How to Write Research Papers

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http://people.engr.ncsu.edu/txie/publications/writepapers.pdf
http://people.engr.ncsu.edu/txie/advice/

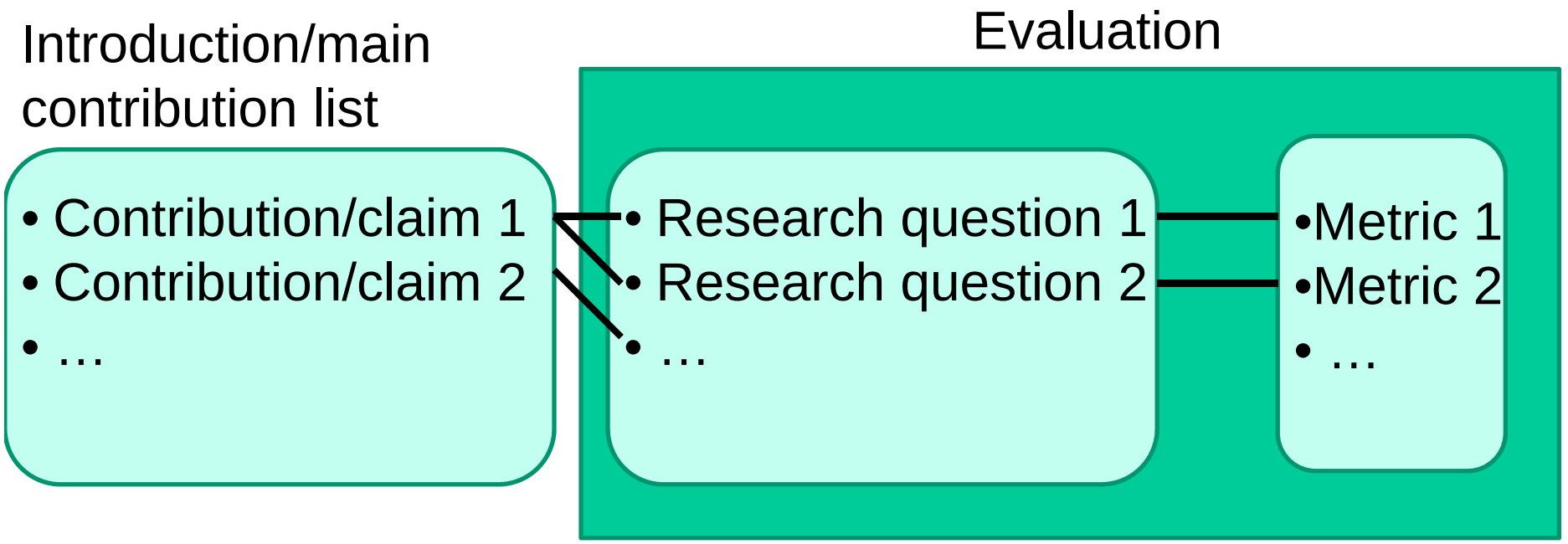
Caveats

- The key research contributions are the deciding factor for your paper's acceptance
  - Don't think that you should pay less attention to the "meat" in your paper
- There is no single standard way of writing research papers
  - Don't think that the writing of your paper should follow every suggestion in these subsequent slides
  - But these suggestions have strong (hopefully good) rationales; you need to understand these rationales before you (blindly) adopt any of these suggestions
  - Discuss with me (xie@csc.ncsu.edu) if you don't understand or disagree some points in these slides

Key Questions to Double Check Your Paper

- Is the research problem significant/important?
  - NOT: a problem created/imagined by you and no one else cares about it
  - YES: a problem that people care (evidenced by concrete statistics or examples)
- Is your research solution significant or addressing technical challenges?
  - NOT: a solution that is incremental over previous work
  - NOT: a solution that is straightforward/trivial (e.g., simple adoption or slight adaption of an existing technique is not significant enough, even when you are the first one in doing so)
- Is your evaluation justifying the claimed contributions or benefits of your solution? (e.g., faster, detecting more faults, …than existing techniques if any)
  - Double check by making traceability from your claims listed in your contributions to your research questions to investigate in your evaluation

