02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

Submit only ONE copy of this form **for each PI/PD and co-PI/PD** identified on the proposal. The form(s) should be attached to the original proposal as specified in GPG Section II.C.a. Submission of this information is voluntary and is not a precondition of award. This information will not be disclosed to external peer reviewers. ***DO NOT INCLUDE THIS FORM WITH ANY OF THE OTHER COPIES OF YOUR PROPOSAL AS THIS MAY COMPROMISE THE CONFIDENTIALITY OF THE INFORMATION.***

PI/PD Name: Salvatore Rappoccio

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status: (Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☐ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☐

Ethnicity Definition:
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Native Hawaiian or Other Pacific Islander. A person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands.
White. A person having origins in any of the original peoples of Europe, the Middle East, or North Africa.

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PI/PD Name: Steven Y Ko

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☒ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White

Disability Status: (Select one or more)
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- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

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PI/PD Name: Lukasz Ziarek

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status: (Select one or more)
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- ☒ None

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List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 13-1

PD 13-7553 **11/29/13**

FOR NSF USE ONLY

NSF PROPOSAL NUMBER

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

PHY - PHYSICS AT THE INFO FRONTIER, (continued)

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				038633251	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)

141368361

SHOW PREVIOUS AWARD NO. IF THIS IS
☐ A RENEWAL
☐ AN ACCOMPLISHMENT-BASED RENEWAL

IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE

SUNY at Buffalo

AWARDEE ORGANIZATION CODE (IF KNOWN)

0028373000

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE

Buffalo, NY 142600000
US

NAME OF PRIMARY PLACE OF PERF

SUNY at Buffalo

ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE

SUNY at Buffalo

NY ,142601660 ,US.

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ IF THIS IS A PRELIMINARY PROPOSAL
☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Clustering Jets at the Exascale**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **951,102**	**36** months	**06/01/14**	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.G.2)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
☐ HISTORIC PLACES (GPG II.C.2.j)
☐ EAGER* (GPG II.D.2) ☐ RAPID** (GPG II.D.1)
☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date _____
PHS Animal Welfare Assurance Number _____

☐ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number _____
Exemption Subsection _____ or IRB App. Date _____
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
_____

PI/PD DEPARTMENT

PI/PD FAX NUMBER

PI/PD POSTAL ADDRESS

402 Crofts Hall

Buffalo, NY 142600000
United States

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME **Salvatore Rappoccio**	**PhD**	**2005**	**716-645-2634**	**rappoccio@gmail.com**
CO-PI/PD **Steven Y Ko**	**PhD**	**2009**	**716-645-4732**	**stevko@buffalo.edu**
CO-PI/PD **Lukasz Ziarek**	**PhD**	**2011**	**716-645-2634**	**lziarek@buffalo.edu**
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent) or Individual Applicant

By electronically signing and submitting this proposal, the Authorized Organizational Representative (AOR) or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding conflict of interest (when applicable), drug-free workplace, debarment and suspension, lobbying activities (see below), nondiscrimination, flood hazard insurance (when applicable), responsible conduct of research, organizational support, Federal tax obligations, unpaid Federal tax liability, and criminal convictions as set forth in the NSF Proposal & Award Policies & Procedures Guide,Part I: the Grant Proposal Guide (GPG). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section 1001).

Conflict of Interest Certification

When the proposing organization employs more than fifty persons, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Conflict of Interest:
By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the organization has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Section IV.A; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the organization's expenditure of any funds under the award, in accordance with the organization's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent), is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:
(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.
(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

Certification Regarding Nondiscrimination

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Grant Proposal Guide.

Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:
(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:
(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

Certification Regarding Responsible Conduct of Research (RCR)
(This certification is not applicable to proposals for conferences, symposia, and workshops.)

By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research.
The AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

CERTIFICATION PAGE - CONTINUED

Certification Regarding Organizational Support

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that there is organizational support for the proposal as required by Section 526 of the America COMPETES Reauthorization Act of 2010. This support extends to the portion of the proposal developed to satisfy the Broader Impacts Review Criterion as well as the Intellectual Merit Review Criterion, and any additional review criteria specified in the solicitation. Organizational support will be made available, as described in the proposal, in order to address the broader impacts and intellectual merit activities to be undertaken.

Certification Regarding Federal Tax Obligations

When the proposal exceeds $5,000,000, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal tax obligations. By electronically signing the Certification pages, the Authorized Organizational Representative is certifying that, to the best of their knowledge and belief, the proposing organization:
(1) has filed all Federal tax returns required during the three years preceding this certification;
(2) has not been convicted of a criminal offense under the Internal Revenue Code of 1986; and
(3) has not, more than 90 days prior to this certification, been notified of any unpaid Federal tax assessment for which the liability remains unsatisfied, unless the assessment is the subject of an installment agreement or offer in compromise that has been approved by the Internal Revenue Service and is not in default, or the assessment is the subject of a non-frivolous administrative or judicial proceeding.

Certification Regarding Unpaid Federal Tax Liability

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal Tax Liability:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has no unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

Certification Regarding Criminal Convictions

When the proposing organization is a corporation, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Criminal Convictions:

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has not been convicted of a felony criminal violation under any Federal law within the 24 months preceding the date on which the certification is signed.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER

* EAGER - EArly-concept Grants for Exploratory Research
** RAPID - Grants for Rapid Response Research

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) - continued from page 1
(Indicate the most specific unit known, i.e. program, division, etc.)

