Chapter 11
“Isms” in Visualization

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Abstract In visualization, there are many different wisdoms and opinions about why visualization works, what makes a good visualization, and how to design and evaluate visualization. Collectively these wisdoms and options have shaped a landscape of the schools of thought in the field of visualization. In this chapter, we examine various schools of thought in visualization, juxtaposing them with schools of thought in computer science and psychology. We deliberate the possibility that some schools of thought in computer science and psychology may have influenced those in visualization. Based on our observation of the development of schools of thought in the discipline of psychology, we believe that it is the empirical evidence that informs the development of theories, which are often embedded in some schools of thought. Meanwhile, empirical studies have crucial role in visualization to inform and validate postulated theories.

11.1 Introduction

The field of visualization does not really have isms, but is not short of schools of thought. In 2012, a VisWeek panel, entitled *Quality of Visualization: the Bake Off* [15], presented four different approaches to evaluating the quality of visualization, which were referred to as “four schools of thought”. Four established visualization scientists, Kelly Gaither, Eduard Gröller, Penny Rheingans, and Matthew Ward, were asked to articulate these approaches. Despite that they held a broader view than the school of thought that each was championing, they presented exquisite and persuasive cases for the four schools.

In the order when the position statements were presented in the panel, these four schools of thought are:

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$\mathbf{V1}_\mathrm{A}$ **School of A**, where A for algorithms or automation. Gröller argued: "*Let us reduce the quality of a visualization to the quality of the involved algorithm.*" "*An optimization process should automatically figure out which algorithms and parameter settings best fulfill the user defined declarations and constraints.*" [15]

$\mathbf{V1}_\mathrm{B}$ **School of E**, where E for Experiments or Empirical Studies. Rheingans reasoned: "*A little empirical evidence never hurts.*" "*Promising results from empirical studies seem to signal that a new tool might be a winner.*" [15]

$\mathbf{V1}_\mathrm{C}$ **School of M**, where M for Metrics or Measurements. Ward articulated: "*As the field of visualization evolves, more and more measures have been proposed as a means of comparing alternate visualizations or even [measuring] the effectiveness of a single visualization.*" [15]

$\mathbf{V1}_\mathrm{D}$ **School of R**, where R for Real users or Real world applications. Kelly Gaither asserted: "*Our success is measured in 'Aha' moments, and these moments are precious and rare.*" "*In my world, visualizations are never produced in isolation or the absence of domain knowledge.*" [15]

Here we use labels in the form $\mathbf{X}_i$ (e.g., $\mathbf{V1}_\mathrm{A}$ and $\mathbf{C}_\mathrm{B}$) to tag a school of thought. The main label indicates a fundamental question that is a bone of contention, while the subscript identifies a specific school of thought in the context of this question. More labels will gradually be introduced in this chapter.

In many scientific and scholarly subjects, different schools of thought were formulated by those who share some common beliefs or some opinions with a set of common characteristics. To denote such schools of thought, sets of principles, belief systems, doctrines, ideologies, or spiritual currents, as well as the related bodies of teaching, the suffix "-ism" is typically used. It derives from the Ancient Greek suffix "-ισμὸς", meaning "taking side with". Among many uses of "ism" as a suffix, all [*stem*]-ism words in this chapter fall into the category of words referring to a belief in [*stem*] or a doctrine or principle of [*stem*].

For example, in psychology, there are structuralism, functionalism, pragmatism, behaviourism, gestaltism, associationism, and cognitivism (see Section 11.4). In philosophy, there are numerous -isms. The wiktionary page, *Glossary of Philosophical Isms* [68], lists several hundreds of isms, reflecting the long history of scholarly investigations into and discourses on many aspects of our world and our mind. Such diversity reflects the advancement and maturity of a discipline.

In the following sections, we first continue our discussion on a number of major clusters of opinions, which can be considered as schools of thought. We then examine schools of thought in computer science and psychology, which are the two disciplines that the subject of visualization is most closely related. Finally we offer our observations and concluding remarks.

11.2 Schools of Thought in Visualization

In Section 11.1, we have already encountered four schools of thought in visualization. In this section, we discuss three more fundamental questions that have been the bones of contention in visualization.

