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Interactive Visualization for Interdisciplinary Research

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Abstract

Studies show that many multi-scalar research problems cannot easily be addressed from the confines of individual disciplines for they require the participation of many experts, each viewing the problem from their distinctive disciplinary perspective. The bringing together of disparate experts or fields of expertise is known as interdisciplinary research. The benefit of such an approach is that discourse and collaboration among experts in distinct fields can generate new insights to the research problem at hand. With this approach comes large amounts of multivariate data and understanding the possible relationships between variables and their corresponding relevance to the problem is in itself a challenge. One of the most valuable means through which to comprehend big data and make it more approachable, is through data visualization. This paper presents a trial to encompass an interdisciplinary research centers collaborators, experiments, and results, and represent them simultaneously through the use of a high-resolution visualization. Multiple studies on how best to visualize the multivalent parameters of interdisciplinary work are discussed, highlighting how the use of an interactive data-driven documents (D3) visualization is proving very useful in managing and analyzing the interdisciplinary work of the center in the pursuit of common research goals.

Keywords: Interdisciplinary, interactive visualizations, visualization techniques, knowledge discovery, web interface

1. Introduction

Studies show that a single discipline is not solely able to adequately address certain multi-scalar research questions in a comprehensive manner [1,2]. In order to answer complex questions, solve complex problems, and gain coherent understanding of complex issues interdisciplinary collaborations were formed. This trend has been driven by a rise in funding for multidisciplinary projects [3]. Each expert conducting his experiment will produce a noteworthy amount of data. Sharing these results transparently within the interdisciplinary cohort is key for the participation of many experts, each viewing the problem from their distinctive disciplinary perspective potentially leading to the emergence of novel answers. The presence of multiple data sets and large numbers of elements add to the complexity. An interdisciplinary concept consciously integrates separate disciplinary data, concepts, theories, and methods to produce an interdisciplinary understanding of a complex problem or intellectual question.

There is a need for sophisticated analytic systems which enable large-scale, interactive, and insightful analysis. These analytic systems, which use the computer's ability to process large-scale data, integrate the human through the use of visual analytics [4]. In an interdisciplinary context the need to reveal relationships between constituents presents a complex representational problem. A successful visualization can make the relationships between datasets comprehendible, offering a shorter route to help guide the decision making process and become a tool to convey information critically [5]. Studies show that the difficulty of interdisciplinary work is often disciplinarily in nature, in that a discipline is seen as an identity or boundary condition of specification not differentiation. In order for interdisciplinary work to occur such boundaries or stereotypes need to be broken. To help break these boundaries and allow researchers to better understand how their knowledge can enhance the interdisciplinary process by assisting in the completion of a holistic evaluation of an interdisciplinary problem, studies in this area suggest the need to visualize and diagram interdisciplinary practice [6]. This paper outlines how our study of visualizing interdisciplinary work experienced limitations with static representation and, to be truly actionable addressed interactivity to overcome this shortfall of static visualizations. Our approach, through the design of a web-based user interface, produces an aesthetically pleasing, easy to use, understandable, meaningful, and approachable data visualization which facilitates a deeper multilevel and multi-focus insight to the analyst through simultaneous analysis of datasets in their overall context.

2. Context and Background

2.1 Interdisciplinary Research Approach

"The real world research problems that scientists address rarely arise within orderly disciplinary categories, and neither do their solution" [7].

The concept of interdisciplinary studies is not a new phenomenon. Before the enlightenment a division between the arts and sciences was unintelligible [8]. For example in the fifteenth and sixteenth centuries, Leonardo da Vinci was known as both a scientist and artist. During the Renaissance to make such distinctions between the two disciplines (i.e. the arts and the sciences) was meaningless. The revival of interdisciplinary thinking is a reaction to the belief highlighted by C.P. Snow in the mid-twentieth century that considering our world from a single viewpoint could not lead to answers which would be fruitful for all of society [9]. Snow was addressing the notion that in 1950s Britain, society, the educational system and intellectual lives were characterized by a clear divide between two cultures, that of humanities or the arts and the sciences. Although focusing on British society, the Rede Lecture he gave in 1959 at Cambridge University, titled "The Two Cultures", sparked much discussion in western civilization where the split in humanities and scientific disciplines was a common practice. Today academia is still comprised of disparate and specific areas of study, however there is recognition for the need of interdisciplinary studies, especially in tackling specific problems of a multifarious magnitude. The argument made by Snow was that there is danger in

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one discipline becoming extremely dominant or inaccessibly recondite, and this danger is particularly relevant when trying to solve world problems. One such multifaceted, global problem is that of environmental sustainability. To tackle this problem, which has economic, social, cultural and environmental ramifications, an interdisciplinary response is called for [10].