PHY - PHYSICS GRID COMPUTING

PROJECT SUMMARY

Overview:

In the past, particle physics has relied upon improvements in processing speed of single computing cores in order to improve data acquisition rates. This feature will be critical to the proposed ‘‘High Luminosity Large Hadron Collider’’ (HL-LHC) and other colliders, where the computational challenges move from the petascale to the exascale. Unfortunately, since the mid-2000’s, this improvement in single-core processing speed has hit a limit, and improvements in processing time must now come from concurrent processing. However, the current reconstruction techniques are not enabled for concurrent processing. In order to continue improving the processing capabilities of particle physics experiments in the HL-LHC era, it will be necessary to explore cutting-edge techniques in parallel processing.

There are several general classes of problems in particle physics event reconstruction that could be modified in order to achieve concurrent processing. One such opportunity that has not yet been explored is in ‘‘jet clustering,’’ a nearest-neighbor type of algorithm used to cluster hadronically-fragmented jets into a single object.

Intellectual Merit :

This proposal focuses on parallelizing the existing jet clustering algorithms in use at the LHC experiments. The proposed improvements will be to use this as a test case for deployment of cutting-edge parallelization techniques such as lightweight concurrency extraction, speculative computing, and smarter distribution. Some recent experience shows that the nearest-neighbor type of algorithm used by the jet clustering is amenable to such improvements.

Broader Impacts :

The benefits of this proposal are twofold : firstly, there will be an immediate improvement of the jet clustering algorithms themselves that will lead to higher data acquisition rates at the LHC. Secondly, the computing techniques developed could be used in other applications, inside of particle physics and elsewhere. Since nearest-neighbor algorithms are ubiquitous in scientific computing, it is expected that techniques developed to parallelize this particular problem will be applicable to a wide variety of others in academia and industry.

In addition, these core developments can train students in the newest computing techniques, giving them cutting-edge experience that is highly relevant in academia and private industry.

TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Clustering Jets at the Exascale

Steven Ko, Salvatore Rappoccio, Lukasz Ziarek

1 Introduction

The research proposed here will focus on deploying advanced techniques in parallelization to improve algorithms involved in particle physics research at the Large Hadron Collider (LHC) and beyond. As a specific test case, this research focuses on immediate improvements to one particular algorithm, jet clustering, although the principles developed could be deployed in other areas of particle physics reconstruction and elsewhere.

With the discovery of the Higgs boson by the Large Hadron Collider (LHC) experiments ATLAS and CMS [1, 2], the standard model (SM) of particle physics is now complete. This model unifies the electromagnetic force (carried by the *photon*) with the weak force, responsible for radioactive decay (carried by the *W and Z bosons*). At long last, physicists now understand that via interactions with the Higgs field, the W and Z bosons acquire a mass, but the photon does not. This is referred to as "electroweak symmetry breaking".

A new phase of particle physics has therefore begun. The questions have shifted from the cause of electroweak symmetry breaking, to the study of the Higgs boson and its interactions in detail. To understand the larger picture of the fundamental forces in nature, it will be imperative that high-luminosity colliders be built to study the Higgs in detail, requiring exascale computing tools (in speed and throughput) to reach the goals.

One of the major technical challenges that lies ahead in exascale-level computing for these high-luminosity colliders is the continuation of the scaling of computational power year by year, known colloquially as "Moore's Law". To set the scale, at the CMS experiment with the LHC collision flux ("luminosity") reaching $7 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, the processing time to reconstruct each collision event by CMS was approximately 20 seconds per event. However, as the luminosity is increased, the computational time currently scales quadratically. The luminosity at the HL-LHC is expected to reach as high as $> 1 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, which would correspond (naively) to enormous processing times, on the order of many minutes to several hours per event! Clearly, it is necessary for the computing power to scale in order to compensate for this dramatic increase in CPU time with increasing luminosity.

Unfortunately, the expected end of the historic scaling of single-core processing capability [3] can adversely affect the long-term processing capability for particle physics experiments. Without improvements in single-core computational speed, the only avenues left are algorithmic improvements, and parallelization. Algorithm development is being undertaken at the LHC experiments to reduce the computational time of the software for data acquisition and reconstruction, using both single-core and multi-core approaches. However, long-term improvements will require fundamental improvements in processing capabilities using parallelization.

The currently proposed exploratory research will deploy new and innovative computer science techniques to particle physics. One algorithm that is particularly amenable to improvement using these techniques is the clustering of final-state particles produced in collisions into groups called "jets". Jets are produced via quantum chromodynamic (QCD) interactions of quarks and gluons that hadronize. These "jet clustering" algorithms group the particles into jets based on nearest-neighbor clustering (NN). This algorithm can become computationally expensive as the number of particles that are produced in a collision grows, scaling as $N^2 \log N$ or $N \log N$. Techniques that

leverage and combine speculative computing, lightweight concurrency, and smarter distribution can strongly impact these types of NN algorithms [4, 5, 6, 7, 8]. Thus, this research will serve as a real-world test case for the deployment of these algorithms, with both immediate and long-term benefits.

2 Prior Work

2.1 Results from Prior Support

All three PIs are junior faculty members at the University at Buffalo. PI Rappoccio and Co-PI Ziarek joined the faculty in their respective departments in August 2012.

2.1.1 PI Rappoccio

PI Rappoccio does not have NSF support yet as he has recently started his faculty career.

2.1.2 Co-PI Ziarek

Co-PI Ziarek does not have NSF support yet as he has recently started his faculty career.

2.1.3 Co-PI Ko

Co-PI Ko has been awarded "CI-ADDO-NEW: PhoneLab: A Programmable Participatory Smartphone Testbed" on 06/01/12. The award number is CNS-1205656 and the amount is $1,358,510.00. The duration is for three years. The results include the following.

