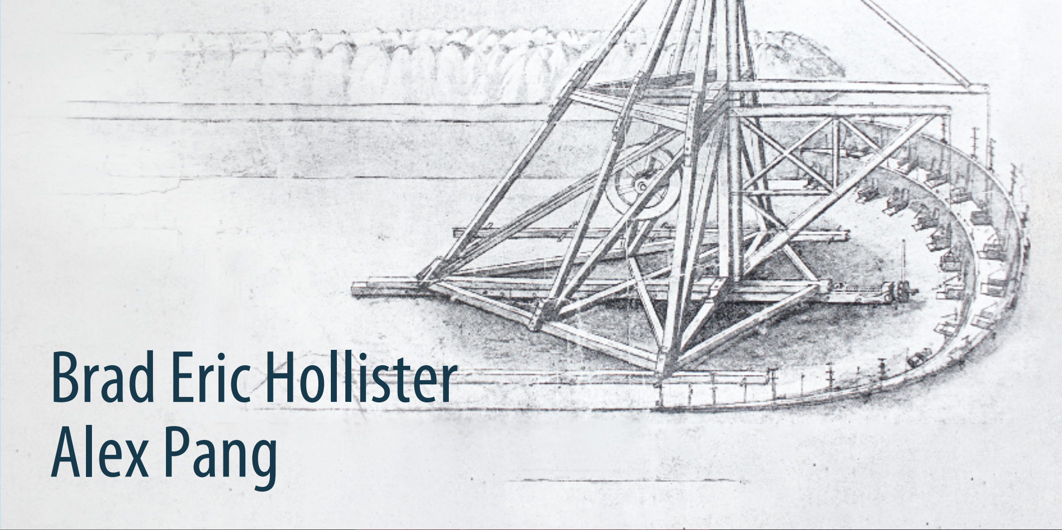

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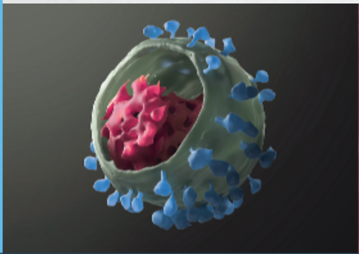
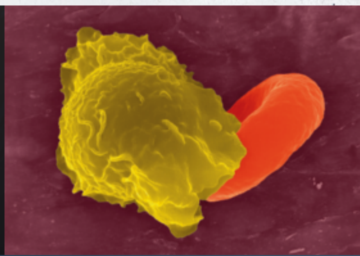
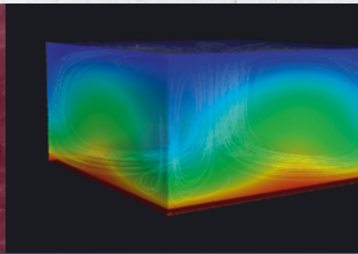

A Concise Introduction to Scientific Visualization

Past, Present, and Future

Springer

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Preface

Much of our cortex is dedicated to processing visual information, and it imposes upon mental models a physical intuition. While there are exceptions in modern science when our visual nature leads to artifact, for the vast number of problems our ability to visualize the natural world has elevated human understanding to its current level. Using imagery, we are able to see the unseeable, and thus further knowledge.

This treatise will outline scientific visualization. While there is an established related field of information visualization, we mostly address visualization for scientific purposes. Despite modern buzzwords like "data science" and computer graphics in popular media, the general public (and even some academics) remain unfamiliar with scientific visualization. But, anyone capable of mental pictures, often instinctively uses visualization to solve problems they encounter. If their solutions model the natural world, or produce useful abstractions from it, then this type of problem-solving is considered scientific visualization.

Scientific visualization is not an isolated area of research. While today, visualization is primarily computer-generated, visualization in science stretches back to a time well before computers! That said, we do not consider problems in the broader discipline of visualization that are not scientific. Nor do we consider areas of study such as realism in art. When illustration relates to scientific visualization, it is discussed to convey context.