The Center for Architecture Science and Ecology (CASE) is an interdisciplinary research center encompassing many fields of research and industry within *The Two Cultures* of humanities and sciences (including but not limited to sciences, arts, social sciences, industry, technology, architecture, computer science, biochemical science, chemistry, mechanical engineering, data analysis, communication and media, environmental economics, microbiology, material science, cognitive science, epidemiology and medical science). CASE's goal is to accelerate the translation of scientific discoveries into the design of buildings and urban environments which are capable of harnessing local ecological energy, and integrating better with both human and natural systems. CASE looks at the built environment from an ecological viewpoint. From this perspective one can realize that the interconnections which make up our cities and built ecologies must be characterized. In a built ecology this includes the interconnection of science and culture in a spatial temporal network. CASE's interdisciplinary approach and thinking, allows for the characterization of such vast and complex relationships. It is within such a framework that we can begin to look at the impacts and implications of transformations to our built environments and how to approach world problems such as achieving environmental sustainability. The visualization typologies adopted by CASE to explain these complex relationships between the multiple collaborators, their research experiments and their model attributes will be explained further in Section 2.2. They aim to support each collaborator in visualizing the significance of his/her research on the other disciplines involved in this interdisciplinary work, hence assisting in the realization of a common goal.

2.2 Related Work

The use of diagrams in formal logic reasoning has generated a great deal of interest in recent years due to the need to visualize complex logic problems that are difficult to understand. The visualization of complex datasets is an increasingly important part for interdisciplinary research. Many experiments involve the integration of multiple datasets to understand complementary aspects.

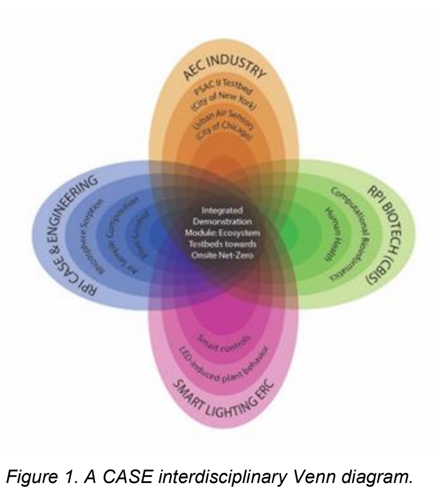

Figure 1. A CASE interdisciplinary Venn diagram.

Venn diagrams, named after John Venn (1834–1923), who used diagrams of overlapping circles to represent propositions, are commonly used in set theory to visualize the relationships between different sets [11]. The familiar three circle Venn diagram is usually drawn with a three-fold rotational symmetry. Venn diagrams can be defined as diagrams that use simple geometrical shapes such as circles and ellipses to display all 2n -1 possible areas created by the interaction of n sets. Venn diagrams are increasingly use due to their familiarity, ease-of-interpretation, and graphical simplicity. The use of simple geometrical shapes reduces figure complexity and size relative to space-consuming tables or network layouts (see Figure 5). Additionally, if some intersecting or non-intersecting areas in a Venn diagram do not exist, another class of diagrams called Euler diagrams [12] may be more desirable. Euler diagrams are equivalent to Venn diagrams when all intersecting and non-intersecting areas exist. However, areas containing zero elements are shown on Venn diagrams (by definition), whereas Euler diagrams show only non-zero areas. In many cases, Euler diagrams further reduce figure complexity, increase graphical accuracy and improve overall readability relative to Venn diagrams.

