reasoning process. This is a question often asked in the intelligence community, where how an analyst arrived at a conclusion is as important as the conclusion itself.

The adaptive architecture does not create a recommendation system and will not guide the user in this respect. It is, however, a form of intelligent system that creates a feedback loop between the system and the user that enable the whole system to change in response to the demand the user places on them. For example, going back to the digital library example, at the beginning of the information seeking process – a PhD student might start by performing a search on the name of their supervisor. From there, the student would slowly start expanding their search by searching on the co-authors of their supervisor, the authors who their supervisor cited, the authors cited by the authors cited by their supervisor and before long, as illustrated in Figure 5, the student has a number of clusters of information and is seeking to explore relationships between them.

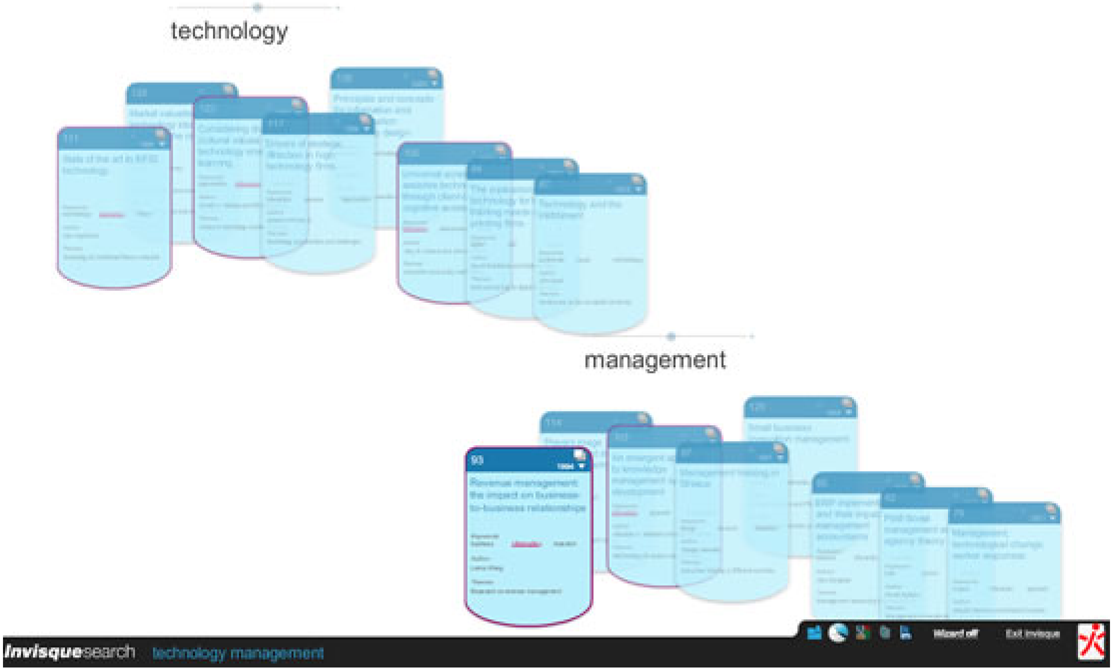

Figure 5: INVISQUE With Two Information Clusters

In Figure 5, we are just showing two clusters of information on the INVISQUE reasoning workspace with the fade, focus and a purple outline showing the relationship of objects within the two clusters. However, embodied in the INVISQUE concept is the idea of an infinite canvas on which records of the order of magnitude of 120 million can be displayed. This type of dynamic scalability requires a system that can dynamically adapt to the demand of going from 8 records to 120 million records.

5 Conclusion

In this paper we have outlined INVISQUE, a reasoning workspace with an adaptive architecture through which we are exploring the concept of tactile reasoning in the sense-making process. INVISQUE has been applied to the digital library domain. We are currently investigating how INVISQUE can be used in intelligence analysis. We believe that the concept of tactile reasoning, supported by a reasoning workspace with an adaptive architecture supporting steps in the Pirolli & Card model would benefit the intelligence community by devising new methods and tools for investigative analytical reasoning. We are currently investigating the validity of this hypothesis.

6 References

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