

How to Read a Visualization Research Paper: Extracting the Essentials

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When pursuing an unfamiliar research direction, a researcher, possibly a PhD student, must undertake a literature search. This search aims to discover what research has already been carried out in a given field (solved problems) and what research hasn't (unsolved problems).

However, in visualization and computer graphics, reading a refereed conference or journal paper can be challenging owing to its high level of specialization, complexity, and detail. Such papers often present a detailed mathematical framework accompanied by algorithms and data structures to carry them out and are usually written by (or with the aid of) experts in the field with many years' experience. This complexity comes as no great surprise because a single paper is often the result of many (combined) person-years of work.

Furthermore, a PhD student or a researcher starting in a new direction must wade through scores, if not hundreds, of papers. This task can be daunting. In 1998, Jim Blinn identified keeping up with the explosion of literature as a top unsolved problem.¹ Obviously, this is still true. However, gaining a complete understanding of every published research paper, including all its details, is neither possible nor necessary.

Here, I give guidelines for extracting the essen-

tial information when reading a visualization (or computer graphics) paper. In particular, I describe how to read the paper to perform a literature review—for example, to write a Eurographics STAR (state-of-the-art report). Such a report is a helpful way to get an overview of published research in a subfield of visualization and computer graphics.

This article builds on my experience in both writing literature reviews²⁻⁹ and teaching in the classroom. I've given these guidelines for undergraduate, master's, and PhD students taking my Data Visualization class, as part of an assignment requiring them to summarize a visualization paper, extracting and capturing the most important concepts and information. This is the first time many of the students have had to do this. These guidelines have demonstrated themselves useful for this task. They can be given out directly in the classroom and discussed. They've also formed the basis for several successful literature reviews as part of students' PhD work.^{2-6,8}

Concept versus Implementation

First, it's important to understand the difference between a concept and its implementation. Looking up the meanings of "concept" and "implementation" online yielded this:

- *Concept.* "1. a general notion or idea; conception. 2. an idea of something formed by mentally combining all its characteristics or particulars; a construct. 3. a directly conceived or intuited object of thought" (dictionary.com).
- *Implementation.* 1. "the act of accomplishing

Visualization students or researchers investigating an unfamiliar topic often review the scientific literature about that subject. Reading the many scientific papers and capturing their essential information is a challenge. However, remembering all the details isn't necessary. Several simple guidelines can help you extract the most important information from visualization research papers.

some aim or executing some order;” 2. “the act of implementing (providing a practical means for accomplishing something); carrying into effect” (<http://wordnet.princeton.edu>).

In other words, a concept is an idea or thought. As Ralph Waldo Emerson said, “Every revolution was first a thought in one man’s mind.” This applies to not only revolutions but also every human-made object. A concept is abstract. It’s not something with mass that you can weigh on a scale.

An implementation is the actualization of a concept. In other words, it’s a concept that has been brought into reality. Most implementations are actual objects with mass that you can weigh on a scale (software being one exception). A concept usually starts out as an idea in someone’s mind. It’s then often written down on paper, perhaps as a hypothesis or specification. (It’s better to write it down than simply communicate it verbally.) Finally, it’s implemented.

The concept behind a paper can be mapped to the paper’s contribution in terms of a literature review. Here’s an example of a basic concept mapping:

- **Concept**—a writing utensil. A writing utensil is a tool that a person (or animal) can use to communicate with others by drawing symbols.
- **Implementation**—a pencil. A pencil uses graphite to write on a piece of paper.

Furthermore, a writing utensil can have many different implementations: pens, markers, PDAs, and so on. The variety of implementations is essentially unlimited. Think of how many different pens and pencils you’ve seen in your lifetime. There are many varieties of pencils alone—for example, those made out of plastic, wood, or metal.

The notion that a given concept might have different implementations is important when you’re reading or writing a research paper, as well as in most other areas of life that require critical thinking.

Regarding this article, I described its concept in the introduction and will describe its implementation in the next section. Conceptually, the guidelines I give here act as a filter. An entire research paper is the filter input, whereas the essential information is what passes through the filter.

Extracting the Essentials

When you’re reading a visualization research paper, focus on and write down this information:

- **The concept.** What, conceptually, are the authors trying to achieve? What’s the research’s goal?

In other words, what’s the paper’s contribution? (What’s new here?)

- **The implementation.** How do the authors realize the concept? How do they support their hypothesis? How do they implement the concept?
- **Related work.** What previous research does this paper build on? Almost all research papers build heavily on the research reported in one or two previous papers. What are these papers?

In visualization and computer graphics, reading a conference or journal paper can be challenging owing to its high level of specialization, complexity, and detail.

- **Data characteristics.** What are the characteristics of the data analyzed and visualized in the paper? What’s the spatial dimensionality—2D, surfaces, or 3D? What’s the temporal dimensionality—static or time-dependent? What’s the dataset’s resolution and size? Is the dataset multi-resolution or adaptive resolution? Are the data samples given on a structured or unstructured grid? Is the data scalar, vector, or tensor? Is it multivariate?

For example, let’s look at the essential information extracted from a sample research paper—“Fast and Resolution Independent Line Integral Convolution,” by Detlev Stalling and Hans-Christian Hege:¹⁰

- **The concept.** This paper presents a faster version of the line integral convolution (LIC) algorithm. This research brings the algorithm toward interactive frame rates.
- **The implementation.** The authors achieve this by reducing the number of redundant streamline computations. They also use an improved streamline integrator with adaptive step-size control.
- **Related work.** This research builds on and improves Brian Cabral and Leith Leedom’s original LIC algorithm.¹¹
- **Data characteristics.** The spatial dimensionality is 2D. The temporal dimensionality is steady (static). The resolution is uniform. The grid structure has uniform resolution and is regular. The data type is vector.