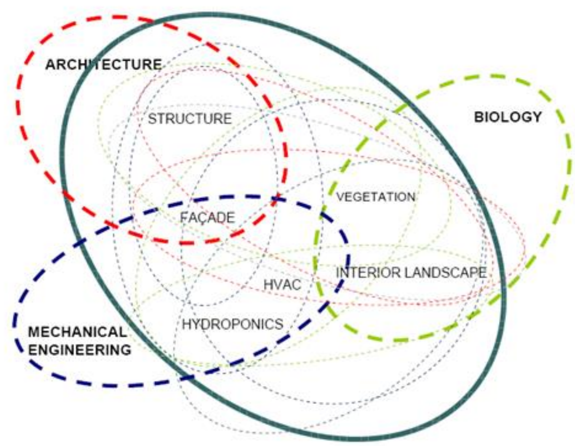

Figure 2. A CASE interdisciplinary Euler diagram.

Circos (see Figure 3) is one of the successful application widely adopted by the biological scientific community to visualize genome data [13]. This visualization tool employs a circular layout in order to simplify the display of the relationships between pairs of positions by the use of various graphical elements, including links and heat maps. Circos is efficiently applied to the exploration of complex relationships within large data sets. Circos was created as a tool not only to draw data but to help make data look beautiful. The circular form is helping to create a diagram which is a more successful compact one than the linear layout which is in most of the time more efficient in delivering information. It is easy to plot, format and layer your data with Circos.

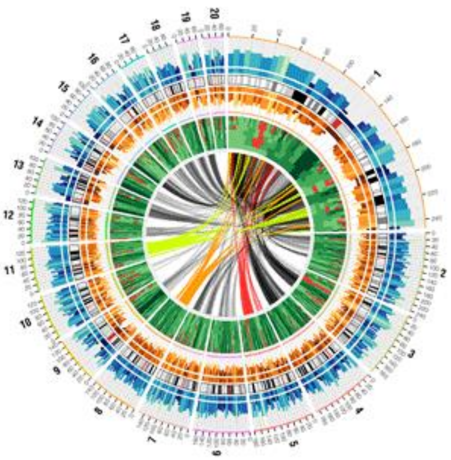

Figure 3. CIRCOS circular diagram (credit Circos.ca)

A large variety of parameters are customizable, helping creating the image that best communicates the data. Circos is a very powerful tool; however it was designed to manage a wide variety of analyses, and this flexibility leads to rather complex handling.

CASE has used both Venn (see Figure 1) and Euler diagrams (see Figure 2) to explain the relationships between different disciplines in each research topic and the interaction between different schools at the institute. These diagrams are successful to explain the relationships on a simple or specific level however, their limitation arises through their static nature. They tell us one piece of information about a condition. We are interested in moving towards a move dynamic framework that explains not only the relationships between entities but also the significance of each entity in the research question at hand. As we move towards more integrated research solutions these static diagrams are not enough. In order to achieve more synchronized and multilevel visualizations we chose to work with Data-Driven Documents (D3) [14]. The D3.js library was selected for its flexibility and ease of use in producing dynamic, interactive data visualizations for web browsers.

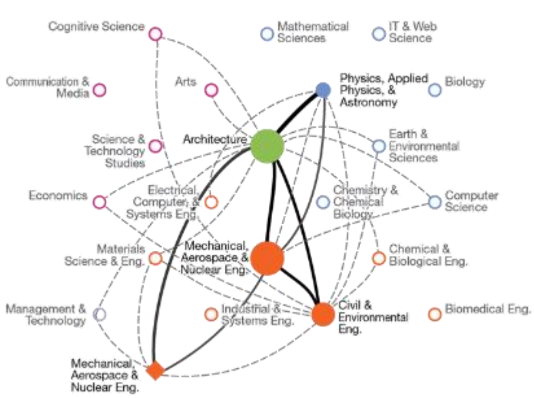

Figure 4. A CASE interdisciplinary network diagram.

