Research STATEMENT

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Introduction: Research Philosophy

My research philosophy revolves around the belief that successful systems research has to demonstrate two things: 1) a novel and interesting approach to an important research problem, and 2) usability. I strongly believe that for a system to be successful, it has to be usable by the target audience. On the other hand, a highly usable system that doesn't advance the state of the art in any way is not particularly interesting from a research perspective either.

My research style is strongly systems-oriented with a large emphasis on hands-on system implementation. A real implementation is crucial, in my opinion, for testing complicated distributed systems as the complexity inherent in these systems is incredibly hard to capture by simulation studies alone. A real implementation is also vital in validating the usability of the system. In addition, the software artifacts from such implementations are important contributions that drive future research and even product development in the area. I am also a strong proponent of collaborative research. Modern systems are so complicated that it is impossible for one person to have all the answers to every problem encountered. As such, I tend to work with at least 2 to 4 other people, each with slightly different skills and backgrounds, to tackle a large systems problem. This multi-disciplinary approach is very apparent in all my research undertakings.

Finally, I strongly believe that it is better to take more time and do something well and then submit it to the best venue possible instead of submitting piece-meal as research is finished. As such, even though my total number of publications may not be that high, almost every publication is published in the top venue (ICSE, FSE, MobiSys, Infocomm, etc.) for that research area. I describe some of these undertakings along with avenues of future research in the next few sections.

Overview of Key Research Milestones and Awards

1) Published numerous top-tier research papers in venues such as MobiSys, ICSE, FSE, and Infocomm
2) Co-Director of the LiveLabs Urban Lifestyle Innovation Platform. This is a large effort involving multiple external partners and I have been involved from the conceptual stage all the way to the current research and operational aspects.
3) Obtained over SGD $12 million in government research funding in the last 6 years. The funding is as follows:
   a. MOE ACRF Tier 2 entitled "Power and Network-Aware Software Infrastructure for Multiplayer Mobile Games". This project was worth ~ SGD $1 Million and I was the principal investigator. The other two co-PIs were from NUS. This project was from December 2008 until May 2012.
   b. MOE ACRF Tier-2 Grant entitled "Energy-Efficient Stream Analytics on Smartphones for Realtime Contextual Insight". This project is worth ~ SGD $1 Million and I am the co-principle investigator (Archan is the main PI). The project duration is from January 2012 until January 2015.
c. The LiveLabs Urban Lifestyle Innovation Platform. We obtained SGD $10 million from Singapore’s National Research Foundation (through the Interactive Digital Media Office of the Media Development Authority) for this research initiative. In addition, this tested is expected to receive matching amounts of funding from our industry partners. I am a co-director of this platform and was instrumental in its conceptualization, funding drive, and current operations. The platform is officially funded from April 2012 until March 2017.

4) 2 ACM SIGSOFT Distinguished Paper awards for our work in empirical software engineering.

5) High visibility in the ACM SIGMOBILE community with invitations to serve as program chair and the steering committee of HotMobile (the top workshop) and to serve on the program committee of MobiSys (the top conference) for the last five years.

6) Numerous systems (such as mFerio, myDeal, the LCD and OLED power management systems, and our indoor location system) that have been demoed to various companies and researchers as well as one system (the taxi trip prediction system) that has been deployed into a production data center.

Primary Research Theme – Mobility

My research revolves around the central theme of mobility. However, I take a holistic view of the theme and look at the problem of mobility from multiple perspectives and in different scenarios. In particular, my research can be characterized into three broad areas: applications, infrastructure, and organizations and processes.

- **Applications** – In this space, I focus on new and novel mobile applications that either extends an existing domain in interesting ways or which enable whole new usage paradigms.

- **Infrastructure** – In this space, I build, develop, and test infrastructure support that either makes it easier to add new applications to a mobile device, makes specific types of mobile applications run more effectively in a mobile context, or allows efficient and effective testing of mobile solutions.