11.2.1 What is Visualization for?

One fundamental question that everyone in the field of visualization cannot help ask is "what is visualization really for?" In a 2014 article published in a philosophy venue[14], Chen et al. gathered some twenty different statements offering answers to this question, including five statements in Scott Owen's original 1999 collection [45]. Recently Streeb compiled a comprehensive collection of some 120 statements [57]. Here we broadly divided these statements into five schools of thought, for which we improvise some "ism" terms.

V2$_{\text{A}}$ **Insightism.** Many visualization researchers and practitioners argued that the main purpose of visualization is for gaining insight from data. For example, McCormick et al. stated in 1987 [44]: "*The goal of visualization in computing is to gain insight by using our visual machinery.*" Earnshaw and Wiseman stated in 1992 [18]: "*Visualization is concerned with exploring data and information in such a way as to gain understanding and insight into the data.*" Similar statements can easily be found in numerous written documents.

Some statements presented stronger arguments, making visualization as the main source of insight, such as the statement by Hearst [30] "*Visualization has been shown to be successful at providing insight about data for a wide range of tasks.*" Others presented weaker arguments, designating visualization to an assisting role, such as the statement by Thomas and Cook [59]: "*People use visual analytics tools and techniques to synthesize information and derive insight from massive, dynamic, ambiguous, and often conflicting information.*" Note that this statement implies three sources of insight, i.e., "people" as the main source, "visualization", and "analytics" as the assisting tools.

The spectrum from strong insightism to weak insightism partly depends on the interpretation of the word "insight". In Gaither's statement for the school of R, **V1**$_{\text{D}}$, an insight is considered as a deep understanding of a complex problem, or an "Aha" moment in a complex situation. Many others define an insight in visualization as a correct conclusion inferred from viewing visualization. For example, Gomez et al. define gaining insight as tasks in the forms of "who+when+where $\rightarrow$ what", "when+where+what $\rightarrow$ who", and so on [29]. The strong insightism usually correlates with a broad or "weak" definition of insight, while the weak insightism usually correlates with a narrow or "strong" definition of insight.

V2$_{\mathrm{B}}$ **Cognitivism.** Using the term borrowed from psychology, we outline a school of thought that focuses on the perceptual and cognitive benefits of visualization. Perhaps the strongest statement is that by Spence [56], who asserted: "*Visualization is solely a human cognitive activity and has nothing to do with computers.*" A number of visualization researchers offered answers to the question what visualization is for by articulating that visualization can enable *seeing the unseen* [44], *maximizing human understanding* [45], *amplifing cognition* [12], and *helping think* [22].

While the fundamental idea of cognitivism in visualization is not in anyway the same as that of the cognitivism in psychology, this school of thought does reflect the essence of the fundamental idea in psychology, i.e., cognition impacts the behaviour of visualization.

V2$_{\mathrm{C}}$ **Communicationism.** Most people appreciate that visualization can provide effective aid to information communication and knowledge dissemination. Tableau, a major provider of visualization technology, stated at its website [58]: "*Data visualization is another form of visual art that grabs our interest and keeps our eyes on the message.*" "*Data visualization helps to tell stories by curating data into a form easier to understand, highlighting the trends and outliers. A good visualization tells a story, removing the noise from data and highlighting the useful information.*"

In her book *Effective Data Visualization* [20], Evergreen offered an animated answer to the question why we visualize: "*Seriously, that's the most important question to ask when creating a data visualization. It's the first thing I ask a client who sends me data for redesign. And it's the primary reason we visualize: Because we have a point to communicate to the world. We have a compelling finding to share, a big idea revealed in our analysis that need to say to people. A point.*"

V2$_{\mathrm{D}}$ **Economism.** Some visualization researchers and practitioners attempted to answer the "what for" question from some more tangible benefits of visualization, avoiding hinging an answer on a less observable and measurable benefit such as insight. For example, Bertin referred to the benefit of external memorization in his book *Semiology of Graphics* [6] as "*the artificial memory that best supports our natural means of perception.*" Friedhoff and Kiely highlighted the benefit of saving time in [26]: "*If the information is rendered graphically,*" researchers "*can assimilate it at a much faster rate.*" Ware offered a similar statement in his book *Information Visualization: Perception for Design* [65]: "One of the greatest benefits of data visualization is the sheer quantity of information that can be rapidly interpreted if it is presented well." Tufte asserted the relative benefit of visualization in comparison with statistics in his book *The Visual Display of Quantitative Information* [62]: "*Indeed graphics can be more precise and revealing than conventional statistical computations.*"

