Part 2: Science, Technology, Engineering, and Math (STEM) Research

Deadline: September 16, 2019 at noon

Instructions:
Work with your faculty advisor (and teammates, if applicable) to customize and complete this template according to your own project. Submit your customized template to the STSS at http://scholarsthesis.tamu.edu.

Contact

LAUNCH: UGR
ugr@tamu.edu
http://tx.ag/ApplyToURS
(979) 845-1957

Part 2 Planning Template Explained

Part 2 of the application is submitted through the Scholars Thesis Submittal System (STSS) at http://scholarsthesis.tamu.edu.

You will be asked for academic, project, faculty advisor information, and the proposal, research compliance questionnaire, and timeline document you see below.

In preparing your proposal, research compliance questionnaire, and timeline in a single document, keep in mind that the academic year you participate in the program should to be devoted to research, writing, and presentations.

The Undergraduate Research Scholars Thesis that results from your research should be more than a laboratory report or a literature survey; research uncovers new or novel approaches, or significant contributions to existing discussions in the field. It should be suitable for publication in a professional journal, for delivery at a scholarly conference, or exhibited at a competitive, exclusive external venue.

Remember that final theses must be completed by the final thesis submission deadline in April. Choose your research topic and plan your project accordingly with your faculty advisor.

General word count on the proposal should be around 1,000 words.

All red text should be replaced or rewritten with your own project-specific content.

Upload this file as a single document to the STSS. The document you upload to the STSS MUST include these THREE sections:

1. Proposal (1,000 words)
2. Research Compliance Questionnaire
3. Timeline

The proposal you need to customize begins on the next page.

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Reminder: Replace the red text with your own words.

Proposal (required)

Update the red text below with your project-specific content. All sections below are **required**.

1. **UIN:** 425003497
2. **FULL NAME:** Troy Fulton
3. **PROPOSAL TITLE:** Active Routing: Parallelization and Scheduling of 3D-Memory Vault Computations
4. **PROJECT SUMMARY**

Recently, the demand for analysis on large data sets has dramatically increased, and in order to keep up with the increasing need for computation in large, multicore systems with several memory units, On-Chip Networks have been widely accepted as the most effective way to move data from one unit to another on a System-On-Chip (SoC). Recently, 3D memory cubes known as Hybrid Memory Cubes (HMC) configured as a grid of DRAM vaults with a logic layer for performing simple computations in memory have emerged as a new memory architecture. Research proposed by Dr. E. J. Kim for "on the way" computations in the form of "Active Routing," which takes advantage of a network topology of HMCs to perform certain computations in memory, suggests up to 7x runtime improvement [1]. We propose that such aggregate computations can be further parallelized by strategically dispatching in-memory computation to separate vaults within each memory cube. After implementing such parallel computations, we plan to investigate if performance can be further improved by dynamically scheduling such computations among the vaults available to the network. Using an architecture simulation testbed for SoCs, we will implement these proposed techniques and assess their performance using industry standard benchmarks.

5. **INTRODUCTION**

For much of the history of computer architecture since the mid-1980s, there has been a significant, growing gap between CPU latency and that of memory [2]. To address this memory gap, researchers have designed new memory systems to increase memory bandwidth that extend into the third dimension with Through-Silicon Vias (TSV), such as Hybrid Memory Cubes (HMC) [3]. By stacking layers of DRAM on top of a logic layer, 3D memory not only makes memory denser, but also allows for Processing-in-memory (PIM). This means that when the CPU requests data for just a simple arithmetic operation, it can be computed in memory without ever making the time-consuming journey to the CPU, which causes bottlenecks in data-intensive applications.

Often, so much memory is consumed by programs that several of these memory cubes are needed to store large data sets. For components such as these to communicate with one or more CPUs (cores), an interconnection network known as an On-Chip Network is necessary [4]. Since each component of an On-Chip network has a network interface, each component can communicate with other network components by sending and receiving packets of data and interpreting them accordingly. Thus, for the CPU to receive data from

memory or to offload computations to memory, it must send a packet to the right HMC unit and wait for the data before it can do anything with it.

Because many algorithms, such as machine learning, depend on processing large data sets in memory, there is an increased need to improve this memory access latency by taking advantage of the fact that these memory cubes can perform PIM across an On-Chip Network. Since many algorithms in machine learning tend to follow common memory access patterns, such as extracting the dot product of two matrices, researchers have developed ways to optimize these patterns in hardware. One way these patterns can be optimized is by implementing an "Active Routing" Algorithm, introduced by E.J. Kim, where the topology of the network and locations of the data across the network are used to construct an active routing "tree," such that intermediate computations can be done on the data "on the way" to the CPU along the tree [1].