The first two chapters cover the role of geometry in natural science and scientific visualization. A link is drawn between Euclid and the work of da Vinci (and others) of the Renaissance period. Then, the kinematics of celestial motion is presented in connection with later methods for shape and curvature description. Starting with chapter three, we describe Faraday's insight into invisible electromagnetic fields. Faraday was known to have had his great revelation through visualization of the phenomena. As another case study, Lawrence Bragg, a scientist known to possess an early aptitude for spatial problems, contributed to molecular visualization and the first direct experimental structural determination of matter. Computers still had not been invented yet during this era of scientific visualization, but that was soon to change. In the last two chapters, modern scientific visualization starts to take form. We see how early computer use was directed exclusively at problems of science.

However, not until the latter part of the twentieth century, did the computer become sophisticated enough to draw interactive imagery.

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Early Visual Models

Abstract This chapter serves as an entry point into our introduction of *scientific visualization*. The first externalizations of visual thought are considered [1]. The focus is on the work in the pre-Enlightenment before the middle ages, which are discussed in Chap. 2 as a precursor to the Renaissance. This period's drawings were crude comparatively, but suggestive of the future trajectory of human expression and cognition [2]. The time span is also vast, greater than what is covered from the other chapters combined. However, prehistory is sparse with example. It is most significant when viewed as the watershed before systematic analytical thought [3, 4]. The transition from prehistory to Greek mathematical philosophy [5], especially regarding Euclidean geometry, was key to the later developments in perspective theory and the scientific method.

Prehistory

From the vantage point of modern culture and technology, it is difficult for us to directly relate to the perspective and actions afforded those of considerably early times. It was generally the case that most visual artifacts were produced as records of the world, and less of mental imagery and ruminations on reality.

Unless, however, we consider prehistoric "art." Then, by discrepancies between prehistoric drawings juxtaposed with rational modern representation (perspective, proportion, etc.), we begin to see what is considered deficiencies in our ancestors' own internal view and today's conceptualization of the external world. Analyzing these discrepancies lead us to an estimation of what was visualized (the products of earlier minds) in the prehistoric period.

Another running theme of the prehistoric period is the lack of delineation and intent between the various forms of visual invention. As there was no "science," one can not interpret this period's achievements as directly in service of *scientific* visualization.

We will see later how these symbolic inventions became general forms of expression which were to be later built upon and shaped into more specific tools for scientific endeavor.

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Because of visual tools, namely glyph (i.e., carving) and art, subsequent generations were able to extend and elaborate upon prehistoric visualization, using ideas enabled by the earlier foundations.

Parietal Art

In southern France, approximately 30000 BCE, was the site of the earliest known petroglyphs (stone carvings) and parietal art, see Fig. 1. Many of these works also contained additional repetitive markings superimposed over animal imagery.

It can only be speculative, but the prevailing notion is that these glyphs were meant to contain information (number of animals in a herd, etc.), akin to information linked to spatial representation [6]. No speech was recorded yet, as this was well before phonetic writing.

Fig. 1 Cave painting and engraving from Marsoulas in France approximately 30,000–32,000 years ago. From [HTO, Wikimedia Commons]

Fig. 2 Non-political view of the Tigres and Euphretes rivers. From [DEMIS Mapserver, Wikimedia Commons]

The Near East

The invention of symbolic representation itself was a key accomplishment. Symbolism represented itself most prominently with the emergence of script. The most successful prehistoric societies were successful in their ability to extract from reality defining features and externalize them; for communication, expression, and by consequence planning and understanding.

The earliest records of this come from Mesopotamia, between the Tigres and Euphretes rivers (the "Fertile Crescent"), often considered the "cradle of civilization." See Fig. 2.

Proto-Writing

The first known forms of proto-writing (or proto-cuneiform) were clay "tokens" dating back to around 8000 BCE. These tokens consisted of small geometric objects such as cones and spheres (see Fig. 3) [7]. They are considered by archeologists to have been used for accounting in trading and commerce. It is likely that the geometric forms represented items of inventory, symbolized by basic shape.