You can use these essential attributes to categorize visualization papers. The previous list isn’t

comprehensive; other characteristics you could use and summarize include these:

- *Visualization techniques.* What basic visualization techniques does the research use? Examples include volume rendering, ray tracing, geometric or texture-based flow visualization, and information visualization techniques such as parallel coordinates or treemaps.
- *Application domain.* What application domain are the visualization techniques being applied to? Examples include physics, earth sciences, astronomy, chemistry, and biology.

Once you've identified a specific research project, you'll most likely require a greater understanding of a select few research papers.

A paper's essential information can be extracted concisely. You can use the previous pieces of information as a template to fashion the foundation of a literature review. Ultimately, you could classify a group of papers in many different ways. Extracting the essential information facilitates constructing an appropriate classification scheme.

As an additional illustration, I summarize a paper everyone in visualization is familiar with—"Marching Cubes: A High Resolution 3D Surface Construction Algorithm," by William Lorensen and Harvey Cline:¹²

- *The concept.* This paper describes a novel algorithm for constructing isosurfaces. The generated isosurfaces stem from maintaining the original data's interslice connectivity.
- *The implementation.* The basic implementation takes seven steps. First, examine a cube. Second, classify each cube vertex as the isosurface's interior or exterior. Third, build an index into the case table of all possible surface topologies through the cube. Fourth, get an edge list from the case table. Fifth, interpolate to find the edge locations. Sixth, compute the gradients. Finally, go to the next cell.
- *Related work.* The marching-cubes algorithm builds on and improves algorithms devised by Lih-Shyang Chen and his colleagues¹³ and Gabor Herman and Jayaram Udupa.¹⁴
- *Data characteristics.* The spatial dimensionality is 3D. The temporal dimensionality is steady

(static). The resolution is uniform. The grid structure has uniform resolution and is regular. The data type is scalar.

- *Visualization techniques.* The research employs volume visualization and isosurface rendering.
- *Application domain.* The domain is the visualization of medical-record data and single-photon emission computed tomography data.

Reviewers' biggest criticism of literature reviews is that they're simply a list of papers. This is why I emphasize related work. It's important to know how a paper relates to its predecessors and to state this explicitly. This forms a piece of the overall puzzle, which you can build piece-by-piece as in Figure 7 of "The State of the Art in Flow Visualization: Dense and Texture-Based Techniques"³ or Table 1 of "Topology-Based Flow Visualization: The State of the Art"⁴ or "Over Two Decades of Integration-Based, Geometric Flow Visualization."⁶

Although this process might not seem difficult to experienced researchers, it's a skill that takes time and practice.

Breadth versus Depth

So far, I've described how to speed up the acquisition of a breadth of knowledge. After the breadth phase of research comes the depth phase. Once you've identified a specific research project, you'll most likely require a greater understanding of a select few research papers. During this phase, you'll spend more time on individual papers rather than, say, the one to two hours per paper in the breadth phase. In addition, multiple passes through a paper will likely be necessary.

Also, a complete understanding of the results presented in a paper might require knowledge of a previous paper. In the previous section, I identified this previously published literature as one of the essential items to extract. Reading and understanding this literature might not be necessary during the breadth phase. However, reading and understanding it is necessary if you use a given paper in the depth phase—that is, when you've decided on a research prototype you'd like to implement.

If the goal of reading a paper is to actually implement the presented approach, you'll need a deeper understanding of the technique. So, you'll need to reread the parts of the paper describing the authors' model (concept) and its implementation, possibly multiple times. If some aspect of the model or implementation isn't clear (this can happen often, because page limits prevent inclusion of some details), you could query the authors. My experience in this regard has generally been

Related Work on Reading and Writing Research Papers

Several online resources are available for writing a literature review. Emerald Group Publishing has posted a general how-to guide.¹ Dena Taylor focuses on the health sciences,² whereas Kim Lie focuses on psychology.³ You can find other online guidelines by searching for “literature survey” or “literature review.”

What I present in the main article isn’t a how-to guide on writing a literature review, however. I focus on a specific component of the literature review process: given one paper, how to extract the vital, most important information. This is meant to complement and facilitate a literature review. It also complements my previous papers on how to write a visualization paper.^{4,5} To my knowledge, my article is the only guide to reading research papers that focuses on visualization. However, I believe it can be generalized and adapted to other topics, especially computer graphics.

Alan Smith described how to read a manuscript from a referee’s viewpoint.⁶ Allen Lee presented another interesting paper on how to read a research paper to conduct a review.⁷ My article’s goal isn’t how to read a paper from a referee’s viewpoint, which is a different process.

Al Globus and Eric Raible wrote a great tongue-in-cheek article on how to cheat when presenting visualizations.⁸ Tamara Munzner provided a nice overview of ways to prevent an information visualization paper from being rejected during review.⁹

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quite positive. Authors are often happy to discuss and answer questions regarding their published research. They might even be willing to share their implementation, or subsets of it. Alternatively, you could contact other experts in the field who have closely related experience.

It’s difficult to judge how fruitful a research direction or project might be on the basis of just one research paper, unless you’re already an expert in the field or have a good number of years’ experience. This is where a literature review’s value lies. A good literature review identifies mature areas where much work has been done and newer directions where more unsolved problems lie. Luckily, a wealth of literature reviews exists, such as those found in *ACM Computing Surveys* and *Eurographics STARS*. *Computer Graphics Forum* and *IEEE Transactions on Visualization and Computer Graphics* also publish literature reviews.

I hope this article is a helpful aid to anyone reading visualization research papers for the first time or carrying out a literature review in the field. For a look at related work on reading and writing research papers, see the sidebar. ■■

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