Chen et al. gave a somehow "economism" definition of visualization [14]: "*Visualization (or more precisely, computer-supported data visualization) is a study of transformation from data to visual representations in order to facilitate effective and efficient cognitive processes in performing tasks involving data. The* *fundamental measure for effectiveness is correctness and that for efficiency is the time required for accomplishing a task.*" A few years later, Chen and Golan (an economist) proposed an information-theoretic metric for analyzing the cost-benefit of human- and machine-centric data intelligence processes [13]. In the context of visualization, the metric defines the benefit as the amount of information (Shannon entropy) in the original data subtracted by the amount of information in a visualization image and further subtracted by the potential informative distortion that is mainly caused by information loss in visualization and may also be due cognitive biases, but can be alleviated by human knowledge. They considered energy is the fundamental measure of the cost, which can be approximated by time and monetary measurements.

V2$_\mathrm{E}$ **Pragmatism.** Visualization researchers and practitioners are in general open-minded as to what is visualization is really for. While the question is yet to be convincingly answered, the majority in the community focus on the utility of visualization in different application contexts. This approach echoes the school of thought of pragmatism. One example is the list of functions summarized by Marty [43]: "*answer a question*", "*pose new questions*", "*explore and discover*", "*support decisions*", "*communicate information*", "*increase efficiency*", and"*inspire*". Another list by Chen et al. [14] include functions "*making observation*", "*facilitating external memorization*", "*stimulating hypotheses and other thoughts*", "*evaluating hypothesis*", and "*disseminating knowledge*."

Many taxonomies of visualization (e.g., [11, 70, 50]) and many surveys on visualization topics (e.g., [53, 33, 61, 4, 38, 9, 37]) include "tasks" as one of the main dimensions for categorization, reflecting the typical view of pragmatism.

Having schools of thought is not in any way suggesting that the visualization community is divided. Many in the community often embrace different schools of thought. For example, the aforementioned statement by Thomas and Cook [59] is an instance of weaker insightism but it also captures a sense of pragmatism. In the book, there is also a statement: "*Visual representations and interaction technologies provide the mechanism for allowing the user to see and understand large volumes of information at once.*" This captures senses of cognitivism and economism. van Wijk presented a visualization pipeline from data to knowledge (insight) [**?**], while proposed an economic model for measuring the gained knowledge (insight) as well as the cost of visualization processes. This exemplifies the views of both insightism and economism. Stasko [**?**] made perhaps the broadest argument about the value of visualization, including contributing factors of time, insight, essence, and confidence. These four factors correspond to the arguments of economism, insightism, communicationism, and cognitivism respectively.

11.2.2 Faithfulness and Integrity vs. Embellishment and Distortion

In the field of visualization, many passionately argue that data visualization must be faithful to the data being depicted, and should not be embellished with chartjunks.

Tufte made a powerful argument for "graphical integrity" in his book *The Visual Display of Quantitative Information* [62], and coined the term *lie factor* to indicate the level of deviation of a visualization image from its source data, and the term *chartjunk* to describe decorative visual features in a visualization image.

This school of thought is widely endorsed by visualization researchers and practitioners. There are countless online blogs that repeat and reinforce Tufte's views on graphical integrity and chartjunks. Pandey et al. presented an empirical study, confirming that several types of distortion in visualization can have deceptive effects on viewers [46]. Kindlmann and Scheidegger presented an algebraic framework for defining three principles that formalize the notion of graphical integrity [36].

Whilst hardly anyone in the visualization community would support any practice intended to deceive viewers, there have been many visualization techniques that inherently cause distortion to the original data. These include logarithmic plots, metro maps, magic lenses, focus+context visual designs, color and opacity transfer functions, illustrative deformation, and so on. There might just be a hidden gap between theory and practice or between between idealism and pragmatism, until the debate about chartjunks brought the bone of contention to the fore.

The debate started with a paper by Bateman et al. [3], which reported an empirical study showing that visual embellishment could aid memorization of the data depicted. Another paper by Hullman et al. [31] proposed a possible explanation that "*introducing cognitive difficulties to visualization*" "*can improve a user's understanding of important information.*" Since the finding and the explanation represented a major departure from the widely endorsed views on chartjunks, the works stimulated much discussions in the community (e.g., [24, 23]).

