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Visual Analytics as a Method of Analysis for Socio-Technological Systems: A case for mapping innovation intermediaries

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Abstract

With the advent of increased computer processing power and pervasive Internet usage over the past 20 years, the volume of data is fueling a tsunami. Wurman (1996) predicted this event as "a tidal wave of unrelated, growing data formed in bits and bytes, coming in an unorganized, uncontrolled, incoherent cacophony of foam. It's filled with flotsam and jetsam. It's filled with the sticks and bones and shells of inanimate and animate life. None of it is easily related, none of it comes with any organizational methodology". Data is raw and unorganized information that has been translated into a processable format, grouped and then stored in a database. In response to this swell, data science researchers have examined and studied a multitude of scientific methods, processes, algorithms and systems to extract knowledge. Surprisingly, relatively few researchers have examined the emerging Visual Analytics (VA) methodology to defuse this data tidal wave. This paper examines the value of Visual Analytics (VA) as an interdisciplinary method of analysis for complex systems, such as innovation intermediaries, and offers a typology of methods and tools to analyze, visualize and map their organizational processes.

Keywords: *Visual Analytics, Innovation Intermediaries, Innovation Process, Socio-technological Systems*

Visual Analytics: a brief literature review

VA is an interdisciplinary approach that combines computer processing analytic tools with human perception to interactively and visually process large data sets. First used by Keim in 2004, the term Visual Analytics (VA) refers to a new multidisciplinary field that combines visualization, human-computer interaction, data analysis, data management, geo-spatial and temporal data processing, spatial decision support and statistics research areas. The Institute of Electrical and Electronics Engineers (IEEE) suggests VA is an extension from the scientific visualization and information visualization fields. Scientific visualization is primarily concerned with 3-dimensional scientific and 3D phenomena, such as fluid flow or molecular structures, and data from the world of natural science and engineering with the aim to represent the data, often temporal, as physical entities, such as surfaces, volumes and flows. Their visual representations focus on natural or real geometric images, which do not require extensive interaction. Information visualization refers to methods for the visualization of abstract data, often with many dimensions where no explicit spatial references are given. These include business data, demographics data, social networks and scientific data that are numeric, textual and complex as graphical, musical, video, and sound (Keim et al, 2010).

The main domain for information visualization is in the area of business intelligence, which spans financial data, fraud detection, consumer data, social data and data associated with health care services. This domain's key challenge is to analyze data under multiple perspectives and assumptions to understand historical and current situations, and then monitor the market to forecast trends through the identification of recurring situations or patterns. These representations are 'freeze frames' of data, and do not emphasize any interaction, nor consider the cognitive relationship with their representation. Visual analytics evolved from these earlier visualization fields and is currently positioned as the "science of analytical reasoning facilitated by interactive visual interfaces" (Thomas and Cook, 2005) It brings together several scientific and technical communities from computer science, information visualization, cognitive and perceptual sciences, interactive design, graphic design, and social sciences. It addresses challenges involving analytical reasoning, data representations and transformations, visual representations and interaction techniques, and techniques to support production, presentation, and dissemination of the results. Although

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VA has some overlapping goals and techniques with information visualization and scientific visualization, it is especially concerned with sense-making and reasoning and motivated to aid in problem solving and decision making (Dill et al, 2012).

VA includes four focus areas: (1) analytical reasoning techniques that let users obtain deep insights that directly support assessment, planning, and decision making; (2) visual representations and interaction techniques that exploit the human eye's broad bandwidth pathway into the mind to let users see, explore, and understand large amounts of information simultaneously; (3) data representations and transformations that convert all types of conflicting and dynamic data in ways that support visualization and analysis; and, (4) techniques to support production, presentation, and dissemination of analytical results to communicate information in the appropriate context to a variety of audiences" (Thomas and Cook, 2005).