Results Related to Intellectual Merit: the PhoneLab team has distributed 300 smartphones to the faculty, students, and staff of UB who are using the smartphones as their primary phone. The team has developed the testbed infrastructure where they can monitor the usage of each phone. The team has also developed a front-end website where experimenters and participants can use for various testbed-related functions. The team has opened the PhoneLab testbed for public experimentation on 10/31/13. There are two public experiments running on the testbed and 7 experiments are waiting for approval.

Results Related to Broader Impact: the PhoneLab team is in the process of recruiting 4 undergraduate students as part of their outreach program. Two undergraduate students have been working with the team for one month now. The team is actively interviewing undergraduate students to hire. In addition, the team is in talks with Buffalo Academy of Science Charter School in order to explore the possibility of establishing a program where the team teaches high school students with smartphone programming skills.

Publications: the PhoneLab team has published one paper so far, "PhoneLab: A Large Programmable Smartphone Testbed" in the First International Workshop on Sensing and Big Data Mining, 2013.

Evidence of Research Products: the PhoneLab testbed is currently in use; there are roughly 300 participants and several experiments are either running or waiting for approval. Experimenters can submit their experiments through the website: `http://www.phone-lab.org`.

2.2 Overview of Activities

The investigators of this proposal have a widely-varied and applicable skill set to accomplish the goals of extending LHC computing to the exascale.

Salvatore Rappoccio (tenure-track Assistant Professor) joined the Faculty at the University at Buffalo, SUNY (UB) in 2012. He has 15 years of experience programming in a high-energy physics environment, as well as other numerical software design for the private sector.

Since 2007, Rappoccio has been a member of the Compact Muon Solenoid (CMS) experiment at CERN. From 2008-2010, he was the co-leader of the Analysis Tools group of the CMS Software Project. He was responsible for deployment of jet reconstruction algorithms as well as other tools for data analysis of LHC collision data during the startup phase of the LHC. His primary responsibilities included managing deployment of highly-performing software (including visualization) tools in a team consisting of $\sim$15 people. He has been instrumental in improving the single-core computational speed for jet clustering at CMS since 2008.

His research interests include utilizing jet clustering algorithms in new and innovative ways to search for signals of physics beyond the standard model of particle physics. His pioneering efforts resulted in the first measurements and searches for new phenomena with advanced jet clustering algorithms at CMS, outlined in Refs. [9, 10, 11]. These techniques have become hugely popular in the LHC experiments and in the theoretical community. Prof. Rappoccio is a leader in the jet reconstruction community, contributing to and editing seminal reports on the subject in Refs. [12, 13, 14]. In addition to this academic work, he has also been involved in numerical software design for MIT's Lincoln Laboratories (the details of which are classified).

Currently, Rappoccio is mentoring two students (one graduate student, Jaba Chelidze, and one undergraduate student, Jonathan Goodrum) in achieving parallelization of the jet clustering algorithms. The latter is working under the "Collegiate Science and Technology Entry Program" (CSTEP) [15]. As described by the program, CSTEP exists "to support talented underrepresented students pursuing science, technology, engineering and mathematics".

Lukasz Ziarek has 9 years of experience in language, compiler, and runtime design targeted at improving multicore performance. He has worked on 5 compilers and 3 Java VMs. He is an expert at speculative and transactional computation focusing on the extraction of parallelism and lightweight concurrency.

Steven Ko has 10 years of experience in distributed systems. His recent focus has been large-scale data processing in the cloud using MapReduce and other technologies built on top of it. He also has 5 years of experience in large-scale storage and data management in data centers.

3 Proposed Program of Research

The "jet clustering" technique is employed by many different particle physics experiments and theorists worldwide, and is implemented in a common software framework called `fastjet` [16]. The mathematical problem is analogous to the "K-nearest neighbors algorithm" [17] (kNN).

The specific jet-clustering algorithms that have become enormously popular in the particle physics community are based on sequential clustering, similar to nearest-neighbor clustering [18]. In these sequential-clustering algorithms, a list of the four-momentum of particles are input. These algorithms combine the input four-vectors pairwise until certain criteria are satisfied, defining the resultant combination as a jet. For the jet algorithms considered in this proposal, for each pair of particles i and j, a "distance" metric between the two particles (d_{ij}), and the so-called "beam distance" for each particle (d_{iB}), are computed:

$$d_{ij} = \min({p_{\mathrm{T}}}_i^{2n}, {p_{\mathrm{T}}}_j^{2n})\Delta R_{ij}^2/R^2 \quad (1)$$

$$d_{iB} = {p_{\mathrm{T}}}_i^{2n}, \quad (2)$$

where $p_{\mathrm{T}i}$ and $p_{\mathrm{T}j}$ are the transverse momenta of particles i and j, respectively, "min" refers to the lesser of the two p_{T} values, the integer n depends on the specific jet algorithm, $\Delta R_{ij} = \sqrt{(\Delta y_{ij})^2 + (\Delta\phi_{ij})^2}$ is the distance between i and j in rapidity ($y = \frac{1}{2}\ln(E + p_z)/(E - p_z)$) and azimuth ($\phi$), and R is the "size" parameter of order unity [19], with all angles expressed in radians. The particle pair (i, j) with smallest d_{ij} is combined into a single object. All distances are recalculated using the new object, and the procedure is repeated until, for a given object i, all the d_{ij} are greater than d_{iB}. Object i is then classified as a jet and not considered further in the algorithm. The process is repeated until all input particles are clustered into jets.