In general, the question about distortion differs from that about chartjunks, though most of those who are against distortion are likely also against chartjunks. Here we treat these two questions separately in our definitions of the following four schools of thought.

V3$_\mathrm{A}$ **Essentialism.** Do not introduce any visual embellishment that is unnecessary for comprehending the data depicted.
V3$_\mathrm{B}$ **Decorationism.** Visual embellishment can be used in visualization and can bring benefit.
V3$_\mathrm{C}$ **Isomorphism.** Do not introduce any distortion that is inconsistent with the source data.
V3$_\mathrm{D}$ **Polymorphism.** Distortion can be featured in visualization and can bring benefit.

In fact, if one reads carefully some original discourses, one may find that the gaps between essentialism and decorationism and between isomorphism and polymorphism are not totally unbridgeable. On a case by case basis, most people with different schools of thought can often agree on whether an embellishment is unnecessary or not, or whether a distortion is inconsistent or not. For example, Few, who has been a champion against chartjunks, stated impartially: "*Embellishments can at times, when properly chosen and designed, represent information redundantly in useful ways, ...*" [24].

There are many other questions that are bones of contention and other clusters of opinions that can be characterized as schools of thought. For example, the necessity and usefulness of many techniques (e.g., animation, 3D visual designs, virtual reality, and so on) often attract different opinions in a manner similar to the contention between essentialism and decorationism or between isomorphism and polymorphism.

11.2.3 Human-centric Processes vs. Machine-centric Processes

In the field of visualization, regardless whether one is in favour of any particular school of thought in terms $\mathbf{V1}_\mathrm{A}$-$\mathbf{V1}_\mathrm{D}$, $\mathbf{V2}_\mathrm{A}$-$\mathbf{V2}_\mathrm{E}$, or $\mathbf{V3}_\mathrm{A}$-$\mathbf{V3}_\mathrm{B}$, everyone holds a view that human intelligence is necessary in any reasonably complex or mission-critical data intelligence processes. Here *data intelligence* is an encompassing term for processes such as statistical inference, computational analysis, data visualization, human-computer interaction, machine learning, business intelligence, simulation, prediction, and decision making.

Around 2004, a new area *visual analytics* [59] emerged in the field of visualization to develop data intelligence workflows that always have humans in the loop.

This view may not be shared by many researchers and practitioners in data mining, machine learning, and some other machine-centric aspects of data intelligence. For example, in a textbook on data mining and machine learning [69], Witten et al. wrote "*Economists, statisticians, forecasters, and communication engineers have long worked with the idea that patterns in data can be sought automatically, identified, validated, and used for prediction. ... as the world grows in complexity, overwhelming us with the data it generates, data mining becomes our only hope for elucidating hidden patterns. ... It can lead to new insights, ...*"

In a textbook on machine learning [54], Rothman wrote "*In May 2017, Google revealed AutoML, automated machine learning system that could create an artificial intelligence solution without the assistance of a human engineer. IBM Cloud and Amazon Web Services (AWS) offer machine learning solutions that do not require AI developers.*"

Today, the latter view is widely believed, which can be evidenced by many non-fictional scientific writings, such as Fry's book *Hello World: How to be Human in the Age of Machine* [27], and Frank's book *What to do when Machines do Everything* [25].

Here, we can clearly see two schools of thought about whether humans should have a significant role in any reasonably complex or mission-critical data intelligence processes:

$\mathbf{V4}_\mathrm{A}$ **Mechanism** Most, if not all, data intelligence processes can be automated using data mining and machine learning techniques. The amount of data available in this era of "big data" makes automation both necessary and feasible.

V4$_\text{B}$ **Anti-Mechanism** Any reasonably complex data intelligence workflow should always have humans in the loop, where humans' analytical capability can be enhanced using interactive visualization techniques.

We will continue this line of discussion in the next section.

11.3 Isms in Computer Science

The discipline of computer science and engineering, where the subject of visualization resides mainly, has inherited a wide-range of mathematical concepts and methods but has displayed very limited interest in most philosophical schools of thoughts in mathematics, except on the topic and machine intelligence. Johnson-Laird first outlined four postulations [34], which were discussed in detail in Penrose's book *Shadows of the Mind* [49]. Here we list these four postulations by quoting Penrose' text [49] with "ism" tags found in the literature.