VA offers a way to see the complicated path from data to decision (Keim et al, 2008), through the processing of data into transparent information and visualizations. Through interactive computer interfaces, VA seeks to make the invisible, visible and observe the science of analytical reasoning between human and machine. VA's goal is to create tools and techniques for effective, timely, detected, discovered, and visually synthesized insights (Keim et al, 2008). This is accomplished by the synthesis of information to derive insight from massive, dynamic, ambiguous, and often conflicting data; the detection of the expected and discovery of the unexpected; the timely, defensible and understandable assessments; and, the visual representations that communicate assessments effectively for action (e.g. decision-making).

VA is a knowledge discovery process that involves designing and completing a series of analytical tasks to identify patterns, trends and correlations of data and allowing others to enter the sense-making loop through an interactive interface. Its computational and theory-based tools are based on cognitive, design, and perceptual principles. Visual displays support cognitive tasks of pattern finding, connecting concepts to patterns (design) and pattern recognition (perception). VA tools and techniques reflect these principles in enabling the science of analytical reasoning.

VA supports the Grounded Theory methodology, which seeks to uncover relevant conditions, observe the responses to these conditions, and reflect on the consequences derived from the actions to the responses. Glaser and Strauss (1967) first proposed grounded theory as a methodology that frames a series of iterations as a process of 'constant comparison', in which the researcher moves back and forth among the data, advancing from coding to conceptual categories in order to generate an hypothesis. It is an iterative approach where data collection and analysis are an interrelated process. Grounded theory also allows for all potential concepts to be considered and then seeks out a repetition of concepts or themes, as patterns to be identified.

As an emerging analysis method for many disciplines, identifying the right tools for the right data format is critical for a successful visual analytic process of either highly structured data (quantitative or numerical data) or unstructured data (qualitative or textual data). VA appears to be gaining traction with practitioners such as IBM, SAP and Boeing as a method of making big data-driven analytics more accessible to the people empowered to make better business decisions. "Visualization is so compelling because our brains are really pattern-matching machines," said Noah Iliinsky, a visualization expert with the IBM Research Center for Advanced Visualization. "There's a huge amount of data you can bring in, and the brain has a great capacity for pattern matching and pattern recognition" (Jedras, 2013).

Visual Analytics (VA) as a proposed method of analysis to examine complex socio-technological systems.

Visual Analytics, as a method of analysis, aims to provide a synthesis of observed complex relationships comprised of facts and insights, into one or a series of images in a sense-making exercise. The cognitive process involved in sense-making is now moving from being mostly in the head, to a collaborative process that occurs partly in the head and partly in computer-based cognitive tools (Ware, 2008). Visual Analytics proposes that we combine the human and computer together as a single cognitive entity, with the computer functioning as a kind of 'cognitive co-processor' to the human brain (Ware, 2008). The computer pre-processes vast amount of information so that the human can rapidly analyze patterns and make flexible decisions. This human-computer knowledge discovery and pattern finding process is the core method employed by VA. It is sometimes described as an exploratory analysis, a spiral design process (Ware, 2008) and a visual analysis process (Keim et al, 2008). The process involves data being explored without a perceived hypothesis, through interactive, directed and undirected searches for structures and patterns, and results in visualizations that inform hypotheses about the data (Keim et al, 2008). The process reflects Shneiderman's (1996) original mantra described as "overview first, filter and zoom and details on demand", which emphasizes interaction in the data mining and data analysis tasks.

VA's initial research agenda was to design and develop methods and technologies to thwart terrorism by supporting human judgment in the prevention, deterrence and response to threats (Thomas and Cook, 2005). The research agenda panel then proposed a broad interdisciplinary effort to design, develop, and evaluate technologies to make advanced computational techniques available to human analysts through the use of interactive visualization (Fisher et al, 2011). It now involves the observation, analysis and generation of hypotheses of other complex situations involving unstructured data in different forms, languages, and cultures. Complex situations such as interrelationships inside organizations between human actors, non-human actors (technology) and networks can potentially benefit from VA. Andrienko et al (2007) offer "a simple combination of visualization with computational analysis and modeling is not sufficient for facilitating the mutual reinforcement of the abilities of humans and computers. New methods are needed, and such methods can only result from a focused cross-disciplinary research based on the achievements in the fields of geo-visualization and information visualization, human-computer interaction, geographic information science, operations research, data mining and machine learning, decision science, cognitive science, and other disciplines, so that a synergy of approaches and technologies could lay a basis for a synergy between humans and computers in solving complex decision problems."