The value for n in Eqs. (1) and (2) governs the topological properties of the jets. For $n = 1$ the procedure is referred to as the k_{T} algorithm (KT). The KT jets tend to have irregular shapes and are especially useful for reconstructing jets of lower momentum [19]. For $n = -1$, the procedure is called the anti-k_{T} (AK) algorithm, with features close to an idealized cone algorithm. The AK algorithm is used extensively in LHC experiments and by the theoretical community for finding well-separated jets [19]. For $n = 0$, the procedure is called the Cambridge–Aachen (CA) algorithm. This relies only on angular information, and, like the k_{T} algorithm, provides irregularly-shaped jets in (y, ϕ). The CA algorithm is useful in identifying jet substructure [20, 21].

The single-core optimization of jet clustering is outlined in Ref. [18]. In a single core, the computational time scales as $O(N^2)$ or $O(N \ln N)$, where N is the number of inputs to the algorithm, which scales linearly with luminosity. Since the luminosity of future colliders is expected to drastically increase over existing machines, it will be critical to develop parallelization strategies to maintain scalability of the jet clustering algorithms that exist to future machines.

Since the particles are clustered pairwise, there are numerous opportunities to separately compute portions of the event and then combine them at later stages. We now discuss specific strategies that can be developed to optimize concurrent performance in this algorithm.

3.1 Technical Challenges

To achieve the necessary improvements in performance required for scalability of jet clustering, we propose to examine parallelization opportunities across the entire software stack, including three specific areas : (1) the use of lightweight concurrency extraction to mask high-latency computations or I/O actions, (2) extraction of parallelization from the computation itself in the form of optimistic speculation and specialized transform, and (3) new methods for distributing the computation to maximize parallelization on each node.

Lightweight Concurrency for Latency Masking

Many mathematical kernels contain opportunities for extracting "micro parallelism," usually on the order of tens of instructions, from their computational components. Unfortunately, it is very difficult to parallelize this computation profitably as the overhead of thread creation, scheduling, synchronization, and migration outweigh the gains in parallelism. Instead of extracting explicit parallelism from such computations, we propose to explore methods of lightweight asynchrony to allow for computation to proceed while waiting on high latency I/O operations to complete or on the results of other computations. Since the creation of threads and associated schedule and synchronization costs are typically prohibitive, we will explore new threading models that allow

for logically-distinct computations to execute within a given construct. Co-PI Ziarek's previous research has indicated that such schemes can profitably boost overall performance in the context of ML code [22, 23]. The salient research challenges in applying this strategy are as follows: 1) identifying what computation can be executed safely during high latency operations at compile time, 2) providing a lightweight threading runtime and programming model in the context of an imperative language, 3) specializing the approach to numeric kernels, and 4) building support for computation in a distributed setting.

Speculative Computation

In addition to exploring explicit parallelization of the numeric kernels in jet clustering, we propose to explore extraction of parallelism via speculative computation. At its core, speculative computation breaks apart sequential or parallel tasks into smaller tasks to be run in parallel. Once the speculation has completed, the runtime system validates the computation. If the computation is incorrect (*i.e.* a "datarace" is detected, the computation cannot be serialized, *etc.*), the incorrect computation is re-executed in a non-speculative manner. If the rate of mis-speculation is low, such techniques can be leveraged to extract additional parallelism. There have been many different proposals, including large efforts on transactional memory [24, 25, 26, 27], lock elision [28], thread level speculation and speculative multithreading [29, 30], for integrating speculative computation into programming languages and their associated runtimes. The PIs have extensive experience with transactional memory [31], lightweight rollback methods [32], leveraging memoization to reduce re-computation costs [33, 34], and deterministic speculation [35]. We propose to explore a specialized speculation framework leveraging different speculation strategies, including speculation extracted by the programmer via programming language primitives, library level speculation, and compiler extracted speculation. The salient research challenges in applying this strategy are as follows: 1) identification of the appropriate speculation model and discovering speculation points at compile time, 2) providing a speculative runtime specialized for jet clustering and capable of realizing user, library, and compiler injected speculation, and 3) exploring new and specialized lightweight validation and re-execution mechanisms, including validation across multiple speculation strategies.

Smart Distribution

In order to increase parallelism, we will explore the use of the MapReduce execution framework [36, 37]. MapReduce is a runtime system recently developed for large-scale parallel data processing. It enables programmers to easily deploy their applications on a cluster of machines. Programmers only need to write two functions, Map and Reduce, and submit these two functions as a job to the system. Then the MapReduce framework takes care of all the aspects of the execution of the job. For example, the framework packages and distributes the two functions over the cluster so that the whole cluster can be utilized to execute the job; it also takes care of fault-tolerance by monitoring the cluster during the execution of the job and redistributes the job if some machine fails.

Due to this simplicity and power, it is quickly gaining popularity in industry for large-scale data processing. Many applications in scientific computing have not yet explored the use of MapReduce in depth, however previous research has explored implementing similar kNN-style algorithms with MapReduce [7, 8]. We intend to explore this question in the context of jet clustering for the LHC.

3.2 Research Strategy

Preliminary studies of naive parallelization of a few specific routines in the `fastjet` package reduced processing times by factors of 2-3 by moving to concurrent processing with 8 cores, with no increase

in memory cost. By further deploying the advanced strategies described above, this factor of 2-3 improvement is expected to grow significantly. These preliminary studies were performed by Rappoccio and Mr. Goodrum (undergrad student) over the summer of 2013. Having a postdoctoral fellow to work on this project will greatly increase the likelihood of success.

The postdoctoral fellow requested in this proposal is envisioned to have a computer science background. There will be two graduate students, one with a physics background (but with strong computational skills), and one with a computer science background. Furthermore, it is expected that Mr. Goodrum will continue to work with the group under his CSTEP Fellowship. This team, under the guidance of Rappoccio, Ziarek, and Ko, will perform the implementation and study of these algorithms in the real-world `fastjet` software environment, testing the improvements at the extensive cluster at the **Center for Computational Research** here at UB.