C$_\text{A}$ "*All thinking is computation; in particular, feelings of conscious awareness are evoked merely by the carrying out of appropriate computations.*" [**strong AI**, **hard AI**, **functionalism**, **mechanism**, **computationalism**].

C$_\text{B}$ "*Awareness is a feature of the brain's physical action; and whereas any physical action can be simulated computationally, computational simulation cannot by itself evoke awareness.*" [**weak AI**, **soft AI**].

C$_\text{C}$ "*Appropriate physical action of the brain evokes awareness, but this physical action cannot even be properly simulated computationally.*" [**anti-mechanism**].

C$_\text{D}$ "*Awareness cannot be explained by physical, computational, or any other scientific terms.*" [**mysticism**].

In terms of human and machine intelligence, these four postulations exemplify four different schools of thought. Penrose has been the most prominent champions the postulation of **C**$_\text{C}$ through his two books [48, 49]. Interestingly Penrose started with his reasoning in [49] using two examples of visualization as shown in Figures 37 and 38. He pointed out that one can visually inspect the patterns shown in these two examples, and conclude that the proof can be extrapolated to the general formulations as mentioned in the captions of Figures 37 and 38. Penrose then offered a proof for the postulation [49]:

> "*Human mathematicians are not using a knowably sound algorithm in order to ascertain mathematical truth.*"

by following the reasoning strategy that Gödel used to prove his Incompleteness Theorems [28, 7], and Turing used to prove his theorem on the Halting Problem [63, 17]. This proof provided a basis for his School of Thought **C**$_\text{C}$.

In the literature, a number of authors have provided critical comments on Penrose's conclusion, while making cases for the school of thought **C**$_\text{A}$, including, for instance, the critiques by Sloman [55], LaForte et al. [39], and Berto [7].

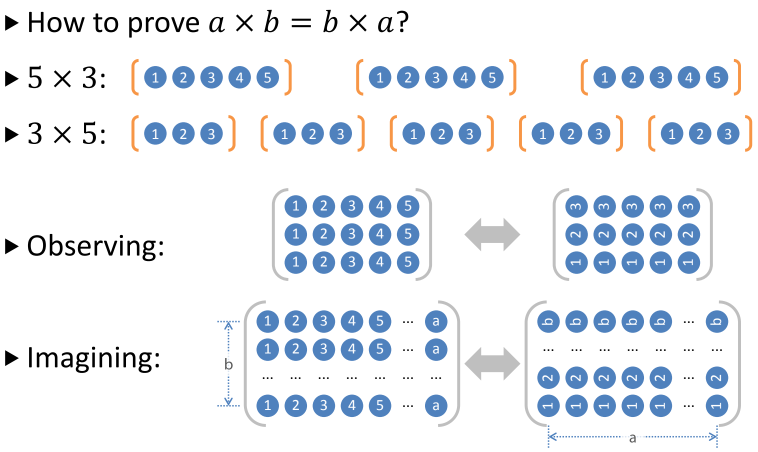

Fig. 37 This example shows that a human mathematician can make observation of the configuration of 5×3 and another configuration of 3×5 and ascertain that $5 \times 3 = 3 \times 5$. The mathematician can then make further observations for different values of a and b or imagine how the 5×3 and 3×5 configurations may be extended to different values of a and b. The combined effort of observation and imagination enables the mathematician to conclude that $a \times b = b \times a$. This figure was redrawn based on an illustration in [49]

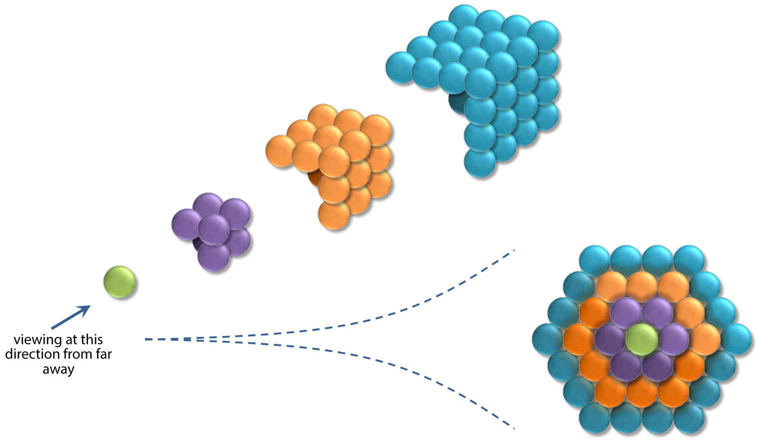

Fig. 38 Hexagonal numbers are numbers that can be arranged as hexagonal arrays: 1, 7, 19, 37, 61, 91, 127, etc. To prove a postulation that the sum of successive hexagonal numbers is a cube (e.g., $1+7+19 = 3^3$ $1+7+19+37 = 4^3$), a mathematician can visually observe the relationship between the illustrated 2D and 3D configurations and then imagine there extensions. This figure was redrawn based on an illustration in [49]