Traceability Links



- Make sure each contribution/claim is translated to (appropriate) research question(s) ➔ no unsubstantiated claims
- Make sure each question is answered with help of (appropriate) metric(s)

See GQM by Weiss/Basili
http://en.wikipedia.org/wiki/GQM

Know What Your Audience is

- Explicitly explain how your paper is relevant to the conference (or journal) you submit to (if not that obvious)
  - E.g., if ICSM, explain clearly in abstract and intro how your work is related to maintenance; if WWW, explain clearly in abstract and intro how your work is related to web; …
- Explicitly explain some basic assumptions/concepts underlying your work (even which may be obvious to your subfield but not to the conference reviewers/audience)
  - E.g., if your approach is about achieving high structural coverage of code, need to explain why achieving high structural coverage is important (e.g., related to fault detection) when you submit to WWW or even some sub-field conferences whose reviewers may not be testing experts

Justify Your Choices

- Pitfall: In intro sec, you describe that you propose a way of solutions (e.g., dynamic analysis) to address your stated problem, BUT you never discuss why alternative way of solutions (e.g., static analysis) would not be chosen
- Pitfall: In approach sec, you describe that you use a technique (e.g., hierarchical clustering) to address a sub-problem in your approach, BUT you never discuss why alterative way of techniques (e.g., partitional clustering) would not be chosen
- Pitfall: In your evaluation sec, you don’t compare the results of including or not including an important technique (e.g., filtering) claimed to be a major contribution
- Pitfall: in your evaluation sec, you don’t justify why you choose the experimental subjects or a subset of subjects used by previous work

Don’t Write Too Little or More Than Enough

- Pitfall: A student tends to write a lot of low-level implementation details, which they spent most time on; these details are of no or little interest to readers who don’t plan to reimplement the approach for the same language or using the same library/framework

- Pitfall: A student omits some important details of experimental setup causing readers not to be able to reproduce the experimental results

- Need balance on reproducibility and new idea/research contributions
  - Solution: separation of approach and implementation sections

Formalize Just Enough

- Formalization examples: formal definitions, algorithms, …
- Formalization helps
  - write clearly
  - force you to think and write rigorously
- But don’t over-formalize to pose barrier for understanding – formalization is to better rather worsen understanding
- Learn how to write by reading and mimicking styles of papers (related to your work) written by PL/compiler/formal method researchers (e.g., from TACAS, POPL, PLDI, SPLASH/OOPSLA, ECOOP, CAV)

Typical Paper Structure

- Title/Abstract
- Introduction
- Optional: Background
- Optional: Formal Problem Definition
- Related Work (alternatively put before conclusion)
- Example
- Approach/Framework
- Implementation
- Evaluation
  - Experiment/Case Studies/Experiences/Examples
- Discussion
- Conclusions (and Future work)

Title and Abstract

- Title writing pitfall:
  - Don’t put uncommon buzzwords there
    - Otherwise, bad for paper search engines or readers who would like to understand what the paper is about by reading the title
  - Be specific enough but not too specific (related to the previous bullet)
- Abstract structure:
  - Short motivation (problem); Proposed solution; Evaluation; Evaluation results
- Abstract writing pitfall:
  - Don’t put unexplained or undefined terms whose meanings are not well known
  - Solutions: explain them; rephrase them using plain words; not get into too much detail (without mentioning them).

Introduction Structure

- Long motivation, problem to be solved, why existing solutions are not sufficient (sometimes examples help)
- Need show the problem is significant (desirable to use concrete statistics, concrete examples, or citations)
- Proposed solution and brief summary
- Optional: brief mention of related work if it is very related and explain differences (caveat: don't make it read like too much related work already done)
- Evaluation and evaluation results
- Optional: "The paper makes the following main contributions: + bulleted items"
  - Easy for reviewers to spot out major contributions
  - Being of the "first" in something is desirable as a contribution; if not first, why novel after all?
- Structure layout of the paper (you want to give readers high level ideas how different parts are related to each other)
  - Similar principle applied throughout the paper for subsections

Introduction –cont.

