ABSTRACT
How to Read a Paper

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4. Glance over the references, mentally ticking off the

Researchers spend a great deal of time reading research pa pers. However, this skill is rarely taught, leading to much wasted effort. This article outlines a practical and efficient three-pass method for reading research papers. I also de scribe how to use this method to do a literature survey.

Categories and Subject Descriptors: A.1 [Introductory and Survey]

General Terms: Documentation.

Keywords: Paper, Reading, Hints.

1. INTRODUCTION

Researchers must read papers for several reasons: to re view them for a conference or a class, to keep current in their field, or for a literature survey of a new field. A typi cal researcher will likely spend hundreds of hours every year reading papers.

Learning to efficiently read a paper is a critical but rarely taught skill. Beginning graduate students, therefore, must learn on their own using trial and error. Students waste much effort in the process and are frequently driven to frus tration.

For many years I have used a simple approach to efficiently read papers. This paper describes the 'three-pass' approach and its use in doing a literature survey.

2. THE THREE-PASS APPROACH
The key idea is that you should read the paper in up to three passes, instead of starting at the beginning and plow ing your way to the end. Each pass accomplishes specific goals and builds upon the previous pass: The first pass gives you a general idea about the paper. The second pass lets you grasp the paper's content, but not its details. The third pass helps you understand the paper in depth.

2.1 The first pass
The first pass is a quick scan to get a bird's-eye view of the paper. You can also decide whether you need to do any more passes. This pass should take about five to ten minutes and consists of the following steps:

1. Carefully read the title, abstract, and introduction

2. Read the section and sub-section headings, but ignore everything else

3. Read the conclusions
   ones you've already read

At the end of the first pass, you should be able to answer the five Cs:

1. Category: What type of paper is this? A measure ment paper? An analysis of an existing system? A description of a research prototype?

2. Context: Which other papers is it related to? Which theoretical bases were used to analyze the problem?

3. Correctness: Do the assumptions appear to be valid?

4. Contributions: What are the paper's main contribu tions?

5. Clarity: Is the paper well written?

Using this information, you may choose not to read fur ther. This could be because the paper doesn't interest you, or you don't know enough about the area to understand the paper, or that the authors make invalid assumptions. The first pass is adequate for papers that aren't in your research area, but may someday prove relevant.

Incidentally, when you write a paper, you can expect most reviewers (and readers) to make only one pass over it. Take care to choose coherent section and sub-section titles and to write concise and comprehensive abstracts. If a reviewer cannot understand the gist after one pass, the paper will likely be rejected; if a reader cannot understand the high lights of the paper after five minutes, the paper will likely never be read.

2.2 The second pass
In the second pass, read the paper with greater care, but ignore details such as proofs. It helps to jot down the key points, or to make comments in the margins, as you read.

1. Look carefully at the figures, diagrams and other illus trations in the paper. Pay special attention to graphs. Are the axes properly labeled? Are results shown with error bars, so that conclusions are statistically sig nificant? Common mistakes like these will separate rushed, shoddy work from the truly excellent.

2. Remember to mark relevant unread references for fur ther reading (this is a good way to learn more about the background of the paper).

The second pass should take up to an hour. After this pass, you should be able to grasp the content of the paper. You should be able to summarize the main thrust of the pa per, with supporting evidence, to someone else. This level of detail is appropriate for a paper in which you are interested, but does not lie in your research speciality.

Sometimes you won't understand a paper even at the end of the second pass. This may be because the subject matter is new to you, with unfamiliar terminology and acronyms. Or the authors may use a proof or experimental technique that you don't understand, so that the bulk of the pa per is incomprehensible. The paper may be poorly written with unsubstantiated assertions and numerous forward ref erences. Or it could just be that it's late at night and you're tired. You can now choose to: (a) set the paper aside, hoping you don't need to understand the material to be successful in your career, (b) return to the paper later, perhaps after reading background material or (c) persevere and go on to the third pass.

2.3 The third pass

To fully understand a paper, particularly if you are re viewer, requires a third pass. The key to the third pass is to attempt to virtually re-implement the paper: that is, making the same assumptions as the authors, re-create the work. By comparing this re-creation with the actual paper, you can easily identify not only a paper's innovations, but also its hidden failings and assumptions.

This pass requires great attention to detail. You should identify and challenge every assumption in every statement. Moreover, you should think about how you yourself would present a particular idea. This comparison of the actual with the virtual lends a sharp insight into the proof and presentation techniques in the paper and you can very likely add this to your repertoire of tools. During this pass, you should also jot down ideas for future work.

This pass can take about four or five hours for beginners, and about an hour for an experienced reader. At the end of this pass, you should be able to reconstruct the entire structure of the paper from memory, as well as be able to identify its strong and weak points. In particular, you should be able to pinpoint implicit assumptions, missing citations to relevant work, and potential issues with experimental or analytical techniques.

3. DOING A LITERATURE SURVEY

Paper reading skills are put to the test in doing a literature survey. This will require you to read tens of papers, perhaps in an unfamiliar field. What papers should you read? Here is how you can use the three-pass approach to help. First, use an academic search engine such as Google Scholar or CiteSeer and some well-chosen keywords to find three to five recent papers in the area. Do one pass on each pa per to get a sense of the work, then read their related work sections. You will find a thumbnail summary of the recent work, and perhaps, if you are lucky, a pointer to a recent survey paper. If you can find such a survey, you are done. Read the survey, congratulating yourself on your good luck. Otherwise, in the second step, find shared citations and repeated author names in the bibliography. These are the key papers and researchers in that area. Download the key papers and set them aside. Then go to the websites of the key researchers and see where they've published recently.

That will help you identify the top conferences in that field because the best researchers usually publish in the top con ferences.

The third step is to go to the website for these top con ferences and look through their recent proceedings. A quick scan will usually identify recent high-quality related work. These papers, along with the ones you set aside earlier, con stitute the first version of your survey. Make two passes through these papers. If they all cite a key paper that you did not find earlier, obtain and read it, iterating as neces sary.

4. EXPERIENCE

I've used this approach for the last 15 years to read con ference proceedings, write reviews, do background research, and to quickly review papers before a discussion. This dis ciplined approach prevents me from drowning in the details before getting a bird's-eye-view. It allows me to estimate the amount of time required to review a set of papers. More over, I can adjust the depth of paper evaluation depending on my needs and how much time I have.

5. RELATED WORK

If you are reading a paper to do a review, you should also read Timothy Roscoe's paper on "Writing reviews for sys tems conferences" [1]. If you're planning to write a technical paper, you should refer both to Henning Schulzrinne's com prehensive web site [2] and George Whitesides's excellent overview of the process [3].

6. A REQUEST

I would like to make this a living document, updating it as I receive comments. Please take a moment to email me any comments or suggestions for improvement. You can also add comments at CCRo, the online edition of CCR [4].

7. ACKNOWLEDGMENTS

8. REFERENCES

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