Penrose's mathematical and algorithmic reasoning can be traced back to Lucas's article [40], where he opened his discourse with:

> "*Gödel's Theorem seems to me to prove that Mechanism is false, that is, that minds cannot be explained as machines.*"

Mainzer, who is a a philosopher of science and a leading thinker on complex systems, related the discourse further back to the schools of thought in philosophy [41]:

> "*In the history of philosophy and science there have been many different suggestions like Democritus, Lamettrie, et al., proposed to reduce mind to atomic interactions, Idealists like Plato, Penrose, et al. emphasized that mind is completely independent of matter and brain. For Descartes, Eccles, et al. mind and matter are separate substances interacting with each other. Leibniz believed in a metaphysical parallelism of mind and matter because they cannot interact physically. According to Leibniz mind and matter are supposed to exist in 'pre-established harmony' like two synchronized clocks. Modern philosophers of mind like Searle defended a kind of evolutionary naturalism. Searle argues that mind is characterized by intentional mental states which are intrinsic features of the human brain's biochemistry and which is therefore cannot be simulated by computers.*"

While many in the field of visualization and beyond may not have been following these discourses, some of the schools of thought in visualization have exhibited some alignments with these four schools of thought in computer science. For example, the school of thought $\mathbf{V4}_\mathrm{A}$, mechanism, may be related to $\mathbf{C}_\mathrm{A}$, while the school of thought $\mathbf{V4}_\mathrm{B}$, anti-mechanism, may be related to $\mathbf{C}_\mathrm{C}$ or $\mathbf{C}_\mathrm{D}$. Those who sit between $\mathbf{V4}_\mathrm{A}$ and $\mathbf{V4}_\mathrm{B}$ may align with $\mathbf{C}_\mathrm{B}$.

While we do not know whether those arguing for the benefits of visualization believe that aspects of human mind may not be computational, we can reasonably assume that many of them at least hold a view that many aspects of human mind cannot be simulated by computational algorithms available today and in the near future. For example, many statements featuring insightism or cognitivism exhibit likely support for $\mathbf{C}_\mathrm{C}$, or at least a time-limited notion of $\mathbf{C}_\mathrm{B}$.

11.4 Isms in Psychology

The discipline of psychology saw the formation of many schools of thought. As early as 1927, Jastrow wrote perhaps the first survey on "isms" in psychology. A good number of books on philosophy of psychology provide a large collection of readings on the topic, which include volumes edited by Block [8] and Bermudez [5]; and books authored by Margolis [42], Botterill and Carruthers [10], Walsh et al. [64], and Weiskopf [66].

In this section, we first list a number of isms (in alphabetic order) that have been frequently mentioned in the literature, and we then describe these isms following a chronological order.

$\mathbf{PS}_\mathrm{A}$ **Associationism.** Mental connections between events and ideas (H. Ebbinghaus 1850-1909).

PS$_B$ **Behaviourism.** Study of observable emitted behaviour (I. Pavlov 1849-1936).

PS$_C$ **Cognitivism.** Understanding how people think as state transitions (J. Piaget 1896-1980).

PS$_D$ **Functionalism.** Mental operations and practical use of consciousness (J. R. Angell 1869-1949).

PS$_E$ **Gestaltism.** Study of holistic concepts, not merely as sums of parts (M. Wertheimer 1880-1943).

PS$_F$ **Pragmatism.** Knowledge is validated by its usefulness (W. James 1842-1910).

PS$_G$ **Structuralism.** Analysis of consciousness into constituent components (E. Titchener 1867-1927).

Before getting into specific ontologies of psychology, it is important to understand something about philosophy of science in psychology at various times in history, in the form of epidemiological beliefs about truth, opinion and knowledge, and how this shaped the ontologies of the day and have led to the wide range of "isms" that we find today.