- **Organizations & Processes** – In this last space, I look at the issues involved when organizational processes, in an IT setting, become mobile. In particular, I analyze the issues involved in distributed software development and I am planning to look at the issues involved in migrating enterprise systems from one platform to another.

The timeline below summarizes my various research initiatives and places them into the three areas described above.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Start</th>
<th>End</th>
<th>Description</th>
<th>Collaborators</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peer-to-peer easy to use secure mobile payments</td>
<td>2006</td>
<td>2008</td>
<td>We built the mFerio system to allow users to exchange currency, using NFC, by just tapping their phones. The key innovation here was to do it without infrastructure support and in a highly usable fashion</td>
<td>Narayan Ramasubbu (University of Pittsburgh) Jason Hong and Nicolas Christin (CMU)</td>
<td>mFerio was prototyped on Nokia 6131 NFC phones and tested with 75 participants. Research results have been reported in IEEE Computer article and in a full MobiSys research paper. It has been demoed to Tagit, NETS, EZ-Link, MAS, and IDA.</td>
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<td>myDeal</td>
<td>2008</td>
<td></td>
<td>This applications automatically identifies the best deals for a particular user</td>
<td></td>
<td>myDeal won a SMU Innovation award and could</td>
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<tr>
<td>Research Area</td>
<td>Year1</td>
<td>Year2</td>
<td>Description</td>
<td>Authors</td>
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<td>User-Centric Mobile Authentication</td>
<td>2008</td>
<td></td>
<td>We created <em>HuMan</em>, a system that generates questions based on past user interactions on their cell phones. The hypothesis is that these questions will allow the user to login without needing to memorize any passwords while still preventing adversarial attacks.</td>
<td>David Lo and Debin Gao (SMU)</td>
<td>We tested HuMan on Nokia and Android smartphones (with 80 participants in total). Our results have been reported in a Ubicomp publication.</td>
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<td>Infrastructure Research</td>
<td></td>
<td></td>
<td>akiticry</td>
<td>Mahadev Satyanarayanan and James Herbsleb (CMU)</td>
<td>I created a full system, called <em>Chroma</em>, for porting large applications to a mobile device. Chroma has been described in two top-tier MobiSys publications.</td>
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<tr>
<td>Cyber Foraging</td>
<td>2000</td>
<td>2006</td>
<td>This was my thesis work which I continued at SMU for a while. I created a methodology and run-time infrastructure for porting large computationally-intensive applications to resource-constrained mobile devices. Note: I have not continued this research after leaving CMU.</td>
<td>Mahadev Satyanarayanan and James Herbsleb (CMU)</td>
<td>I created a full system, called <em>Chroma</em>, for porting large applications to a mobile device. Chroma has been described in two top-tier MobiSys publications.</td>
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<td>Massively Multiplayer Mobile Games</td>
<td>2008</td>
<td>2011</td>
<td>This project aims to develop mechanisms to improve the energy usage of mobile phones while they are playing games.</td>
<td>A. L Ananda and Chan Mun Choon (NUS)</td>
<td>Awarded ~$1,000,000 MOE Tier 2 Research Grant. I am the project PI. Published a series of research papers (in MobiSys, Infocomm, and other venues) showing how to save power for the display and network components.</td>
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<td>Improving the operations of a large Taxi fleet</td>
<td>2008</td>
<td></td>
<td>In this project, we are working with a large local taxi operator to analyze and improve their fleet operations.</td>
<td>Jason Woodard, Cheng Shih-Fen, Kim Youngsoo, Jiang Lingxiao, and David Lo (SMU)</td>
<td>We have built and deployed a system for identifying the fare and duration of any taxi trip a-priori. This work was described in a MobiSys paper. We are currently building a system to detect passenger demand with any inputs from the passengers themselves.</td>
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<td>LiveLabs</td>
<td>2010</td>
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<td>The goal of LiveLabs is to build an in-situ testbed (deployed at a university, a public mall, a resort island, and an airport) that will allow the testing of mobile applications, incentives, and interventions on real phones owned by real people in real time in real environments.</td>
<td>Archan Misra (SMU)</td>
<td>We have obtained SGD $10 million in funding from the Singapore government. We have agreements with the airport, mall, and island owners to deploy LiveLabs at their venues. We have 15 full time staff and students building the required LiveLabs software systems. We officially launched LiveLabs in Nov 2011 (event was graced by Singapore’s Deputy Prime Minister).</td>
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Minister) and we had a soft launch of the software at SMU in Oct 2011.