- Don’t overclaim (even throughout the paper)!
  - But it is good to put your work in a bigger picture and a larger background
  - But it is important for you emphasize the significance of the problem and your solution (esp in intro)
- Similarly don’t over-criticize other’s work (even throughout the paper)!
- If you want to claim some unjustified points, it is better to put them in conclusion or discussion section
- Even if so, be careful on wording
  - X “Our approach provides a foundation for this new field.”
  - “*We believe* our approach *can* provide a foundation…”
  - “*We believe* our approach *has a good potential* for providing a foundation …”

Introduction –cont.

- Another example: be careful on wording
  - X “Our/X’s approach is the only/first one on ….”
  - “*With the best of our knowledge*, our/X’s approach is the only one/first on …”
  - “Our/X’s approach is one of the/a few approaches …”
  - “Our/X’s approach is a major/representative approach …”
- Some reviewers don’t like you to claim your own approach to be “novel” (at least don’t put “novel” in your paper title!) – they said novelty is to be judged by them not to be claimed by you
  - “TestEra: A Novel Framework for Automated Testing of Java Programs” → “TestEra: Specification-based Testing of Java Programs Using SAT”

Introduction – insight

- Clearly state the **insight** that your paper conveys
  - explaining why the approach would work, like rationale but beyond and more generalized than rationale
  - shall be over-reaching and can inspire readers to apply the insights to another different problem
- explicitly state your insight in intro like "Our insight is ...."
  - can be immediately before or after the introduction of our new approach; you can also optionally additionally state the insight in the conclusion and/or abstract

This slide made based on discussion with Z. Su. at UC Davis

Stirewalt's 5-paragraph rule on writing Introduction - 1

- Introductory paragraph: Very briefly: What is the problem and why is it relevant to the audience attending *THIS CONFERENCE*? Moreover, why is the problem hard, and what is your solution? You must be brief here. This forces you to boil down your contribution to its bare essence and communicate it directly.

http://www.cse.msu.edu/~chengb/Writing/intro-guidelines-stirewalt.txt

Stirewalt's 5-paragraph rule on writing Introduction – 2/3

- Background paragraph: Elaborate on why the problem is hard, critically examining prior work, trying to tease out one or two central shortcomings that your solution overcomes

- Transition paragraph: What keen insight did you apply to overcome the shortcomings of other approaches? Structure this paragraph like a syllogism: Whereas P and P => Q, infer Q.

http://www.cse.msu.edu/~chengb/Writing/intro-guidelines-stirewalt.txt

Stirewalt's 5-paragraph rule on writing Introduction – 4/5

- Details paragraph: What technical challenges did you have to overcome and what kinds of validation did you perform?

- Assessment paragraph: Assess your results and briefly state the broadly interesting conclusions that these results support. This may only take a couple of sentences. I usually then follow these sentences by an optional overview of the structure of the paper with interleaved section callouts.

http://www.cse.msu.edu/~chengb/Writing/intro-guidelines-stirewalt.txt

The Stanford InfoLab's patented five-point structure for Introductions

1. What is the problem?
2. Why is it interesting and important?
3. Why is it hard? (E.g., why do naive approaches fail?)
4. Why hasn't it been solved before? (Or, what's wrong with previous proposed solutions? How does mine differ?)
5. What are the key components of my approach and results? Also include any specific limitations.

http://infolab.stanford.edu/~widom/paper-writing.html

Problem Definition (optional)

- If your paper proposes a new problem or addresses a formalizable problem, it is good to have a section on problem definition
- Examples
  - Section 2 http://people.engr.ncsu.edu/txie/publications/issta09-ilp.pdf
  - Section 2 http://people.engr.ncsu.edu/txie/publications/icse09-carminer.p
- Such a section is useful to clearly describe the problem being addressed by the paper

