Systems and Networking Ph.D. Qualifier Exam

Research Questions

Spring 2008

Students are expected to provide written answers to questions by 5:00 PM EST on Monday, January 28, 2008. Please e-mail your answers in PDF format to cameron@cs.vt.edu prior to the deadline. Late submissions will not be accepted.

There are six questions on this examination. Each of the six questions will be given approximately equal weight in determining the overall grade. However, as indicated below, the parts of each of the six questions are not necessarily given equal weight in determining the score for that question.

Read the questions carefully and address them fully. You are expected to deal with the questions as posed. Nevertheless, if you have substantial doubt about a question, or believe a question is flawed, please contact Dr. Kirk W. Cameron (cameron@cs.vt.edu) as soon as possible.

The parts of a question on this examination are varied in the level of knowledge and creativity required to provide a full and complete answer. Some parts of a question require only comprehension or application of the concepts presented in the readings on which the questions are based. Other parts of a question require analysis, synthesis, evaluation, or extension of those concepts. Although it is necessary to answer the former type of questions correctly, the grading of the examination will place greater emphasis on the answers to the latter form of questions. Many questions provide in an "instruction/hints" section offering additional guidance on the form of the desired answer and the relative emphasis to be given to each part in the grading.

Now that the exam questions have been released, we expect all discussions related to the exam, associated papers and related topics will cease as students are required to conduct their own work entirely to answer the qualifier questions. This examination is conducted under the University’s Graduate Honor System Code (http://ghs.grads.vt.edu/). Students are encouraged to draw from other papers than those listed below to the extent that this strengthens their arguments. However, the answers submitted must represent the sole and complete work of the student submitting the answers. Material substantially derived from other works, whether published in print or found on the web, must be explicitly and fully cited. For more information on proper citation of sources, we strongly recommend that you study the guidelines and examples given in Appendix IIIa of the Constitution of the Graduate Honor System. Note that your grade will be more strongly influenced by arguments you make rather than arguments you quote or cite.

The reading list for the Systems and Networking qualifier along with links to electronic versions of the papers, and important dates for exam results and oral examinations can be found at http://people.cs.vt.edu/~cameron/qualifier/2008/. For reference, the 2008 list of papers follows the questions in this document.
QUESTION 1: Virtual Hierarchies for Server Consolidation:

A. Explain in no more than a page the motivation for introducing a virtual coherence hierarchy for server consolidation on tiled CMPs. In addition to the motivation discussed in the paper by Marty and Hill, think of other reasons, or settings, whereby a virtual coherence hierarchy would be useful. *Hint: The answer to the first part of the question examines your understanding of the paper and entails at least two reasons for introducing VH. The second part of this question is open-ended and requires you to think out of the box. Consider workloads and applications that could clearly benefit from the work presented in the paper and think beyond virtualization.*

B. Explain in no more than one page the DRAM-DIR, TAG-DIR, and, STATIC-BANK-DIR directory cache coherence protocols. Discuss in detail the implications of the schemes in memory access latency and facilitation of isolation in dynamically space-shared tiled multiprocessors. *Hint: The answer examines your understanding of the related paper. You need to provide concise examples of how a protocol helps or hurts memory access latency and isolation.*

C. Describe the VHA and VHB second-level directory schemes in detail (one page maximum). Explain how the second-level directory names block locations in the first-level directories, and how the second-level directory resolves races and avoids deadlock.

D. If a system allows for dynamic reconfiguration and reassignment of resources to virtual machines, but maintains a one-level cache coherence protocol, what are the requirements by the OS/runtime environment in order to preserve correct operation?

E. The paper relies heavily on the concept of physical proximity between tiles (cores) and data, as a motivation for introducing virtual coherence protocols. Considering possible implications of VH for software, do you think that the VH idea is generally applicable on tiled architectures or does it assume additional software (OS, runtime, compiler,…) support so as to be effective? *Hint: This question requires critical thinking and is open-ended.*
QUESTION 2: Atomicity Violations:

A. Define precisely the terms “atomicity violation” and “benign races”. Provide examples of each of these “bugs”? Hint: The second part of the question can be answered either using information from the AVIO paper, or by considering common concurrent paradigms in general. You may use bibliography or personal experience. Providing your own examples will be considered a plus.

B. Define precisely access interleaving invariance. Explain why serializable accesses do not raise atomicity violations, and conversely, why not all interleavings of accesses to shared variables are unserializable.

C. Describe in less than a page the atomicity violation detection and extraction algorithms. Explain how the number and outcome of training runs may affect the result and why there is a possibility of false positives with these algorithms. Hint: the last part of the question essentially asks why incorrect runs may be mistakenly labeled as correct during the training process. You will need to think beyond the context of the paper to answer this question.

D. The AVIO paper discusses extensively the trade-off’s between hardware and software implementations of the proposed atomicity violation detection algorithms. Taking into account both the discussion in the paper and arguments of your own, if you were a developer of HPC applications characterized by relatively stable codes, long running times (e.g. hours or days) on say a cluster with state-of-the-art multi-core processors, and an absolute need for performance, which of the two atomicity violation schemes would you opt to use? Hint: None of the two answers here is “correct” in the traditional sense. You can answer “hardware” or “software”. Your grade will be based on the arguments you make for opting for one of the two schemes, based on your understanding of the workload.
QUESTION 3: Relative Fitness Modeling

In “Modeling the Relative Fitness of Storage,” Mesnier et al discuss the concept of relative fitness modeling as applied to storage.