Organizations & Processes Research

| Distributed Software Development | 2006 | In this project, we analyze the issues involved with distributed software development. In particular, we analyzed the efficiency of Indian out-sourcing companies and highlighted inefficiencies in their processes along with remedies for those inefficiencies | Narayan Ramasubbu (University of Pittsburgh) | We have done really well with this research theme, producing three top-ranked conference publications (FSE and ICSE) with two papers winning ACM SIGSOFT Distinguished Paper Awards. |
| Cost Estimation for Distributed Project | 2008 2012 | In this project, we develop a new cost estimation method for distributed software projects. Our estimation method uses CASE-based reasoning techniques and incorporates the intrinsic nature of distributed software development into its decision framework. | Narayan Ramasubbu (University of Pittsburgh) | Narayan, the project PI, implemented the CASE-based solution at three Indian software companies and showed that the solution is better than the existing industry-standard estimation methods. This work was described in an ICSE paper. |

In the rest of this statement, I describe the more interesting projects from each of the three areas described above.

The LiveLabs Urban Lifestyle Innovation Platform

LiveLabs in a nutshell can be described as follows: We are allowing 3rd party researchers and companies an opportunity to test their mobile applications, incentives, and interventions on the real phones of real users in real environments in real-time. Currently, we are scheduled to provide service at the SMU university campus, a large public shopping mall, Singapore’s Changi Airport, and Singapore’s premier leisure and tourism island (Sentosa). We will allow this functionality by installing a small application on each participant’s smartphone (with their permission of course). This application will report the location and current preferences and context of that participant to the LiveLabs servers. LiveLabs will then use this information to match the participant with the appropriate applications, incentives, and interventions. A key requirement for LiveLabs is to preserve the privacy of the participants and we do this by isolating the participants from the testing companies. In particular, LiveLabs acts as the middleman between researchers and companies and the participants – they do not interact directly. If the LiveLabs vision comes through, companies and researcher will get incredibly high-fidelity testing of their mobile solutions while the participants will receive incentives, applications, and interventions only when they want it at a time and location when they can use it. i.e., nothing a participant receives should be treated as spam by that participant. For example, a participant will receive a discount for coffee just when they reach the coffee store instead of receiving it at home many hours earlier.

This is a very ambitious project that will occupy my full attention for the next few years. If successful, it will greatly benefit the mobile computing community. To understand the LiveLabs goals, visions, and techniques in more detail, please refer to the attached 2-sided pamphlet as well as the attached white paper. Finally, to understand the benefits of LiveLabs to participants, please watch the “A Day With LiveLabs” video available at [http://apollo.smu.edu.sg/video](http://apollo.smu.edu.sg/video)
We currently have three accepted LiveLabs-related papers - a HotMobile paper, a Mobile Computing Review journal paper, and a COMSNETS paper.

Key Publications:

Reducing the Energy Consumption of Mobile Displays

A key research area has been looking at reducing the power consumption of mobile devices. There have been many previous solutions for reducing the power consumption of the CPU and network components of mobile devices. However, there is not much related work in reducing the power consumption of the mobile display --- which is odd given that the mobile display, when turned on, consumes at least 40-50% of the total power consumption of the device. However, any power conservation technique must not affect the user experience as the user is usually looking at the screen. In this stream of research, we first looked at mechanisms for reducing the power consumption of LCDs. Our solution is quite simple in theory but works brilliantly in practice. In a nutshell, we increase the brightness of the image being displayed and then compensate by reducing the brightness of the LCD backlight. This reduction in the backlight can save tremendous amounts of power. We implemented our solution in a fast-paced games and showed, via a user study with 60 participants, that we could save up to 40% of the display power with no impact on usability. This translates to an extra 4 to 8 hours of phone lifetime for free!