In order to visualize the climatic conditions (the weather file) CASE adopted the circular diagram to visualize a climatic clock which helps to understand the cyclic behavior of the seasons. The climate clock is a diagram which represents the weather of a specific location (in this case New York). It uses EnergyPlus Energy Simulation Software TMY3 [15] weather data to generate the climate clock model. The clock, starting at the center and radiating out, has the potential to show the following: the daily dry bulb minimum temperature; the diurnal swing or apparent temperature; the dry bulb maximum temperature; the ASHRAE comfort zone; a variable climate specific comfort zone; the relative humidity; the wind direction and speed; the direct normal radiation and the diffuse horizontal radiation. Representing all of this data on one clock results in a powerful tool which allows one compare and analyze the weather data of a particular month or day simultaneously. It also clearly illustrates the annual climatic trend patterns of the specific location. Understanding the climate data allows decisions to be made in order to maximize on available resources [16].

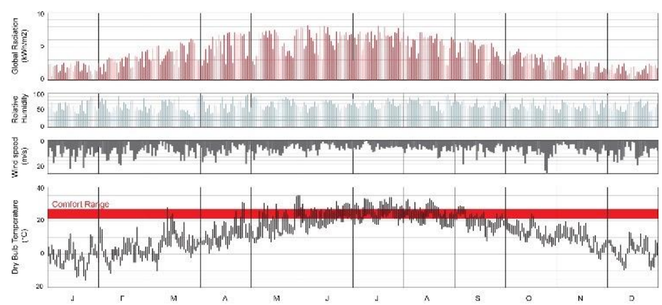

Figure 5. A CASE linear weather data diagram.

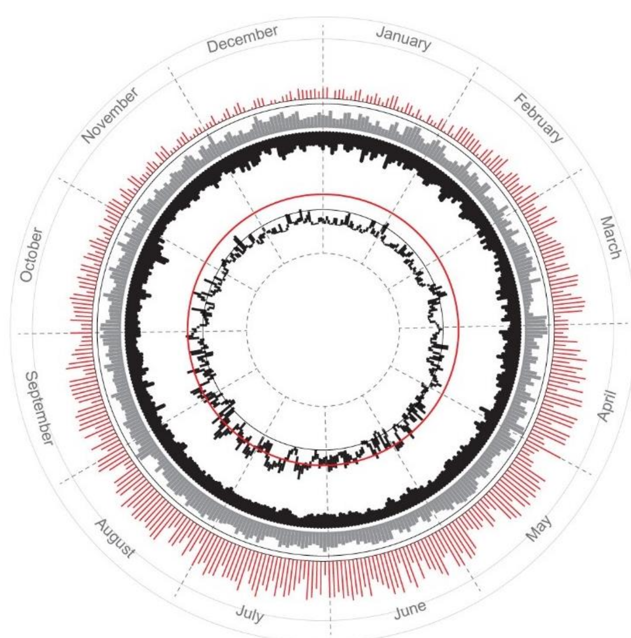

Figure 6. A CASE Climate Clock diagram.

2.3 Data visualization conceptual approach and knowledge discovery

Data visualization techniques can be classified into geometric or symbolic as well as static or dynamic [17]. Like all visual analytics, the starting point is to examine ones data. To achieve a multilevel visualization of our interdisciplinary research, we highlighted the need to clearly identify the relationships between our collaborators, the experiments being carried out and the model attributes of each experimental model. Our raw data has been complied into datasets which focus on collaborators, experiments, model attributes and sorts these datasets into subsets via specific projects and research questions. The data we have is based on relationships, hence our choice of a symbolic visualization technique. Where geometric techniques typically map data to axes such as scatter plot, lines, surfaces or volumes, the symbolic technique is based on relationships. Symbolic visualizations primarily represent non-numeric data, such as networks or in our case clusters and bundles. [18].

2.3.1 Data-driven Documents (D3) Layouts and Conceptual Design Approach

The D3 bundle and cluster layouts [14] were used. The bundle layout stretches paths between entities to represent relationships. This connected paths conceptually relays the message of interdisciplinary relationships between collaborators, experiments and model attributes which we wish to portray. The cluster layout allowed us to specify the root nodes of Collaborators, Experiments and Model Attributes and arranged the array of nodes associated with those specified root nodes in a circular structure. The bundle links which illustrate the relationships at the center of the visualization are the meeting of two root nodes. We specifically did not show these nodes in the center of the circle as conceptually we wished to visualize a less explicit hierarchical construct which followed more an ecosystem logic than a mechanical top down paradigm. The combination of the bundle layout, which implements Danny Holten's [18] hierarchical edge bundle algorithm, and the cluster layout was inspired by Jason Davies "D3 Dependencies" visualization [19] as well as examples from the Guardian, namely an article on "Violence and guns in best-selling video games" [20]. These visualizations clearly classify the categories of entities and show links between the entities of different categories. Conceptually our representation seeks to characterize an ecosystem logic illustrating how the interdisciplinary team works.