During the first year, it is expected that naive improvements using established techniques could be deployed into the `fastjet` package. Deployment of the improvements achieved by Mr. Goodrum and Rappoccio should take several months to a year of full deployment time. This will serve as a baseline for the advanced algorithmic improvements that will be in research and development simultaneously.

The postdoctoral fellow, under the tutelage of Profs. Ziarek, Ko, and Rappoccio, will use this baseline to investigate the impacts of speculative computation and lightweight concurrency. In the first half of the first year, we will first start with the task of exploring lightweight concurrency techniques as this is applicable in multiple settings, including single machines and clusters. Two graduate students will contribute to this effort. During this period, they will gain more experience with the kNN algorithm and also with the existing code base.

Starting from the second half of the first year, the PIs and the postdoctoral fellow will move on to the task of investigating speculative computation, while two graduate students finalize and polish the implementation of lightweight concurrency techniques. Due to the number of options we can investigate and the complexity of the implementation of the techniques, we anticipate that this task will be more involved in terms of the initial investigation and overall development. Thus, we will start this task from the second half of the first year and continue throughout the second year. Based on prior results of the PIs and the community, we expect to gain scalability increases of 2x to 8x over the naive parallel algorithm with these techniques. Additional improvement in throughput is expected by masking high latency I/O operations and network communication.

We will spend the final year mostly with smart distribution strategies and integration of the techniques we develop in the first two years. Due to its unique programming model, MapReduce brings its own complexity and the postdoctoral fellow and the two graduate students will spend the beginning of the third year to learn how to program in MapReduce. After that, we will investigate how to adapt our kNN algorithm with MapReduce. Table 1 shows the proposed project timeline. We expect to get additional overall system throughput for the kNN algorithm and improved scalability. Based on prior results we expect to see improvements of 2x to 4x. Additional improvements can be expected as the cluster size increases.

4 Broader impacts

The broader impacts of this research are manyfold. The jet-clustering algorithm is very similar to the "kNN" algorithm, which is widely applicable throughout research and industry. The improvements that are developed here at the cutting edge of scientific inquiry will possibly be adaptable to other real-life applications. Examples of applications outside of particle physics would be statistical software [38], real-time 3-d rendering of computer graphics [39], and feature extraction [40].

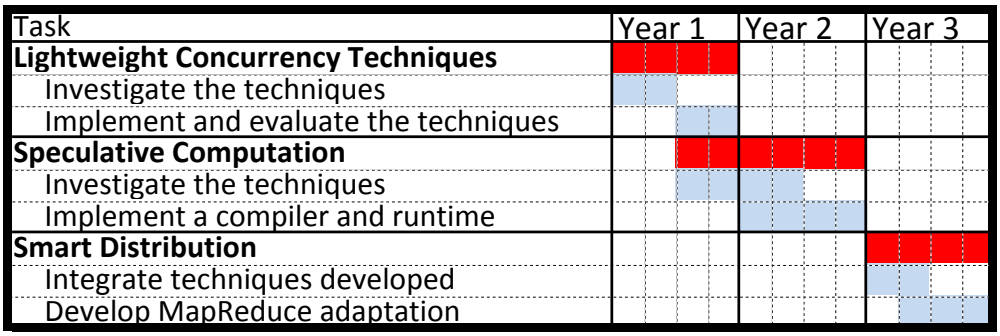

Figure 1: Project Timeline

In addition to the core physics developments enabled by improved scalability of the `fastjet` software environment, this award will also serve as a validation mechanism for core computer science research in programming languages and distributed systems. The development of the system will require systems research in expanding and applying the technological advances made previously by the PIs.

5 Education and Outreach

5.1 Education

All three PIs teach graduate courses at UB and will teach undergraduate courses during the duration of this project. In this section we outline planned activities and how they relate to the proposal.

5.1.1 Curriculum Development

Undergraduate (UG) level. Co-PI Ko teaches undergraduate **Networking** and **Systems** courses. Co-PI Ziarek will teach undergraduate **Compilers** and **Programming Languages** courses. PI Rappoccio teaches undergraduate **Introductory Computational Physics** and **Introductory Physics**. All three PIs plan on creating a cross-listed Physics/Computer Science course focusing on advanced and modern techniques in scientific computing beyond the traditional computational physics classes. The courses will be geared toward advanced undergraduates and graduates in Physics and Computer Science. Software developed under this proposal will be leveraged in the classroom to exemplify practical aspects of the work.

Graduate (G) level. Co-PI Ko teaches graduate **Distributed Systems** and **Android** courses. Co-PI Ziarek will teach graduate **Programming Languages** courses. PI Rappoccio teaches a graduate version of **Introductory Computational Physics**. The PIs plan on teaching a graduate version of their proposed undergraduate course, focusing on advanced techniques and implementation details at the systems level. Students who successfully complete the course will be well suited to begin research at the intersection of particle physics and computer science. To help support students interested in this advanced course, two three week winter session courses will be offered: one for computer science students to teach the necessary physics background and one for physics students to teach systems and distributed programming. The proposed course will be taught in the spring semester after the winter session courses.

5.1.2 Undergraduate research and Diversity

PI Rappoccio works closely with undergraduates, including Mr. Goodrum. Mr. Goodrum is participating in the "Collegiate Science and Technology Entry Program" (CSTEP) here at UB while working on this project. This program focuses on disadvantaged or minority students who would otherwise have a difficult time pursuing STEM-related fields. Prof. Rappoccio is a strong believer in the principles and practice of this program, and intends to continue this work in the future. There are also numerous opportunities for Independent Study and Honors' Theses for undergraduates in the Physics department.