Disciplines where VA methods have demonstrated success (Keim et al, 2010) are with marketing data, where analysts extract interesting patterns of customer activity to launch marketing campaigns or design new products and services, and process industry data from the manufacturing industry. Over the past five years, there has been a significant increase in data visualization tools, techniques and 'infographic' communication. The proliferation of web-based data visualization or visual data mining tools promise to reveal hidden patterns from datasets. These tools are often referred to as social media monitoring platforms, brand reputation dashboards and competitive analysis services. The most prominent sectors to effectively use these visual communication tools are media, marketing, industry research, and creative service companies. With manufacturing industry data, VA provides a scientific method of making sense of the very large volume of data generated by their factories, related to quality parameters, process trends, maintenance events, etc. VA methods and tools aim to solve problems by detecting anomalies and analyzing their causes that, in turn, will lead to the development of more efficient and reliable production processes, and may explain why VA is currently offered in engineering and computer technology disciplines and not in business schools.

VA integrates computational processes with interdisciplinary analysis methods such as ethnographic coding (sociology), visual language analysis (semiology), visual analysis (cognitive science), information architecture (design) and geographic information systems mapping (cartography). Ethnographers systematically sift and sort, described as 'coding and memoing', through their mass collection of fieldnotes, with the aim of transforming them into a coherent analysis about the observed social world, and then translating them for a wider audience (Emerson et al, 1995). Sociologists commonly observe our increasing reliance on visual communication, using symbols, logos and trademarks to define and communicate our identities and social worlds. The 'visual language analysis' process seeks to examine the semiology of graphics in order to facilitate an understanding of visual language. It is based on Bertin's work (1967) which states "graphics are a set of signs that allow you to transcribe the existing relations of difference, order or proportionality amongst qualitative or quantitative data". Visual thinking author Ware (2005) offers 'visual task analysis' as a set of cognitive tasks broken down into a set of visual queries relating to the design process. Wurman (1996) sees the problems of gathering, organizing, and presenting information analogous to the problems an architect faces in designing a building that will serve the needs of its occupants. He argues that the gathering, organizing, and presenting information to serve a purpose, or set of purposes, is an 'architectural task'. He offers "I am an architect as in the creating of systemic, structural, and orderly principles to make something work--the thoughtful making of either artifact, or idea, or policy that informs because it is clear. I use the word information in its truest sense. Most of the word information contains the word inform, so I call things information only if they inform me, not if they are just collections of data, of stuff" (Wurman, 1996).

Visual analytics also involves analytic tasks for discovery, exploration and analysis that resemble a 'mapping' process. Corner (1999) suggests maps are "are constructed from a set of internal instruments, codes and techniques". He highlights Minard's (1885) 'carte figurative' of Napoleon's battle in Russia as an elegant example of a complex amalgamation of facts and interrelationships between people, locations, events, places, time, and weather (Corner, 1999). Corner argues that maps are less about meaning and more about actions and effects. Like VA, he focuses on the creative activity of mapping (or analytic task setting) and not in the finished artifact (data visualization), and proposes an approach to modern cartography that integrates social, cognitive and critical dimensions. He suggests that maps are in-between the virtual and the real, they gather and show things presently invisible, incongruous or untimely, and they harbour enormous potential for the unfolding of alternative events (Corner, 1999). MacEachren (1997) a cognitive geographer, propose that all mapping is considered a form of visual communication, in that it facilitates thinking, problem solving and decision making. He and Kraak (1997) suggest new definitions of visualizations are linked to specific ways computer technologies facilitate the process of "making visible, the invisible, in real time". Thus, it is through a mapping process (Corner, MacEachren et al), with its original purpose of exploration, discovery and enablement, where VA is well positioned as a method to examine and analyze the complex interrelationships of socio-technological systems, such as innovation intermediaries.