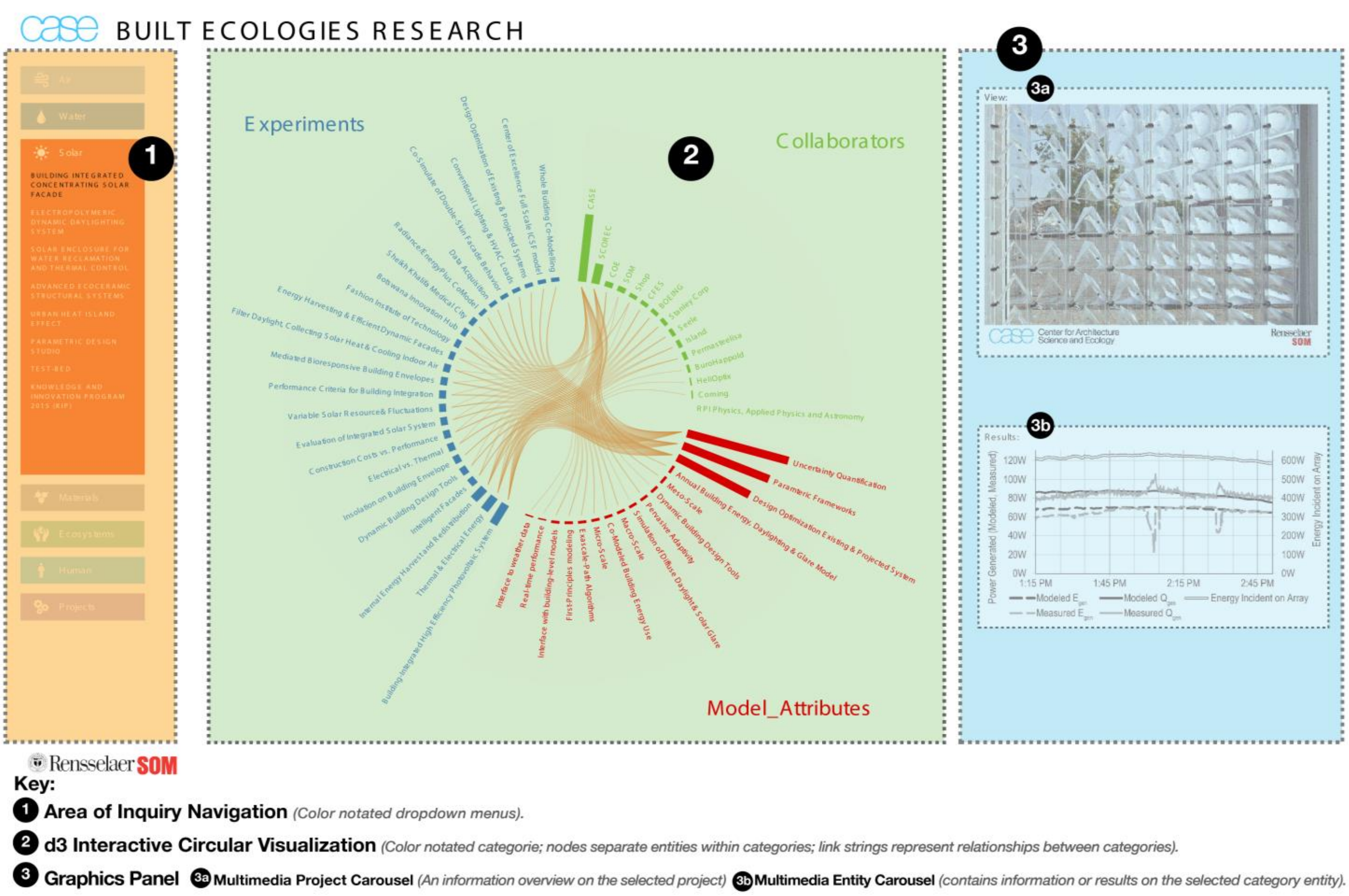

Figure 7. Layout of CASE web interface is organized as follows 1) Area of Inquiry Navigation - color noted dropdown menus; 2) d3 Interactive Circular Visualization - color noted categories, nodes separate entities within categories; link strings represent relationships between categories; 3) Graphics Panel - 3a) Multimedia Project Carousel - provides an information overview on the selected project 3b) Multimedia Entity Carousel - contains information or results on the selected category entity.

Ecosystems form complex networks and have embedded hierarchy. Therefore, similar to an ecosystem representation we show relationships between entities and by the length of the node-bars, highlighting the frequency of links or relationships the entity has, we set up a synchronized and ingrained hierarchical visual language.

3. CASE Interactive Visualization and Web Interface Design

Section 3 outlines the layout of the interactive visualization and web interface, describes the intentions behind its design and highlights the role of interactivity. Section 3.2 explains the goals and numerous applications of the design namely to facilitate a multi-scalar and multi-level data analysis, to allow easy navigation by the user, to support interdisciplinary learning and presentation and to create a framework for data collection, storage and display.

3.1 Visual Representation: Layout of the Web Interface

The layout of the web interface (see Fig. 7) includes:

1. dropdown menus for navigating areas of inquiry on the right of the page,
2. a d3 circular network visualization in the center of the page,
3. a graphic panel for multimedia information on the left of the page.

3.1.1 Navigating Areas of Inquiry

Dropdown menus to the right of the page show the research areas of inquiry and also list interdisciplinary projects specific to CASE. When the user selects an area of inquiry e.g. *Air*, the dropdown menu shows specific projects or research investigations within this area. As one of these subcategories of *Air* is selected a filtered circular network visualization appears which shows the relevant collaborators, experiments and model attributes to that chosen sub category. Using this method we can have multiple projects and investigations accessible from the same framework and they can be represented in a similar visualization format (i.e. the circular network visualization) allowing for comparable data analysis.

3.1.2 D3 Circular Network Visualization