Formal Problem Definition

- Define the problem that our approach intends to address
- Can be put in a section after intro/example section, serve the purpose of the example section as described later
  - When you formalize your problem, readers can have better grasp on what you are trying to address
- There you can also formally define some important concepts referred to in your approach (either in the problem space or solution space)
- Problem formalization can be a new contribution in the contribution list

Important Note

- Abstract and introduction section are very important
- Normally a reviewer can quite accurately predict (or decide) the reject/accept decision of a paper after finishing reading the abstract and introduction section
- Suggested actions
  - Iterate and improve the abstract and introduction in a small discussion group (e.g., read aloud)
  - Pay attention to the logical transitions in sentences in abstract and paragraphs in introduction section
  - Double check whether you convince readers that
    - The target problem is significant/important?
    - Your solution is significant/addressing non-trivial technical challenges

Technical Challenges

- Why listing challenges?
  - If your solution is so obvious and easy, you cannot impress readers/reviewers and justify significance
- Challenges from two levels (you can describe challenges at one or both levels)
- Problem-level challenges
  - Independently of any solution to the problem (e.g., static vs dynamic analysis), what are the challenges of addressing the problem?
- Solution-level challenges
  - For the style/direction that you will commit to (e.g., static in contrast to dynamic analysis; of cz, you need to justify why static not dynamic already here), what are the challenges of carrying out the solution to address the problem?

Challenges ➔ Contribution Points

- Normal structure of main contribution list:
  - The overall approach
  - A list of specific techniques in the approach
  - Implementation and evaluation
  - Evaluation results
- For each specific technique in your contribution list, you shall have at least one corresponding clearly articulated technical challenge
  - If your solution/technique is so obvious and easy, you cannot impress readers/reviewers and justify significance
- Alternatively, you may articulate technical challenges just for the overall approach

Background and Related Work

- Differences between background and related work (c.f. my ASE journal 06 paper)

- You can organize related work with subsections or group them in several categories

Related Work

- Don’t simply list related work without RELATING to your own work!
  - keywords to use: whereas, in contrast, but, however, …
  - “excuses” to use: “does not require specs”, “focus on different problems”, “complement with each other”, …
  - you can describe several similar related approaches together and compare them at once with yours
- Don’t just discuss the differences between your work with related work only in the solution space
  - Need to relate back to the effect/impact on the problem space
  - E.g., You may argue that your work uses dynamic analysis and related work uses static analysis --- but how would these two analysis types impact the problem you are addressing? Static analysis produces too many false warnings? … You need to compare them in terms of observable differences from the approaches’ user’s point of view in the problem space

Background and Related Work cont.

- Don’t make unjustified unobvious criticisms on related work if you don’t have experimental results to back you up.
  - But you can cite others’ experiments to back you up.
- Don’t overclaim your work without justification
- Don’t intentionally leave out your own very related previous papers (reviewers can find them out easily)
  - maybe even need to mention them in Introduction section and explain why the new work is different
  - reviewers often try to identify a marginal/incremental paper or a “least publishable unit (LPU)” (Google this term!)
- Put in PC members’ work if relevant

http://www1.cs.columbia.edu/~kaiser/relatedwork.htm

Related Work cont.

- Where to put the related work section
  - After the introduction/example section
  - Before the conclusion section
- After the introduction/example section
  - Pros: Immediately clear out reviewers' wonder on how the work differs from previous work
  - Cons: hard to let readers to know what you are talking about before showing the approach details
    - But it may be ok to put it after the example section (see next slide)
- Before the conclusion section
  - Pros: Now reviewers' know what your approach is about
  - Cons: reviewers keep wondering how the work differs from previous work till this point
    - But for very closely related work, you should have pointed out the differences in the introduction section