Co-PI Ko is actively involved in mentoring undergraduates. Co-PI Ko is involved in several formal programs such as the McNair Program and UB Honors College Program. Through these programs, two undergraduate students, Edward Poon and Mitchell Nguyen, are currently conducting research with him. Edward Poon, a junior, participates in the McNair Program, which is "designed to provide encouragement and services to low-income and first generation college students, and increase participation from underrepresented groups in pursuing doctoral study." [1] Co-PI Ko is currently listed as a McNair mentor. The other student, Mitchell Nguyen, is a freshman Honors College student. Mitch was involved in Co-PI Ko's research and hopes to continue his research involvement.

Co-PI Ko also has a track record of recruiting women students. Co-PI Ko has successfully recruited two female PhD students, Sonali Batra and Anudipa Maiti. Co-PIs Ko and Ziarek have also been working with a female Master's student, Namita Vishnubhotla, and have successfully recruited her as a PhD student; she will start as a PhD student in Spring, 2014. All PIs will actively continue to recruit female and minority students in their research programs.

5.2 Outreach

While it is critical to pursue a rigorous research program, a large part of the responsibility of scientists is to educate the next generation effectively. There is already extensive work being done to educate high school-level students and teachers about particle physics via the *QuarkNet* program at UB, however there is very little in the way of educating the general public. In addition to participating in the existing *QuarkNet* activities, the plan outlined in this proposal will extend the coverage of the outreach program at UB to engage the broader public in discussions of major results in particle physics, as well as to enliven particle physics for young students. This will be implemented based on similar events as the "HiggsFest" [41] that PI Rappoccio organized at UB. In addition, outreach directly to high school environments will be undertaken based on the Computer Science Teachers Association (CSTA) work done by Co-PI Ziarek.

5.2.1 Higgsfest and other public events

The "Higgsfest" that was organized here at UB in 2012 is highlighted in Ref. [41]. The aim of the event was to invite the general public for "plain English" summaries and hands-on demonstrations that were geared for a multitude of age and knowledge levels. This was attended by over 100 people, including children, high-school students, physics and non-physics undergraduates, and interested members of the community.

Some of the hands-on demonstrations included building models of Feynman diagrams from craft material (for young children), a fully-functional four-layer coincidental muon scintillator detector, a cloud chamber made out of tupperware, felt, and dry ice, and the actual Higgs events from the

[1] `http://cads.buffalo.edu/mcnair`

CMS collaboration in an interactive event display. The event was covered by the "UB Reporter" here at UB [42].

Two more such events are proposed, the first to coincide with the LHC turn-on sometime in 2015, and the second to coincide with the newest results from the LHC after data-taking commences. These are events that should generate high media coverage, and will be a good opportunity to capitalize on public interest in this field. In the event of a major new discovery at the LHC during Run 2, the public interest will be very high, so having the experience of what works and what does not work in such events is extremely valuable to maximize the public impact.

In addition, this removes the stigma associated with science and technology fields at an early age. When young children can attend an event with their parents and take something away from it, this shows them that science is an integral part of life, and nothing to be particularly nervous about pursuing. It may even convince younger people to pursue a scientific career.

One of the major points learned during the last "Higgsfest" is that it is often difficult to have economically-disadvantaged students attend the lectures because of a lack of transportation possibilities. This is something to rectify for future projects along these lines. Therefore, in addition to holding the event directly at the UB North Campus (which is difficult for inner-city Buffalo schools to reach), a duplicated event is also proposed closer to the inner city that is easier to attend, or possibly to visit these schools directly. Some possible locations are the UB South Campus, or at "Babeville" [43], where the UB Physics Department routinely organizes the "Science and Art Cabaret" [44]. Both locations provide the infrastructure needed for the event, and access for disadvantaged schools and students in the inner city of Buffalo.

5.2.2 High School Outreach

Co-PI Ziarek is heavily involved with the local and national chapters of the Computer Science Teachers Association (CSTA), which focus on outreach to local high school teachers. He has helped organize the annual local conference for high school teachers in 2012 and 2013, he has developed and presented a half day Python workshop that shows teachers how to leverage Python and robotics in the classroom, and has been an invited speaker at the CS4HS program offered at Buffalo State University. PI Ziarek expects to continue to offer material for use at the high school level and plans to teach an age appropriate workshop on scientific computing at the next CSTA conference. One goal of the CSTA is to attract underrepresented minorities to study computer science through exposure and education at the high school level. The PIs expects to leverage the software developed under this proposal to offer age appropriate material to HS teachers through the use of a Python interface. Specifically, introductory programming modules along with associated lessons plans to integrate either individual units or entire curriculums into the classroom.

6 Summary

In summary, the problem of expanding LHC computing to the exascale is a difficult, but tractable one. This proposal investigates the possibility of applying cutting-edge parallelization techniques such as lightweight concurrency extraction, speculative computation, and smarter distribution, to the real-world application of LHC data processing. The overall goal is to reduce the computational time for k-nearest-neighbor-like numerical kernels used for jet clustering. The investigators of this proposal have extensive experience in the various aspects of the problem, and the synergistic application of this experience is expected to attain considerable improvements in this area, which are absolutely critical to the success of the future LHC physics program.

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Biographical Sketch for Salvatore R. Rappoccio

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Salvatore Rappoccio
Department of Physics
239 Fronczak Hall
State University of New York at Buffalo
Amherst, NY 14260
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Phone : (716) 645-8068
Fax: (716) 645-2507

Professional Preparation

Harvard University	Physics 2005 Ph.D.
Boston University	Physics 2000, B.A., Mathematics 2000, B.A.