The web interface we have designed uses a d3 visualization to represent the circular network connections in the center. This circular network shows the relationships between three categories - Collaborators, Experiments and Model Attributes. Each entity in these categories has a node. The length of the node indicates the frequency or number of links that that particular entity has with the other category entities. The links between particular entities in each category are represented via paths between each which are highlight once hovered over by the user. The trajectory of the link paths change in color between the categories, highlighting the relationship of the two entities within the categories selected.

3.1.3 Graphic/Multimedia Panel

The left of the page contains a graphic and multimedia panel. This panel appears when an area of inquiry or project is selected. The panel is divided in two. The top panel has a carousel of animation and images which represent the entire project - allowing the framework to adapt to a presentation tool if necessary. The bottom of the panel has a carousel of multimedia (i.e. animations, images, text) which are used to explain the entity selected; e.g. if an experiment on the visualization is selected information on this experiment is shown.

3.2 Application

The visualization framework has multiple applications:

1. It is a tool for navigation and assisting interdisciplinary learning by team members,
2. a presentation tool to explain CASEs interdisciplinary approach and
3. a framework for team members to add experimental and model attribute data such as experimental information and results.

The design of the web interface took these applications into account. A user navigates this web interface by first choosing an area of inquiry to investigate. The dropdown menu facilitates this choice and allows subcategories within that area to be chosen. Once chosen a d3 circular visualization is generated which shows the relevant categories. On the graphic panel the top carousel appears showing all additional information relevant to the project via a multimedia platform. A user selects an experiment by hovering over it which activates the tooltip or by clicking it. Once selected we get additional information about that particular experiment in the bottom carousel of the graphics panel. The goal of such an application is to provide a multilevel visualization. Studies have shown that such multilevel approaches succeed in providing a better position for data analysts to diagnose problems and deduce significant solutions [21].