In order to lower this latency, I propose that the active routing tree can be further granularized to the level of each vault of a memory cube. The current implementation of Active Routing simply contains one "Active Routing Engine" per HMC, which handles all the processing for the cube. However, since HMCs are further divided into vaults with their own space for computational power, it is worth investigating how much more computation can be done at once with the additional hardware. Since data for an operation are often found together in a vault, computation done in vaults should theoretically improve performance of the active routing algorithms because data are spatially local to each other and to their logic unit.

In the current implementation of "Active Routing," data are aggregated in the network based on the path that the packets took to get to the memory cube, without considering the network congestion at those points. I propose that by dynamically scheduling computations in other, perhaps nearby cubes, the load of computing aggregate data can be balanced across the network. Finally, with vault-level parallelism implemented, I can modify this algorithm to take advantage of the least busy vaults throughout the network to improve the performance of such computations, generating better throughput for the network.

6. **OBJECTIVES/GOALS**

My goal is to formulate and implement an algorithm for dividing the computations done in HMCs among the vaults of the logic layer, as well as a scheduling algorithm for scheduling computations at vaults across the network. If computations performed in on-chip memory networks can be divided between the vaults of an HMC and Active Routing Algorithms can dynamically schedule computations to take advantage of such, then the performance of the network will measurably improve.

7. **METHODOLOGY**

Under the direction of Dr. E. J. Kim and Jiayi Huang, I plan to use similar methodologies to those used in the Active Routing Paper mentioned above (seen in Table I) [1]. There are several benchmarks used for measuring the performance of

matrix operations like those used in Machine Learning algorithms for which our lab has an implementation. By running these algorithms through McSimA+, a simulator for CPU including cores and caches that generate active routing packets, with my implementation of the proposed algorithms in the HMC microarchitecture, I will be able to measure the power consumption of the system and network heuristics. Since the source code is on GitHub, I will only need access to my TAMU GitHub account and the computational power to run simulations and measure performance.

8. **REFERENCES/BIBLIOGRAPHY/WORKS CITED**

[1] J. Huang, R. Reddy Puli, P. Majumdar, S. K. Kim, R. Boyapati, K. H. Yum and E. J. Kim, "Active-Routing: Compute on the Way for Near Data Processing, " in *Proceedings of 25th IEEE International Symposium on High Performance Computer Architecture (HPCA)*, Washington D.C, USA, February, 2019.

[2] J. Hennessy and D. Patterson, "Memory Hierarchy Design," in *Computer Architecture: A Quantitative Approach*, 6th ed. San Mateo, CA, USA: Morgan Kaufmann (Publishers, Inc.), 2019, pp. 80.

[3] K. Kondo, M. Kada, K. Takahashi, Eds. *Three-Dimensional Integration of Semiconductors: Processing, Materials, and Applications.* Switzerland: Springer, Cham, 2015. Accessed: Sept. 10, 2019. [Online]. Available: https://onecellonelightradio.files.wordpress.com/2018/11/three-dimensional-integration-of-semiconductors-2015.pdf

[4] N. Jerger, T. Krishna, and L. Peh, "Introduction," in *On-Chip Networks*, 2nd ed. San Rafael, CA, USA: Morgan & Claypool, 2017, ch. 1, sec. 1.1, pp. 1-2. [Online]. Available: https://www.morganclaypool.com/doi/pdf/10.2200/S00772ED1V01Y201704CAC040

Research Compliance Questionnaire (required)

Projects *may* require research compliance approval through the Research Compliance and Biosafety office (http://rcb.tamu.edu) if they involve:

- Human subjects,
- Vertebrate animals, and/or
- Biohazards and Biosafety

All students pursuing the Undergraduate Research Scholars program are required to discuss research compliance with their faculty research advisor before submitting an application.

If you select YES in any of the categories on the next page: Upon approval of your application, you will be placed in the PENDING COMPLIANCE APPROVAL status until your project has been verified. Your proposal will be directed to the appropriate committee(s) within the Research Compliance & Biosafety office for verification. The verification process may include a request to make revisions to your proposal for missing or unclear information. Students and faculty advisors will be required to communicate directly with the appropriate committee(s) until approval has been received. The Research Compliance & Biosafety office will notify the LAUNCH: Undergraduate Research office directly once your project has received all required approvals.