Socio-technological systems are described as systems which include technological, human and organizational components (Berkout et al, 2004). For this paper, we focus on innovation intermediaries are one example of a socio-technological system. Innovation intermediaries, as a subgroup of intermediaries, have been studied as knowledge brokers (Howells, 2006), bridgers (Bessant and Rush 1995), infomediaries (Hagel and Rayport, 1997), innomediaries (Sawhney et al., 2003), and as cultural intermediaries (Bourdieu, 1984). They are most commonly referred to as knowledge brokers or agents, however some have evolved as third parties that mediate between customers and companies (infomediaries) and as bridgers connecting companies to current and potential customers exclusively over the Internet (innomediaries). Daziel (2010) describes them as "organizations or groups within organizations that work to enable innovation, either directly by enabling the innovativeness of one or more firms, or indirectly by enhancing the innovative capacity of regions, nations, or sectors". The incubator-intermediary offers entrepreneurs the cooperative and competitive environment through public-private relationships that isolates them from traditional industries – created by the unique knowledge and composition of the social system within a specific intermediary. Their networks are considered soft infrastructures that combine technological, institutional and economic systems (Hargadon, 2002). Their ongoing interaction is with institutions inside communities and in physical, virtual and interpersonal terms. Considering these intermediaries reflect complex human, technological and organization systems, VA offers a new socio-technological and socio-cultural method of analysis.

A proposed typology of VA methods and tools to examine, analyze and visualize innovation intermediaries and their innovation processes.

Thomas (2005) proposed that the VA method "detects the expected and discovers the unexpected" through computation algorithms that find was they are tasked with finding and the human's ability to discover hidden patterns. Innovation intermediaries are complex systems comprised of interrelationships between humans, processes and networks that are dense and not all visible. As agents or brokers of innovation processes between two or more parties and they play a critical role in regional and national economic development. Therefore, collecting data and making sense of their processes and impact through analytic methods should be a priority for researchers, policy makers and industry leaders.

The academic discourse and industry reports on these intermediaries and their innovation processes provide an extensive corpus for analysis. Visual analytics does provide a method to review, explore and interpret large data sets that one's brain cannot process all at the same time. It also offers a suite of sophisticated analytical tools with appropriate interactive visual interfaces for discovering relationships, synthesizing knowledge, and making informed decisions. As an interdisciplinary approach, VA aids in perceiving patterns and deriving knowledge and insight from them, combining the art of human intuition, the science of mathematical deduction and the computer's processing power. However, it is important to select the right VA tools that will facilitate the discovery of the hidden, weak, or sometimes missing relationships while considering the entire context of the intermediary environment.

Intermediaries are comprised of people who make decisions in time and space every minute of the day. Most of their decisions and actions depend on where they are and when and commonly involve other people and significant elements about the situation that surrounds them. In the spatial domain, it is important to acknowledge 'the first law of geography' stating that "everything is related to everything else, but near things are more related than distant things" (Keim et al, 2010). Spatial structures are complex regardless of geography. Every location has some degree of uniqueness relative to the other locations and is affected by natural or artificial barriers. Spatial relatedness between things may also depend, not only on their distance (proximity) but also on direction. Temporal structures have a hierarchical system of granularities, including seconds, minutes, hours, days, weeks, months, years, centuries, and so on. They are also complex since they have additional dimensions that include ordered time (linear or cyclic), branching time (comparison of alternative scenarios for planning or prediction), and multiple perspectives (varying points of view of observed facts) (Keim et al, 2010). It is impossible to account for all diverse factors affecting spatial and temporal dependence in developing fully automatic methods for analysis. Instead, VA techniques may allow the analyst to see where and how the effect of the first law is modified by particular local conditions and to make necessary adjustments in the analysis, such as by varying parameters of analytical methods or choosing other methods. It is important to acknowledge that the analysis will not be 100% accurate, as real world scenario data is not 100% perfect.