Example

- A simple example
  - Include: where it comes from; a figure listing source code; brief description
  - Throughout the paper, it is important to have illustrating examples for those places that contain “dry” descriptions of your approach
  - If you use several examples throughout the paper, you may not need a separate Example section.
- Optional/important part of the section: high level description of applying your approach on the example
  - describe inputs/outputs of your approach without getting into too much detail
  - very important if the later approach description involves heavy hard-to-understand formalisms
  - see my ASE 04 Rostra and TACAS 05 Symstra papers

Approach or Framework

- Generalize your work in an abstraction level, e.g., positioning it as a framework rather than a tool
  - What you develop should be beyond your own implementation
  - Then you are in a better position when you discuss limitations of your work
    - Inherent limitation of the framework?
    - Or limitation of your current particular implementation of the framework? [See my ASE journal 06 paper]
  - A workflow diagram is useful for explaining your framework
- Try to separate the ideas from (a particular) concrete implementation
  - But sometimes you have to mention it a bit and refer the readers to the implementation section.
- Explain some details with examples (even if you have illustrated your high level ideas in the example section)

Implementation

- What libraries you used in your tool
  - e.g., BCEL, Daikon frontend, Soot
- Detailed implementations of each step in your framework
- List complications of implementing a certain idea and how you get around them
  - if some complications are important and general, you may move them to the framework section.

Evaluation

- (Controlled) Experiment: good for tools that don't involve human interactions within the approach
  experiment writing structure:
  - Hypotheses/Questions to be answered
  - Measures you use to answer these questions (higher better?)
  - Experiment setup: a good number of subjects, some scripts, some third-party tools or reimplemented tools for comparison
  - Independent variables+dependent variables -> metrics
  - Experimental results
    - Illustrate how to read your table/diagrams (columns, x/y axis, etc.)
    - Explain what does the curve or data mean, e.g., "We observed that …", "The experimental results show …"
    - Summarize your findings, remember to get back to answer the hypotheses and questions; it is ok to have an undecisive or negative answer based on the experimental results
    - Optional: discussion subsection; or you can put it as a separate section
  - Sometimes you may not include cost (time/memory) in your experimental results but you need to at least discuss the analysis cost
  - Threats to validity: internal, external, and construct (see my TSE 05 paper); sometimes may not need that fined-grained type classification

Evaluation cont.

- Case studies, experiences, and examples are often good for
  - approaches with human involvements [experiments can also involve humans though]
  - approaches whose results are hard to quantify with numbers (see my ICFEM 05 paper)
  - approaches you don’t have a good enough number of subjects for controlled experiments
- Case studies
  - usually involve human subjects
  - often require careful preparation (tasks, questionnaires, interviews, etc.)
  - uncontrolled but just observe
  - lessons learned
- Feasibility studies: not directly assess or apply the approach on the real environment but give hints on feasibility
- Experiences/Examples
  - anecdotes; maybe just you are the one who are involved
  - You may use some wordings such as “Developers can click … to look for …”

Evaluation cont.

- Need explain evaluation results or describe your insights from the observed results rather than just describing the results
  - E.g., if some subjects' results are especially favorable or unfavorable, explain the reasons or even your hypothesis (wordings: "We suspect that …" "We hypothesize that …"). You may leave confirmation of these hypotheses to future work (e.g., on more experiments)
- Need describe "Experiment Designs"
  - E.g., factors (independent variables), treatments (one factor multiple treatments or one factor one treatment)
    C.f. "Experimental program analysis: A new program analysis paradigm." ISSTA 06
- Need hypothesis testing, t-testing especially if you want to say "A result is **significantly** better than B result"; statistically significant vs. practically significant
  - C.f. "Is mutation an appropriate tool for testing experiments?" ICSE 05

This slide made with contributions from S.C. Cheung at HKUST

Evaluation cont.