Appointments

State University of New York at Buffalo	Assistant Professor	2012-present
Johns Hopkins University	Research Assistant Professor	2011-2012
Johns Hopkins University	Research Associate	2007-2011
Lincoln Laboratories of MIT	Staff scientist	2005-2007

Publications

Five most closely related to the proposal :

1. CMS Collaboration, S. Chatrchyan et al., "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC," Phys. Lett. **B716** (2012) 30-61.
2. CMS Collaboration, S. Chatrchyan et al., "Search for anomalous t t-bar production in the highly-boosted all-hadronic final state," JHEP **1209** (2012) 029.
3. CMS Collaboration, S. Chatrchyan et al., "Measurement of the top quark pair Production Cross Section in pp Collisions at 7 TeV in Lepton + Jets Events Using b-quark Jet Identification," Phys. Rev. D **84**, 092004 (2011).
4. CMS Collaboration, S. Chatrchyan et al., "Determination of jet energy calibration and transverse momentum resolution in CMS," JINST **6** (2011) P11002.
5. CDF Collaboration, D. Acosta et al., "Measurement of the t t-bar production cross section in p p-bar collisions at sqrt(s) = 1.96 TeV using lepton + jets events and secondary vertex b-tagging," Phys. Rev. D **71**, 052003 (2005).

Synergistic Activities

1. Convener of the “Beyond Two Generations” group at CMS (2012-present); convener of the “Standard Model Jet Substructure” subgroup at CMS (2011-2012); convener of the “Analysis Software Tools” subgroup at CMS (2009-2011).
2. As a graduate student, was responsible for two separate subsystems of the CDF detector on-call operations (the Silicon Readout Controller and the Central Muon Extension).
3. As a graduate student, redesigned the existing Silicon Readout at CDF such that a tracking-based trigger at Level 2 was possible, enabling the use of triggers used in the enormously successful B-physics program at CDF.
4. Co-organizer of the “BOOST” conference series focusing on boosted topologies (2009-present).
5. Extensive outreach activities for the Fermi National Accelerator Laboratory (FNAL) and elsewhere.

Collaborations & Other Affiliations

Member of the Compact Muon Solenoid (CMS) Collaboration : 2008-present
Member of the Collider Detector at Fermilab (CDF) Collaboration : 2000-2006

Graduate and Postdoctoral Advisors

Ph.D. Advisors : Melissa Franklin, Andrew Foland (Harvard University)
Postdoctoral Sponsors : Morris Swartz, Petar Maksimovic (Johns Hopkins University)

Thesis Advisor and Postdoctoral Scholar Sponsor

Total number of postdoctoral fellows and graduate students currently sponsored : 3.
Total number of postdoctoral fellows and graduate students advised in the past : 4.

Ph.D. Thesis Advisor:
G. Hu, K. Nash, M. Osherson, Y. Xin (Johns Hopkins University),
J. Kaisen, M. Alyari (SUNY at Buffalo)

Postdoctoral Scholar Sponsor:
J. Dolen (SUNY at Buffalo)

Biographical Sketch for Steven Y. Ko

Professional Preparation

- Yonsei University, Mathematics and Computer Science, BS, 1999
- Seoul National University, Computer Science and Engineering, MS, 2002
- University of Illinois at Urbana-Champaign, Computer Science, PhD, 2009
- Princeton University, Computer Science, Postdoc, 2010

Appointments

- Assistant Professor, 08/10-present, University at Buffalo, The State University of New York
- Postdoctoral Research Associate, 08/09-07/10, Princeton University

Five Products Most Closely Related to the Project

1. Erik Nordstrom, David Shue, Prem Gopalan, Rob Kiefer, Matvey Arye, Steven Y. Ko, Jennifer Rexford, and Michael J. Freedman, "Serval: An End-Host Stack for Service-Centric Networking," Proceedings of the 9th USENIX Symposium on Networked Systems Design and Implementation (NSDI), 2012
2. Steven Y. Ko, Kyungho Jeon, and Ramses Morales, "The HybrEx Model for Confidentiality and Privacy in Cloud Computing," Proceedings of the 3rd USENIX Workshop on Hot Topics in Cloud Computing (HotCloud), 2011
3. Steven Y. Ko, Imranul Hoque, Brian Cho, Indranil Gupta, "Making Cloud Intermediate Data Fault-Tolerant," Proceedings of the 1st ACM Symposium on Cloud Computing (SOCC), 2010
4. Steven Y. Ko, Imranul Hoque, Brian Cho, and Indranil Gupta, "On Availability of Intermediate Data in Cloud Computations," Proceedings of the USENIX Workshop on Hot Topics in Operating Systems (HotOS), 2009
5. Gregory L. Lee, Martin Schulz, Dong H. Ahn, Andrew Bernat, Bronis R. de Supinski, Steven Y. Ko, and Barry Rountree, "Dynamic Binary Instrumentation and Data Aggregation on Large Scale Systems," International Journal of Parallel Programming (IJPP), Volume 35, No. 3 / June, 2007