Important Notes:

- The student's name must be included on any existing or new IRB or IACUC protocols and/or the IBC permit.
- This is not an all-inclusive list of all possible required compliance approvals. Check http://rcb.tamu.edu for full information.
- The URS program deadline for projects to receive approval from the Research Compliance & Biosafety office is February 24, 2020.

The Questionnaire you need to complete begins on the next page.

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All applicants must read and respond to every item on this page.

Do not remove this page.

Human Subjects

Does your research involve:

Information or biological samples from or about living humans including survey data; interviews; oral histories; recordings (voice, video, or images); observation of people; data from social media sites; human cells or tissue; etc…?	☐YES ☒NO
Classroom research including educational practices, instructional strategies, educational tests, or observation of students?	☐YES ☒NO
The study, evaluation, or examination of the benefit of service programs?	☐YES ☒NO
Taste tests or consumer acceptance studies?	☐YES ☒NO
If YES to any of the above, list any existing IRB protocol number(s) (20XX-XXX). Ask your faculty advisor for these numbers.	Click or tap here to enter text.

Vertebrate Animals

Does your research involve:

Vertebrate animals	☐YES ☒NO
Animal tissues/cell lines	☐YES ☒NO
If YES to any of the above, list any existing IACUC protocol number(s) (20XX-XXX). Ask your faculty advisor for these numbers.	Click or tap here to enter text.

Biohazards and Biosafety

Does your research involve:

Human tissue/cell lines?	☐YES ☒NO
Recombinant DNA/transgenic animals, plants?	☐YES ☒NO
Agents infectious to humans, animals, or plants?	☐YES ☒NO
If YES to any of the above, list any existing IBC permit number(s) (20XX-XXX). Ask your faculty advisor for these numbers.	Click or tap here to enter text.

Project Timeline (required)

Update the red text below with your project-specific content. The text in red is a suggested guide for helping you think about ways you might plan your project. The text in black should remain unchanged.

This is not just a cut-and-paste template. You are required to modify the portions in red to fit your specific project and submit your customized document file to the STSS at http://scholarsthesis.tamu.edu.

This is a good time to talk to your faculty advisor as your work through the design of your own personal "class" (a.k.a. your research project). Treat your customized timeline as your "syllabus" and document the steps you need to take to complete all necessary components of your research project from preparation to draft to polished final product.

Remember that your thesis must be completed within the scope of the URS program dates (final thesis due on April 6).

The timeline you need to customize begins on the next page.

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URS Program Deadlines and Events
Fall 2019 Semester

Fall Weeks	Date	Description
3	9-Sep-19	Research Compliance Drop-in Session *(optional)*
4	16-Sep-19	Application Deadline
7	TBA-Oct-19	Galveston Students Only: Orientation and Workshops (required)
8	14-Oct-19	College Station Students Only: Orientation (required)
8	15-Oct-19	Research Compliance Drop-in Session *(optional)*
8	18-Oct-19	Qatar and Dental Hygiene Students Only: Orientation and Workshops Test Deadline (required)
9	22-Oct-19	Citation Software Drop-in Session *(optional)*
9	25-Oct-19	Thesis Help Drop-in Session *(optional)*
10	28-Oct-19	First Installment and Progress Report Deadline *(required)*
10	1-Nov-19	POWER Writing Productivity Workshop *(optional)*
11-12	8-12-Nov-19	Thesis Submission and Formatting Training *(required)*

Reminder: Replace the red text with your own words.

Fall Weeks 1-9 Goals:

- Brainstorm/Begin a project notebook.
- Literature search: Practice running simulations using McSimA+ and become familiar with the toolchains/framework.
- Structure the thesis outline to include the two ideas of vault-level parallelism and dynamic scheduling in one coherent idea of how to improve active routing.
- Weekly project meetings with faculty advisor: Report results of weekly progress, discuss blocking issues, and detail plans for the next week.
- Discuss when and where you will present your work publicly.
- Discuss the need for research compliance approval with your faculty advisor.
- Identify what training you need and when you will complete it.
- Meet with your faculty advisor to determine the frequency of meeting times throughout the semester and what you will accomplish at each meeting.