Fig. 3 Clay bulla, or "bubble," with token contents displayed. From [Marie-Lan Nguyen, Wikimedia Commons]

Pictographs

As we will see, the concept of glyph is today used throughout scientific visualization as a nonverbal symbolic representation of a quality or quantity (arrow and bar glyphs, for example) [8] as shown in Fig. 4.

Thus, the modern practice of scientific visualization can be considered as pictorial symbols, or pictographs (also know as "pictograms"). In this text, we will not explore how pictograms evolved into phonetic representation, as we are interested in the historical development of the practice of visualization for scientific inquiry.

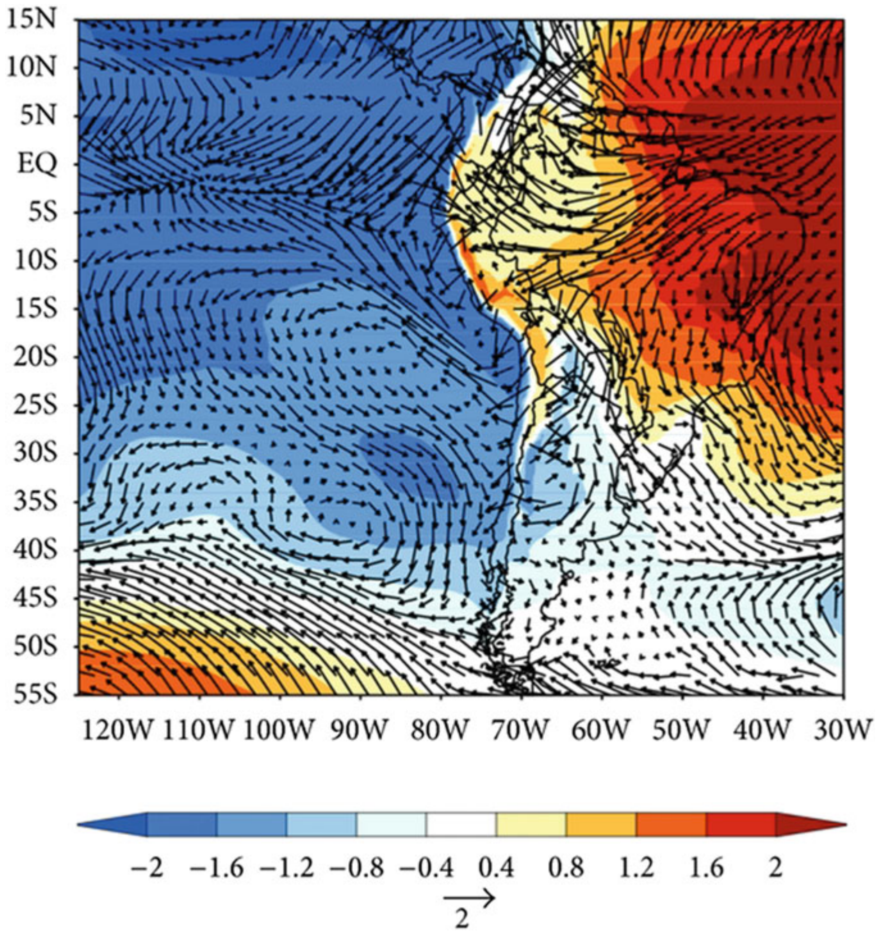

Fig. 4 El ñino effects in South American climate as represented with wind force directions in a vector field plot using arrow glyphs in modern scientific visualization. Reproduced from [South American Climatology and Impacts of El Niño in NCEP's CFSR Data, Hindawi Limited, Open Access 2013]

The first use of pictograms given current evidence, [9] was in the cities of Sumar and Uruk circa 3000 BCE. The pictograms (Fig. 5) consisted of concrete and abstract concepts, in the form of line drawings impressed upon clay tablets using reeds (cuneiform engraving).

A key step in the human visual system is to detect edges through value change in objects [10]. Pictograms resemble this decomposition of form with proportional invariance (or singular perspective).