A. Explain the concept of a relative fitness model. Compare and contrast relative fitness and absolute models.

B. Consider the application of a relative fitness model to other system domains. For example, are relative fitness models applicable to modeling the performance of microarchitectures, complex memory hierarchies, parallel systems, networks, etc. Answer the following questions.

1. Identify an example domain where you believe relative fitness models would be applicable.

2. Describe the applicability of relative fitness models to this domain. How would such predictive models be useful in practice? What would the benefits be to users? What variables in workload and system parameters would need to be accounted for in the model?

3. Provide equations based on those in the Mesnier paper that describe the relative fitness model in the domain you selected. Be sure any and all terms you use are well defined. Are you able to represent all the variables described in the previous question? Why or why not?

4. Describe the methodology you would use to determine the effectiveness of your proposed model for predicting relative performance in the domain you selected. What are your hypotheses? Which variables would you need to obtain measurements for? What techniques would you use to obtain the data? What experiments would you conduct to prove or disprove your hypotheses?

5. Evaluate your proposed approach. What are the pros and cons of the approach? What do you think would work? What do you think would not work or be difficult? Do you think this is something worth pursuing?

Instructions/Hints: Limit your answer to no more than 4 pages total. Part A tries to gauge your understanding of relative fitness models. Spend no more than 1 page on Part A. Part B asks you to apply the concept of relative fitness models to other domains. Pick a domain you are familiar with; one where you know the common workloads and the system characteristics. Research other absolute models in the domain you have chosen to gain perspective. Overall, try to propose a model that you think has a reasonable chance of being accurate on a real system. Be sure to justify all the parametric choices you make as well as the types of workloads you would use to validate your approach.
QUESTION 4: Memory Management

In “LIRS: An Efficient Low Interference Recency Set Replacement Policy to Improve Buffer Cache Performance,” Jiang and Zhang present a variation on the LRU algorithm.

A. Describe the limitations of LRU page replacement policy. Implement a synthetic application that emulates LRU page replacement policy given a series of accesses. This code should be at a granularity similar to the examples used in the paper. Describe your implementation as part of your answer to this question. Provide results from your application and describe the examples you used that show when LRU performs well and when it performs poorly. Be prepared to provide your source code at the request of the committee.

B. Modify your code to also implement an LIRS policy. Describe your modifications as part of your answer to this question. Provide results from your application that show the advantages of LIRS page replacement policy. Compare and contrast these results with your findings in part A. Does LIRS perform better, worse, or the same? Why? Be sure to describe step-by-step how the algorithm selects pages for replacement and provide quantitative results to support your claims.

Instructions/Hints: This question is designed to test your understanding of LRU and LIRS as well as your ability to demonstrate that understanding by creating examples that test the strengths and weaknesses of both. Writing source code is simply the tool we want you to use to solve the problem. Do not over implement here. You do not actually have to implement page replacement on your system – you’re just creating a program that emulates it using standard data structures and source code. A simple design in any language on any system will do. Your code should take as input a stream of references (e.g. 1, 5, 9, 12, 3, 3, 4), and the “size” of memory in pages (e.g. 5 pages or however many you need to illustrate your example). You can assume memory starts out empty, then allocations and replacements occur based on the input stream and the algorithm (LRU, LIRS). Be sure to track some metric of performance to compare the algorithms (e.g. number of misses or page replacements). Justify your choice. Use the paper as a guide for how to present the results in your solution. Since there are likely to be graphs in this answer, you can use up to 6 pages total to provide your answers. Do not include your source code. The committee will let you know if it is needed.
QUESTION 5: Distributed Hash Tables

A. Structured peer-to-peer (p2p) networks implement distributed hash table abstraction. Explain what this statement means. Reflect on the role of consistent hashing in enabling p2p systems.

B. Explain how the full-membership model employed in Amazon’s Dynamo system can help improve the performance of available DHT implementations. You can use any of the widely used DHT’s (Chord, CAN, Pastry) as an example or discuss using generic abstractions.

C. The usefulness of DHT’s is heavily dependent on uniform distribution of load to the participants. Under what conditions will a DHT become unbalanced? What do you see as some of the major drawbacks of an unbalanced DHT? Discuss ideas for maintaining a well-balanced DHT.

Instructions/Hints: State all your assumptions, and provide all references. Original ideas will be given more credit. Please limit your answers to a maximum of one page per part.
QUESTION 6: Sprockets

A. Reflect on the pros and cons of having an execution rollback mechanism in the operating system kernel. Give characteristics of operations where rollback is (a) not possible, and (b) not advisable. The Sprockets design shows that it is superior to the simpler fork-based approach. Give a specific example of a scenario where fork-based would be better.

B. Systems such as sprockets and nooks target safe execution of buggy software. What are the fundamental principles that provide safety in these systems?

C. Consider the widely used file system Network File System (NFS). Provide details of ACME – a new system designed by you, which employs the lessons learned from Sprockets to enable safe execution of NFS in standard environments.

D. Can the concepts of Sprockets be extended to enable speculative execution of an entire operating system? Discuss if such a design is possible, and if so what will be the key components of the design.

Instructions/Hints: State all your assumptions, and provide all references. Original ideas will be given more credit. Please limit your answers to a maximum of one page per part.
2008 Systems and Networking Ph.D. Qualifier Reading List