Fall Weeks 9 and 10 Goals:

- At this point, clarify the hypothesis in terms of the expected outcomes for improved network performance. The thesis statement should more clearly reflect how vault-level parallelism and dynamic scheduling can improve active routing. To get ready for the first installment deadline, present current writing to faculty advisor.
- Literature review: Survey the related works on In-Memory Computing and In-Network Computing.
- Adjust the research plan according to the progress and findings of the current research stage.
- It is expected that there will be a lot of debugging in the research development process when trying to implement these new algorithms in the simulator. When faced with these issues, seek advice of Dr. E.J. Kim and Jiayi Huang.
- Keep track of approaches taken so far and the results of these experiments. Summarize research findings and results in the past few weeks in a research notebook.
- Adjust the thesis outline according to the progress and findings of the current research stage.
- Weekly project meetings with faculty advisor: Report results of weekly progress, discuss blocking issues, and detail plans for the next week.
- Identify a venue for a public presentation.
- Have you received all research compliance approvals and/or been added to all necessary protocols? NA

Fall Weeks 11, 12, and 13 Goals:

- Finalize your thesis statement/hypothesis/research question/problem.
- Literature review: Survey more recent related work to the research problem.
- Conduct experiments, collect and processing research results, and discuss and analyze the research findings.
- Keep track of approaches taken so far and the results of these experiments. Summarize research findings and results in the past few weeks in a research notebook.
- Draft content for second installment and progress report submissions.

- Weekly project meetings with faculty advisor: Report results of weekly progress, discuss blocking issues, and detail plans for the next week.

Fall Weeks 14 and 15 Goals:

- Literature review: Survey more recent related work to the research problem.
- Conduct experiments, collect and processing research results, and discuss and analyze the research findings.
- Implement the new vault-level parallelism algorithm by extending active routing and quantify its improvements from the original implementation using well accepted benchmarks in terms of the heuristics described in the thesis statement.
- Keep track of approaches taken so far and the results of these experiments. Summarize research findings and results in the past few weeks in a research notebook.
- Writing process: Write a rough draft of the introduction and the sections about vault-level parallelism, as well as the related result sections. Show rough draft to faculty advisor.
- Weekly project meetings with faculty advisor: Report results of weekly progress, discuss blocking issues, and detail plans for the next week.
- Draft content for second installment and progress report submissions.
- Have you considered submitting your project to *Explorations: The Texas A&M Undergraduate Journal (*http://explorations.tamu.edu*)?* Remember that *Explorations* has a new digital platform in addition to the traditional printed journal.

Fall Weeks 16 and 17 Goals:

- Literature review: Survey more recent related work to the research problem. Research solutions to common scheduling problems to build my background on the topic.
- Conduct experiments, collect and processing research results, and discuss and analyze the research findings.
- Once the vault-level parallelism implementation is complete, begin identifying possible bottlenecks in the current active routing scheduling algorithm for the second installment.
- Keep track of approaches taken so far and the results of these experiments. Summarize research findings and results in the past few weeks in a research notebook.
- Weekly project meetings with faculty advisor: Report results of weekly progress, discuss blocking issues, and detail plans for the next week. Discuss the results of vault-level parallelism and summarize the findings in writing.
- Writing process: Improve the current draft by including the results of vault-level parallelism discussed above. Polish the introduction to include the initial draft of the background for the scheduling algorithm.
- Draft content for second installment and progress report submissions.
- Have you considered submitting your project to *Explorations: The Texas A&M Undergraduate Journal (*http://explorations.tamu.edu*)?* Remember that *Explorations* has a new digital platform in addition to the traditional printed journal.

URS Program Deadlines and Events
Spring 2020 Semester

Spring Weeks	Date	Description
1	13-Jan-20	UGST 405-900 Begins in Spring 2020 *(optional)*
2	24-Jan-20	Writing Abstracts Workshop *(optional)*
2	24-Jan-20	Thesis Help Drop-in Session *(optional)*
3	27-Jan-20	Second Installment and Progress Report Deadline (required)
3	29-Jan-20	URS Symposium Registration Deadline *(optional)*
6	18-Feb-20	Presentation Skills Workshop *(optional)*
7	24-Feb-20	Research Compliance Approval Cut-off (required)
7	25-Feb-20	Presentation Practice Session *(optional)*
7	26-Feb-20	URS Symposium *(optional)*
7	28-Feb-20	Thesis Help Drop-in Session *(optional)*
8	2-Mar-20	Third Installment and Progress Report Deadline (required)
12	30-Mar-20	College Station Students Only: Presentation Report Deadline (required)
12	2-Apr-20	Thesis Help Drop-in Session *(optional)*
12	3-Apr-20	Thesis Help Drop-in Session *(optional)*
13	6-Apr-20	Final Thesis Deadline (required)
15	20-Apr-20	Galveston, Qatar, and Dental Hygiene Students Only: Presentation Report Deadline (required)

Reminder: Replace the red text with your own words.