- What to be qualified as case studies? (more strict sense)
  - Must be conducted on real, uncontrolled industrial settings
  - If conducted at university settings, not qualified; then shall target at the experiment type (with a good number of samples); sometimes it may not be feasible to get a good number, can alleviate by writing if you can cite a pervious significant paper and state try your best to reach or go beyond their sample size; reviewers may be reasonable on it
- Case studies may also need hypothesis; in journals, even additionally need “rival hypothesis”
  - Different from “null hypothesis vs. alternative hypothesis” in experiments
    http://www.stats.gla.ac.uk/steps/glossary/hypothesis_testing.html
    C.f. “Statistical significance testing—a panacea for software technology experiments?” Miller JSS 04
  - E.g., Hypothesis: quality increases due to software inspection
    Rival Hypothesis: quality increases due to better working environments
  - C.f. Yin’s book on Case Study Research

This slide made with contributions from S.C. Cheung at HKUST

Evaluation cont.

- In evaluation (experiments or case studies), we write

Research question (first)
Hypotheses (then) [Optional]

- Research questions
  - Abstract, general, high level
- Hypotheses
  - Concrete, specific, often answers to the research questions
- In the experimental results, need describe how the results relate back to which hypotheses and how hypotheses relate back to which research questions

- When using colored figures, make sure you describe both colors and gray-scale in text (since people may read papers in black-white copy)

This slide made with contributions from S.C. Cheung at HKUST

Evaluation cont.

- Construct a project web including the evaluation subjects, evaluation results …
  (e.g., http://research.csc.ncsu.edu/ase/projects/carminer/)
  - If tool is releasable, release your tool here
  - If a demo video is available, put it up here (e.g., http://osl.cs.uiuc.edu/~ksen/cute/demo.htm)
- Why? Building **trust** on reviewers in your work and your results
- When doing manual verification/inspection/confirmation of your evaluation results (e.g., confirming real defects), use >=2 persons to do so. When these persons don't have consistent decisions, they need to discuss to reach a consensus. Describe such process in the paper.

Evaluation cont.

- Evaluation on real industrial code bases is good; however, these code bases are not in the public domain and therefore, other researchers cannot reproduce the results or compare their own approaches with the approach in the paper
- Solution:
  - Include both evaluations on industrial code bases AND open source code bases
- E.g., using “benchmarks”
  - Some areas such as fault localization have “de facto” benchmarks: siemens programs, space, ….
  - Note that often using only small siemens programs is not enough (e.g., in fault localization) and need additional large benchmarks
  - Check UNL SIR: http://sir.unl.edu/portal/index.html

Evaluation cont.

- Some guidelines on doing/writing experiments
  - "Experimental program analysis: A new program analysis paradigm." ISSTA 06 http://esquared.unl.edu/articles/downloadArticle.php?id=208 http://esquared.unl.edu/wikka.php?wakka=ExperimentalProgramAnalysis
  - http://www-users.cs.umn.edu/~heimdahl/ase08ds/AndrewsEvaluation.pdf
  - http://www.acm.org/crossroads/xrds7-4/empirical.html
  - http://www-static.cc.gatech.edu/~harrold/8803/Classnotes/
    - Notes of Weeks 18, 19, 20, and 21
- Some relevant papers/examples of doing/writing various types of evaluation
  - http://www.cs.washington.edu/education/courses/590n/04sp/
- Experiments vs. Case Studies
  - "Evaluating emerging software development technologies: lessons learned from assessing aspect-oriented programming" by Murphy et al. http://ieeexplore.ieee.org/search/wrapper.jsp?arnumber=799936
- A good book on case study research in general
  - "Case Study Research : Design and Methods" by Robert K. Yin
  - http://www.amazon.com/gp/product/0761925538/104-9365607-2004707?v=glance&n=283155

Evaluation cont.