3.2.1 Navigation and Interdisciplinary Learning

When used as a tool for discovery the dropdown menus allows a user to navigate the areas of inquiry in order to explore the network relationships for each project. Our web interface can support interdisciplinary learning, an important aspect of any interdisciplinary research [22]. The d3 circular visualization highlights the experiments that certain collaborators are carrying out, showing the entire team of collaborators working on a specific experiment. It identifies the model attributes of that experiment. In an interdisciplinary team, as well as the convergence of disparate disciplines and ways of thinking in the pursuit of a common goal, the willingness for each member to learn the concepts of each other's disciplines is also critical in transcending disciplinary boundaries. This allows for a learning process that challenges reductionist disciplinary knowledge and promotes collaborative and emancipatory research [23, 24]. This tool can begin to facilitate this knowledge discovery, for example, by seeing similarities or differences in experimental methodologies and understanding why that particular approach was taken.

3.2.2 Presentation Tool

When used as a presentation tool, the area of inquiry that the presenter wants to focus on can be selected and the relevant images to that experiment can be shown simultaneously. Using the carousels functionality the presentation tool can be enhanced by scaling up the images and presenting them at full screen.

3.2.1 Framework for Data Collection and Display

When the analyst chooses an experiment – he/she knows the project the experiment is related to, the collaborators involved and the associated model attributes as well as the scale(s) of the experiment. The tooltip is used to receive more information on the project, and by clicking on an experiment one sees an image or multimedia display of the experiment in the multimedia entity carousel. For more detailed information on the experiment one can select the multimedia entity, and for greater clarity of that particular dataset, scroll through more data on the experimental makeup at a larger scale. Therefore showing the experimental methodology and the results of experiments is crucial to this aspect of the visualization. Going forward, team members can access the experiment multimedia entity carousel of the graphics panel and upload their results. The method of visualizing these results can be static (images), animated or interactive depending on the choice of the team member and the most relevant technique. The idea is to develop an entire framework for visualizing interdisciplinary work. With multiple collaborators at play the framework must be easily accessible by the entire interdisciplinary team. It has to be easy to plug into with their results and datasets and it has to be easily navigable so it becomes a tool for exploration and discovery at a higher level.

3.3 Interactive

The other key characteristic at play in our visualization is the use of interactivity, namely a dynamic display technique. The power of interactivity is multifold: it allows for user engagement; it simplifies complex data sets to facilitate clarity of specific data relationships; it enhances knowledge discovery as moments of serendipity unearthing occur; and it makes for a more complex layered representation of the data that can be navigated through steps in order to retain clarity.

4. Conclusion

Through this paper we have outlined the difficulties faced by interdisciplinary research including the ability to bring disciplines or disparate fields of research together. Once an interdisciplinary team has been established their work can produce multiple disparate datasets which must be comprehendible by the entire team. We looked at studies which highlighted the need for visual communication as a means of clarity and integration for the whole team. We used the interdisciplinary work of CASE as a means to explain how one goes about visualizing such communicative representations. We have described how an investigation into visualization typologies which best suit the representation of interdisciplinary design have led us from more static traditional methods such as the Venn diagram, to an interactive visualization on a web interface which can offer many more benefits to an interdisciplinary team other than solely representing the process at hand. Such benefits included the use of the visualization as a management tool, an area for users to upload their results feeding live information to other members of the team, a tool for knowledge discovery which can spark interdisciplinary collaboration between members and also a presentation tool. Through this paper we have highlighted the benefits of such a visualization to manage and support interdisciplinary research. The multi-level, multi-functional & multi-scalar ability of our web interface facilitates simultaneous analysis of multiple aspects of the interdisciplinary research by placing the analyst in the middle of the ecosystem of relationships and views of the entity in hand. The limitations of this method lie in the willingness of team members to participate in such a framework and the educational methods necessary to facilitate such a ramping up in knowledge. This is where strong metadata to support the back end of the visualization would help making the process more robust and automatic. Further work will look at how a clear ontology from the outset can create a symbiosis relationship with the chosen visualization typologies creating a strong framework as the basis of interdisciplinary representation, management and data collection.

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