The map is a simple tool that helps people orient themselves in geographical space and gain an understanding of events and evolving phenomena and to make discoveries (Keim et al, 2010). More complex problems, involving interrelationships and heterogeneous processes within global networks, require more sophisticated maps generated from advanced computational tools. Geovisualization activities provided by VA through interactive tools, can facilitate cross-disciplinary communication and collaboration (MacEachren et, 1997). Thus, to examine geo-based innovation intermediaries and their innovation processes, mapping analysis tools focused on spatio-temporal data will be identified from the VA suite. Below is a table listing of visual analytics tools commonly used by VA researchers and practitioners:

Visual Analytics Methods and Tools	Description
IN-SPIRE	IN-SPIRE™ is an information visualization software developed by Pacific Northwest National Laboratory. It analyzes a multitude of text files and determines key topics or themes in each to create a signature for each document in the collection. IN-SPIRE's two main visualizations display representations of the documents in which those with similar or related topics appear closer together. The Galaxy visualization uses the metaphor of the stars in the night sky with each star representing an individual document. The ThemeView™ visualization uses a 3-dimensional terrain map display to provide a high-level overview of the data. Source: http://in-spire.pnnl.gov/
Jigsaw	Jigsaw is a visual analytics system that explores, analyzes and makes sense of document collections. Its objective is to help analysts reach more timely and accurate understandings of the larger stories and important concepts embedded throughout textual reports. It focuses on presenting the identifiable important entities (people, places, organizations, etc.) and their direct or indirect connections. Source: http://www.cc.gatech.edu/gvu/ii/jigsaw/
KNIME (Konstanz Information Miner)	KNIME is a modular data exploration platform that enables the user to visually create data flows (or pipelines), selectively execute some or all analysis steps, and later investigate the results through interactive views on data and models. Source: http://www.knime.org
ManyEyes	ManyEyes is a web-based tool from IBM used for a social data analysis. It supports unstructured text data sets and offers a simple and intuitive interface for a suite of interactive visualization tools. Many Eyes' visualization techniques include word clouds, tag clouds, word trees and phrase nets. It is no longer available for public access.
Omniscope	Omniscope is a visual analytics tool which enables analysts to cover all stages in the visual analytics process; from sourcing data, through visual transformation, matching, combination, exploration and discovery, all the way to interactive visual presentation of results. Source: http://www.visokio.com/omniscope
Qlikview	Qlickview is a business intelligence and data visualization tool that's designed to make the creation of ad-hoc reports and dashboards, from existing data, quick and simple.d Source: http://www.qlik.com/
Rapidminer	Rapidminer is an environment for machine learning and data mining tasks, which allows the user to create data flows, including input and output, data pre-processing and visualization. It also integrates learning schemes and attribute evaluators from the Weka learning environment. Source: http://rapid-i.com/
Spotfire	Spotfire brings the power of visualization-based data discovery to everyone in your organization. With Spotfire, you can instantly visualize, interact with, and share data so you can spot opportunities and risks buried in the data before anyone else. Source: http://spotfire.tibco.com/discover-spotfire
Tableau	Tableau is a popular VA tool that helps people see and understand their data as information is presented in consistent, easily-digested forms that suit a wide of end-user applications. Source: http://www.tableausoftware.com/public/
VizTree	VizTree, a time series pattern discovery and visualization system based on augmenting suffix trees. VizTree visually summarizes both the global and local structures of time series data at the same time. In addition, it provides novel interactive solutions to many pattern discovery problems, including the discovery of frequently occurring patterns (motif discovery), surprising patterns (anomaly detection), and query by content. Source: http://www.cs.gmu.edu/~jessica/viztree.htm
VUE (Visual Understanding Environment)	VUE is a free open source mind mapping and data visualization software developed by the Academic Technology group at Tufts University in Boston. VUE offers a range of functions such as tagging of nodes and of relationships, support for images, videos, and other objects within the mind map structure, and the ability to import and analyze datasets using semantic mapping. It also functions as an Powerpoint-style presentation tool, allowing users to define "presentation pathways" on top of the mind map structure, and to create presentation-style content that is associated with the mapped concepts. Source: http://vue.tufts.edu/
Weka (Waikato Environment for Knowledge Analysis)	Weka is a collection of machine learning algorithms for data mining tasks, which allows the user to create pipelines in order to perform data pre-processing, classification, regression, clustering, association rules, and visualization. It is an open source code developed in Java. Source: http://www.cs.waikato.ac.nz/ml/weka/