Spring Weeks 1-3 Goals:

- Finalize the thesis outline and timeline according to the research progress and goals.
- Finish the literature review and write the survey of previous work section in the thesis draft.
- Draft Bibliography. Start embedding references in the thesis using BibTeX techniques learned from previous workshops.
- Conduct experiments, collect and processing research results, and discuss and analyze the research findings. Implement the scheduling algorithm in the simulator framework.
- Keep track of approaches taken so far and the results of these experiments. Summarize research findings and results in the past few weeks in a research notebook.
- Draft and submit content for second installment and progress report submissions.
- Weekly project meetings with faculty advisor: Report results of weekly progress, discuss blocking issues, and detail plans for the next week.
- Tentatively plan to present at the URS Symposium in February or another alternative. Make sure the public presentation includes the LAUNCH and Undergraduate Research Scholars program logos.
- Have you received all research compliance approvals and/or been added to all necessary protocols? Have you completed all required training? **Cut-off deadline: February 24**
- Have you considered submitting your project to *Explorations: The Texas A&M Undergraduate Journal (*http://explorations.tamu.edu*)?* Remember that *Explorations* has a new digital platform in addition to the traditional printed journal.

Spring Weeks 4-8 Goals:

- Draft thesis project outline and Bibliography.
- Make corrections to your second installment, if requested.
- Draft and submit content for third installment and progress report submissions.
- Keep track of approaches taken so far and the results of these experiments. Summarize research findings and results in the past few weeks in a research notebook.
- Conduct experiments, collect and processing research results, and discuss and analyze the research findings. Finish the implementation of the scheduling algorithm.
- Draft content for the third installment and progress report to include an update on the new scheduling algorithm.
- Weekly project meetings with faculty advisor: Report results of weekly progress, discuss blocking issues, and detail plans for the next week.
- Have you received all research compliance approvals and/or been added to all necessary protocols? Have you completed all required training? **Cut-off deadline: February 24**

Spring Week 9 (Spring Break)

Spring Weeks 10 and 11 Goals:

- If you have already made a public presentation, begin drafting the presentation report through eCampus.
- Send the latest draft of your final thesis to your faculty advisor for review before the April 9 deadline.
- Make corrections to third installment, if requested.
- Conduct experiments, collect and processing research results, and discuss and analyze the research findings.
- Continue revising final draft of your thesis.
- Weekly project meetings with faculty advisor: Report results of weekly progress, discuss blocking issues, and detail plans for the next week. Discuss the results of the scheduling algorithm and summarize the findings in writing.

Spring Weeks 12 and 13 Goals:

- Weekly project meetings with faculty advisor: discuss research progress and written thesis content.
- Submit public presentation report by the March 30 deadline.
- If you have not already sent the latest version of your final thesis to your faculty advisor, do so now.
- Continue revising your final thesis. Pay particular attention to the Common Mistakes page in the Thesis Manual and make sure your document is uniformly formatted throughout.
- Talk to your faculty advisor about the appropriate embargo selection for your thesis.
- Familiarize yourself with the final thesis submission process. Read the instructions guide and attend a drop-in session.
- Define keywords for the final thesis submission. Finalize your abstract for the final thesis submission.
- Submit the final thesis by the April 6 deadline.

Spring Weeks 14 and 15 Goals:

- Once you are approved in eCampus, complete your final submission in the Scholars Thesis Submittal System (STSS). This includes uploading a completed abstract, keywords, and embargo selection.
- Complete the program exit survey.
- Make corrections to your final thesis, if requested, for both parts 1 and 2.
- Final submission to the STSS after approval in eCampus.
- If you are graduating in May 2020: RSVP for the LAUNCH Recognition Ceremony to receive your URS medallion!
- GALVESTON, QATAR, AND DENTAL HYGIENE STUDENTS ONLY: April 20 at noon, Deadline to make a public presentation and submit a Presentation Report through eCampus.
- Submit a paper draft to a journal for publication.