We then moved on to look at OLED displays which are increasingly common on newer smartphones (especially those from Samsung). These displays are harder to save energy with as they don’t use a backlight. Our solution is to darken portions of the screen that are “less important” to the user. We implemented our solution in the Android kernel and tested it with 13 popular applications (Facebook, Twitter, WhatsApp, Firefox, Email, etc.) and 2 games and achieved up to a 40% reduction in the display power consumption. A user study with 30 participants showed that, even though our solution was quite noticeable, it was still very usable. The perceived usability increased even more once the participants understood how much power (with the corresponding increased phone lifetimes) they could save. This work was published at UbiComp 2013 and was very well received.

Key Publications
Improving the Efficiency of Singapore’s Taxi Networks

I had the opportunity, in 2007, to talk to the senior management of Singapore’s largest taxi company. They explained that they were looking for advanced R&D to help them solve some of the problems that they (being a hands-on logistics company) did not have the capability to solve. I readily took up the challenge as a great opportunity to impact a real company. The first solution we developed for them was a system to predict, a-priori, the expected fare and time for any taxi trip. This is particularly complicated in Singapore as there are various time and location based charges that affect the final taxi fare. In addition, congestion is also location and time correlated. Our solution was to build a super-fast system that is able to, in real-time, compute the expected time and fare for any two points in Singapore (accurate to within 100m for both the start and end positions). The system uses machine learning techniques to quickly find similar historical trips. It then uses those historical trips, coupled with aggressive outlier filtering, to compute an expect fare and time for the proposed trip. Our solution runs in real-time and has an average error of SGD $1 for the fare and 2 minutes for the time. The company was quite excited by these results and we proceeded to install the system in their data center.

Currently, we are building a system that will allow taxi drivers to be dynamically routed to the most likely locations to find passengers (Singapore has a street pickup system similar to New York City and London). The challenge with this system is threefold: 1) The passengers do not provide any input to the system. All predictions must be done using just supply side information. 2) There may not be enough demand for all the taxis in the area. Hence, which taxi do you route where?, and finally 3) what do you display on the in-taxi LCD screen when presenting this advice to the drivers? We plan to deploy and test our solution later this year.

Key Publications

Globally Distributed Software Development: Mobile Org. & Processes

Finally, together with Narayan Ramasubbu (now a faculty member at the University of Pittsburgh), we have analyzed the effect of outsourcing software development to other companies. In particular, we looked at the impact on performance outcomes (such as productivity, errors, and profits) of developing software in a distributed fashion (where the client and development company are not co-located). Our research was facilitated by very high fidelity project data collected from various large software development firms (mainly based in India). Our results were very well received by the software engineering community and we have had numerous papers accepted to the top tier software engineering conference venues (ICSE and FSE). In addition, two of our papers have also won the ACM SIGSOFT Distinguished Paper Award. Our key results show that distributing software development can have terrible impact on project productivity unless corrective actions are taken (FSE 2007 paper). We then showed that using the right process was vital for achieving good project performance (ICSE 2009 paper). We then showed that if you want to achieve the highest profits, you need to configure your distributed software teams in ways that reduced their overall productivity (ICSE 2011 paper). We then developed and deployed (at three different Indian software companies) a new method to perform cost estimation for distributed software projects (ICSE 2012 paper). This new methods resulted in an average per-project savings of 20% across all three deployment sites. Finally, we also looked at how a large company managed both client requests and bug fixes for a large software product line (FSE 2010 paper). We are currently looking at the effects on performance outcomes of functionally distributing work across various distributed development teams and also looking at the effect the project manager of a distributed project has on the final project performance outcomes.
Key Publications
1. "Overcoming the Challenges in Cost Estimation for Distributed Software Projects", Narayan Ramasubbu and Rajesh Krishna Balan, Proceedings of the 34th International Conference on Software Engineering (ICSE), Zurich, Switzerland, June 2012