Conclusion

To understand innovation intermediaries and their complex socio-technological and socio-economic systems, researchers require analysis and visualization tools capable of examining the interrelationships of phenomena that shapes and informs their decisions and economies. The volume of organization-based data, analog (i.e. physical events, observations, etc) and digital (i.e., emails, photos, files, music, movies, etc) is rapidly increasing. Visual Analytics (VA) offers a method to analyze the vast amount of data generating from these intermediaries and visually distill it down to valuable and relevant information leading to insight (Keim et al, 2008). Emerging from the Internet-based systems, VA and its tools are positioned to engage governments, academia and industry in the visual analytic process to help make sense of their data. With the right tools, it might be possible to uncover a perspective that a politician, consultant or academic researcher did not plan for.

Cook (2013) suggests the increase in visual representations, data visualizations or information graphics is based on technology and psychology -- the technological advance of data accessibility through computer processing power and the Internet, in combination with human need for synthesized information. He proposes that information visualizations are the 'new cartography', developed by artists, journalists, designers, researchers and data scientists, those who seek to inform others of 'where they are' and 'where they might be going'.

Through VA's scientific process and tools, the innovation process inside an intermediary context can be mapped and visualized for broad interpretation. VA and its associated tools may be able to interpret meaning from the economic and political world that shapes the creative industries and the innovation intermediaries within it. Visualization may function as a more accessible way to engage creative industry citizens by breaking through the intimidating amounts of textual and numerical data. Expressive and effective visualizations offer an alternative to the numerically intensive economic visualizations typically offered by government and industry consultants. To understand the current creative economic climate, one must begin to make sense of the language, values and motivations of all those involved in the building and growing of a region's innovation intermediaries.

VA literally "maps the connection between different alternative solutions, leaving the opportunity for the human user to view these options in the context of the complete knowledge generation process and to discuss these option with peers on common ground" (Keim et al, 2008). VA is considered a method of mapping, where three types of spaces that can be conceivably mapped: (1) the information space (finding patterns in large quantities of data): (2) the physical space (orienting the body to the physical environment); and, (3) the social space (representing relationships between people). Broadly speaking, therefore, VA as a method of mapping can be considered a process that determines how objects, or entities, are related to each other by representing them on a conceptual field (Abrams and Hall, 2005). Maps, as geo-visualizations, have demonstrated their value in reflecting spatial contexts and making problems visible, "so as to engage the most powerful human information-processing abilities, those associated with vision" (MacEachren, 1992).

In summary, visual analytics' goal is to create tools and techniques for people to effectively and rapidly detect, discover and synthesize insights (Keim et al, 2008). VA proposes a new interactive and interdisciplinary approach to study, measure and predict human behaviour, translating data into knowledge for firms, governments and society. Through its scientific measures, human-computer interfaces and data visualizations, VA "might best facilitate the cognitive processes of analysis and decision-making" (Fisher et al, 2011). For socio-technological systems researchers, VA offers an integrative framework to collect, connect and arrange quantitative and qualitative data, and insightful knowledge artifacts, as visualizations. The knowledge artifacts generated from this VA method should inspire more research studies on analyzing complex socio-technological systems, such as innovation intermediaries.

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