- Better Empirical Science for Software Engineering, Basili and Elbaum, ICSE 06
  - http://csce.unl.edu/~elbaum/talks/PresentedICSE2006.ppt
- Preliminary guidelines for empirical research in software engineering, Kitchenham et al. TSE 02
  - http://csdl.ics.hawaii.edu/techreports/05-06/doc/Kitchenham2002.pdf
- FOSE 07: The Future of Empirical Methods in Software Engineering Research
  - http://www.simula.no/research/engineering/publications/Simula.SE.13
- Hints for Reviewing Empirical Work in Software Engineering Tichy ESE 00
  - http://www.springerlink.com/content/rr70j282h2k01960/
- Readings in Empirical Evaluation for Budding Software Engineering Researchers
  - http://csdl.ics.hawaii.edu/techreports/05-06/05-06.html
- Courses
  - http://www.cs.toronto.edu/~sme/CSC2130/index.html
  - http://www.cs.tut.fi/~pselonen/OHJ-1860/

Discussion

- Limitations and issues your approach/implementation currently cannot address
  - Optional: how are you going to address them in future work
- Other caveats (scope of your approach)
- It is often a good idea to list (obvious) limitations and discuss possible solutions for them rather than hiding them
  - Reviewers can often identify obvious limitations even if you don't state them; then they will criticize your work on these limitations (you often don't have a rebuttal against these criticisms in conference reviews).
  - If your paper discusses these obvious limitations as well as their potential solutions, the situation can be alleviated (it is like you have a rebuttal in your paper already before being criticized!).
- Possible applications of your approach that you haven't validated but are convincingly feasible or effective.
- See my TACAS 05 Symstra paper

Solution Characterization

- Related to insight
- Under what situations (e.g., characteristics of the software under test) your proposed solution would achieve the best results and under what situations your proposed (e.g., characteristics of the software under test) would achieve the worst results.
  - "killer apps“/show-off vs. turn-off cases
- You may discuss your solution characterization in the discussion section and/or conclusion section
- It depends whether you want to discuss your solution characterization in the introduction

Conclusions (and Future Work)

- Often easy to write conclusions
  - nothing here should surprise readers; simply summarize your contributions and findings
  - In the introduction, “We propose a new approach …”

  vs. In the conclusions, “We have proposed a new approach …”
- You can state the broader impacts of your approach
- You can optionally describe limitations and future work here if you don’t have a discussion section for them and propose future work

More Readings

http://people.engr.ncsu.edu/txie/advice/

- http://spoke.compose.cs.cmu.edu/ser04/course-info.htm
- http://www.cs.cmu.edu/~Compose/shaw-icse03.pdf
- http://infolab.stanford.edu/~widom/paper-writing.html
- http://www.cse.msu.edu/~chengb/Writing/intro-guidelines-stirewalt.txt
- http://www1.cs.columbia.edu/~kaiser/relatedwork.htm
- http://pag.csail.mit.edu/~mernst/advice/write-technical-paper.html
- http://www-bsac.eecs.berkeley.edu/~muller/jmems.web/sds_editorial_june_2003.pdf
- http://www.cs.berkeley.edu/~pattrsn/talks/writingtips.html

- Common Technical Writing Issues:
- http://www.csc.ncsu.edu/faculty/xie/publications/writeissues.pdf

- http://www.csc.ncsu.edu/faculty/xie/advice.htm#writing
- http://www.csc.ncsu.edu/faculty/xie/adviceonresearch.html
- http://www.csc.ncsu.edu/faculty/xie/publications/writingtools.html
- http://www.csc.ncsu.edu/faculty/xie/seconferences.htm

Example Papers with Good Writing

- Papers with analysis/testing algorithms
  - Su et al. http://www.cs.ucdavis.edu/~su/publications/
- Papers with experiments
  - Harrold et al. http://pleuma.cc.gatech.edu/aristotle/publications.php
  - Orso et al. http://www.cc.gatech.edu/~orso/papers/index.html
- Papers with case studies
  - Murphy et al. http://people.cs.ubc.ca/~murphy/research-papers.html
  - Robillard et al. http://www.cs.mcgill.ca/~martin/papers.html
- Other papers
  - Xie et al. http://people.engr.ncsu.edu/txie/publications.htm