Objective verification through empirical verification came about very slowly in psychology, but had its roots dating back as far as John Locke (1632-1704). Locke had promoted the idea that objective verification through our sensory experience should be sought in order to establish knowledge about the world around us, i.e., knowledge must be based on sensory experience. This forms the basis of the scientific method we have today in relation to prior reasoning, hypothesis testing and a means for falsification using validated forms of objective measurement.

In psychology, this empirical methodology to establishing knowledge was slow to be accepted in the mainstream world view, in comparison to other sciences such as physics, biology and chemistry. As a result of this slow adoption, early schools of thought (or "isms") in psychology were based on subjective methodology rather than objective empiricism. One example of such a school of thought is structuralism.

In the early 1900s, **structuralism**, which was developed by Wilhelm Wundt and Edward Bradford Titchener [60] and inspired by methodological advances in the fields of chemistry and physics, sought to identify and catalogue complex mental operations using introspective methods. It was perhaps the first serious attempt to formulate a school of thought in psychology, and it was believed that this should be conducted through trained introspection. However, this soon became impossible, as just for sensation 40,000 elements were discovered. In addition, criticisms from psychologists such as William James suggested that introspective methods would only lead to distorted perceptions of these sensations and biased by this subjective approach, for which he coined term *the psychologist's fallacy* [32].

The competing perspective of **functionalism** was founded by William James [32], which utilized the idea of the practical use of consciousness, and that mental states are constituted solely by their functional role and causal relations, sensory inputs and behavioural outputs, i.e., their function [13]. This is a school of thought about the nature of mental states rather than the properties of these states, which would be the structuralist approach. It also assumes that psycho-physiological mental states should be recognized by what they do (what they transform) rather than what they are made of [1]. For example, when setting a mouse trap, the individual's mental state can be identified as "something that kills mice" rather than identifying sensation properties, or the particular approach to kill mice. However, functionalism still lacked a formal empirical approach, so was superseded by approaches which involved a more empirical approach with the rise of positivism, post-positivism and critical rationalism.

Gestaltism, which is an early form of cognitivism, was inspired by physics and founded by Max Wertheimer, Kurt Koffka, and Wolfgang Kohler, employed third person phenomenological inquiry to discover principles of perceptual organization of holistic concepts and is identified as independent from the sum of its parts. In this way Gestalt psychology is an attempt to discover the perceptual laws which allow for meaningful perceptions from the regularities in the environment form a chaotic world. The main assumption made in Gestaltism is that the mind forms a perceptual global whole from these chaotic environmental regularities and has self-organizing tendencies [67]. A simple illustration of this is when Wertheimer suggest that: "I stand at the window and see a house, trees, sky. Theoretically, I might say there were 327 brightnesses and nuances of colour. Do I have '327'? No. I have sky, house, and trees." This is a clear illustration that the holistic concept of those environmental regularities become a whole, which is unique from the sum of its parts to form meaningful perception.

Behaviourism, adopting the epidemiological approach of positivism and falsifiability advocated by philosophers such as John Locke in its methodology revolutionized the way that psychological experimentation would take place based on gaining knowledge in science through empirical investigation. Behaviourists attempted to explain psychological phenomenon through empirically defined objective phenomena in the form of overt stimuli-responses which could be objectively measured. In this way they focused on what people and animals do in response to different environmental situations [47].

Behaviourism developed in stages, starting from basic association learning, of the studies conducted by Pavlov such as the pairing association of a bell with food which led to a dog salivating in the learning phase, to the learned association (conditioned response) of the dog salivating to the stimuli of the bell alone – a process called classical conditioning [47]. Skinner then further developed this model through operant conditioning which demonstrated that behaviours which led to some form of pleasant outcome (positive reinforcement) was likely to be repeated, whilst behaviours which led to less pleasant outcomes or painful outcomes were more likely to be avoided (negative reinforcement) [21].

Cognitivism developed when linguist Noam Chomsky criticized Skinner's explanation of operant conditioning to adequately explain the emergence of language. In Chomsky's book *Syntactic Structures*, he suggests that for a language to emerge, then an innate universal grammar was necessary in the form of a Transformational Generative Grammar (TGG) [16]. As this was difficult for behaviourists at the time to explain, the cognitive revolution was born in the 1960s and still dominates mainstream psychology today.

Ulric Neisser (1967) used the term *Cognitive Psychology* for the first time to describe a person as a dynamic information-processing system, where mental operations can be given in computational terms. Cognitive psychology relates to sensory input, how it is elaborated, stored in mental representations, recovered from memory and used in cognitive tasks, rather than focusing on just behavioural outputs.

Though early cognitive psychology work began as far back as Hermann Ebbinghaus mapped out the learning and forgetting curves in experimental studies of memory in 1885 [19]. It also developed continued to develop when [51] explored cognitive development and the four stages of cognitive development, which included (1) sensory motor stage (2) preoperational stage (3) concrete operational stage, and (4) the formal operational stage. Each of these stages added growing cognitive complexity as the child grew older and were able to complete more complex cognitive tasks. However, cognitivism did not really develop until Baddeley and Hitch [2] produced the working memory model (WMM) which specified a central executive, visuospatial sketchpad and articulatory-phonological loop. This model was the first to incorporate information theory into its account, whereby through identifying these memory limitations, this led researchers to make accurate predictions about behavioural performances under these types of conditions.

It should also be noted that in psychology there has been a debate to the nature of behaviour, and to whether it originates from nature or nurture. The idea of **Nativism** dates as far back as the philosopher Immanuel Kant in the 18th century who argued in his critique of pure reason [35] that the human mind knows objects in innate, a priori ways. More recently in psychology, the nurture theorists such as behaviourists have long argued that behaviour (and psychology) is subject to the learning reinforcement contingencies in the environment. However, cognitivists, though they accept learning, also account for innate components such as Chomsky's TGG [16] and other cognitive linguists such as Pinker [52].

11.5 Conclusions

Some schools of thought visualization can be related to schools of thought in psychology and computer science. We have already seen the mentioning of cognitivism in visualization ($\mathbf{V2}_\mathrm{B}$) and psychology ($\mathbf{PS}_\mathrm{C}$), and mentioning of mechanism and anti-mechanism in visualization ($\mathbf{V4}_\mathrm{A}$ and $\mathbf{V4}_\mathrm{B}$) and computer science ($\mathbf{C}_\mathrm{A}$ and $\mathbf{C}_\mathrm{C}$).

During the 2012 VisWeek panel [15], the convener of the panel related the four schools of thought mentioned in Section 11.1 to schools of thought in psychology as:

- School of A (algorithms or automation) $\mathbf{V1}_\mathrm{A} \rightarrow$ functionalism $\mathbf{PS}_\mathrm{D}$;
- School of E (experiments or empirical studies) $\mathbf{V1}_\mathrm{B} \rightarrow$ behaviourism $\mathbf{PS}_\mathrm{B}$;
- School of M (metrics or measurements) $\mathbf{V1}_\mathrm{C} \rightarrow$ structuralism $\mathbf{PS}_\mathrm{G}$;

- School of R (Real users or Real world applications) $\mathbf{V1}_\mathrm{D} \rightarrow$ pragmatism $\mathbf{PS}_\mathrm{F}$.

Although the suggestion by the panel convener was meant to be provocative as a tradition of the panel discussions in IEEE VIS (VisWeek) conferences, the mappings indicate that visualization researchers and practitioners have been thinking deeply about many aspects of visualization in ways similar to many pioneers in other scholarly subjects.

When a scientific or scholarly subject reaches a certain level of maturity, the scientists or scholars will naturally attempt to make abstraction and generalization from empirical evidence and practical experience. It would be wrong if the scientists or scholars did not do that. As an inherent and integral part of the processes for abstraction and generalization, there will be different viewpoints, different abstract theories and models, different postulations, and so on.

As a scientific discipline, there is no reason for the field of visualization to be afraid of different schools of thought. In particular empirical studies will have a significant role in the evolution of schools of thought, including their creation, betterment, convergence, divergence, and obsolesce. Empirical studies are important means for stimulating new postulations, evidencing various viewpoints, and validating abstract theories and models. Meanwhile, for researchers who are interested in theoretical research and empirical studies, having schools of thought is no doubt a blessing. Meanwhile, as researchers, practitioners, authors, and reviewers, we must respect schools of thought that we do not agree. We must learn to judge the novelty, rigour, and significance of a scientific contribution not based on whether or not this fits with our own school of thought.

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