Five Other Products

1. Mohammad Iftekhar Husain, Steve Uurtamo, Steven Y. Ko, Atri Rudra, and Ram Sridhar, "PGV: Pretty Good Verification of Remote Storage," Proceeding of the 31st IEEE International Symposium on Reliable Distributed Systems (SRDS), 2012
2. Roy Campbell, Indranil Gupta, Michael Heath, Steven Y. Ko, Michael Kozuch, Marcel Kunze, Thomas Kwan, Kevin Lai, Hing Yan Lee, Martha Lyons, Dejan Milojicic, David O'Hallaron, and Yeng Chai Soh, "Open Cirrus Cloud Computing Testbed: Federated Data Centers for Open Source Systems and Services Research," Proceedings of the USENIX Workshop on Hot Topics in Cloud Computing (HotCloud), 2009
3. Steven Y. Ko, Praveen Yalagandula, Indranil Gupta, Vanish Talwar, Dejan Milojicic, and Subu Iyer, "Moara: Flexible and Scalable Group-Based Querying System," Proceedings of the ACM/IFIP/USENIX Middleware, 2008
4. Steven Y. Ko and Indranil Gupta, "A New Class of Nature-Inspired Algorithms for Self-Adaptive Peer-to-Peer Computing," ACM Transactions on Autonomous and Adaptive Systems (TAAS), September, 2008
5. Steven Y. Ko, Ramses Morales, and Indranil Gupta, "New Worker-Centric Scheduling Strategies for Data-Intensive Grid Applications," Proceedings of the ACM/IFIP/USENIX Middleware, 2007

Synergistic Activities

- TPC Member: USENIX ATC 2013, BigMine 2013, BigMine 2012, ANT 2012, DataCloud 2012, Middleware 2011, Open Cirrus Summit 2011, CoNEXT Student Workshop 2011, SAHNS 2011, DataCloud 2011, SASO 2010
- Vice-General Chair: IPCCC 2011

Collaborators and Other Affiliations

- Collaborators during the last 48 months: Matvey Arye (Princeton), Roy Campbell (UIUC), Brian Cho (UIUC), Michael J. Freedman (Princeton), Prem Gopalan (Princeton), Indranil Gupta (UIUC), Michael Heath (UIUC), Imranul Hoque (UIUC), Mohammad Iftekhar Husain (SUNY Buffalo), Subu Iyer (HP Labs), Rob Kiefer (Princeton), Michael Kozuch (Intel Research), Marcel Kunze (KIT), Thomas Kwan (Yahoo!), Kevin Lai (HP Labs), Hing Yan Lee (IDA), Martha Lyons (HP Labs), Dejan Milojicic (HP Labs), Ramses Morales (PatternInsight), Erik Nordstrom (Princeton), David OHallaron (CMU), Lucian Popa (HP Labs), Sylvia Ratnasamy (UC Berkeley), Jennifer Rexford (Princeton), Atri Rudra (SUNY Buffalo), Ion Stoica (UC Berkeley), David Shue (Princeton), Yeng Chai Soh (IDA), Ramalingam Sridhar (SUNY Buffalo), Vanish Talwar (HP Labs), Steve Uurtamo (SUNY Buffalo), Praveen Yalagandula (HP Labs), Minlan Yu (UC Berkeley)
- PhD advisor and postdoc sponsors: Indranil Gupta (UIUC), Michael Freedman (Princeton), Jennifer Rexford (Princeton)
- Students advised: None

Lukasz Ziarek
338E Davis Hall, University at Buffalo, Buffalo, NY 14260-2500

Professional Preparation

University of Chicago	Computer Science	B.S. December 2003
Purdue University	Computer Science	Ph.D. May 2011

Appointments

Assistant Professor, Department of Computer Science and Engineering, SUNY Buffalo.	2012 –
President, Fiji Systems Inc., South Bend, IN.	2010 –
Visiting Assistant Professor, Department of Computer Science, Purdue University.	2011 – 12
Vice-President, Fiji Systems Inc., Indianapolis, IN.	2009 – 10
Research Assistant, Department of Computer Science, Purdue University.	2004 – 11

Products

1. KC Sivaramakrishnan, Lukasz Ziarek, Suresh Jagannathan: **A Coherent and Managed Runtime for ML on the SCC.** *Many-core Applications Research Community Symposium* 2012.
2. Lukasz Ziarek, KC Sivaramakrishnan, and Suresh Jagannathan: **Composable Asynchronous Events.** In *Programming Language Design and Implementation* 2011.
3. Lukasz Ziarek and Suresh Jagannathan: **Lightweight Checkpointing for Concurrent ML.** In *Journal of Functional Programming* 2010.
4. Lukasz Ziarek, KC Sivaramakrishnan, and Suresh Jagannathan: **Partial Memoization of Concurrency and Communication.** In *International Conference on Functional Programming* 2009.
5. Lukasz Ziarek, Adam Welc, Ali-Reza Adl-Tabatabai, Vijay Menon, Tatiana Shpeisman, and Suresh Jagannathan: **A Uniform Transactional Execution Environment for Java.** In *European Conference on Object-Oriented Programming* 2008.

Significant Products

1. Ethan Blanton, Demian Lessa, Lukasz Ziarek, and Bharat Jayaraman: **JI.FI: Visual Test and Debug Queries for Hard Real-Time.** *International Workshop on Java Technologies for Real-time and Embedded Systems* 2012.
2. Lukasz Ziarek, Siddharth Tiwary, and Suresh Jagannathan: **Isolating Determinism in Multi-Threaded Programs.** In *Runtime Verification* 2011.
3. Filip Pizlo, Lukasz Ziarek, Ethan Blanton, Petr Maj and Jan Vitek: **High-level Programming of Embedded Hard Real-Time Devices.** In *EuroSys* 2010.
4. Filip Pizlo, Lukasz Ziarek, Petr Maj, Anthony Hosking, Ethan Blanton, and Jan Vitek: **Schism: Fragmentation-Tolerant Real-Time Garbage Collection.** In *Programming Language Design and Implementation* 2010.
5. Lukasz Ziarek, Stephen Weeks, and Suresh Jagannathan: **Flattening Tuples in an SSA Intermediate Representation.** In *Higher Order and Symbolic Computation, Volume 23, Number 3* 2008.

Synergistic Activities

1. Outreach: Member of the Computer Science Teacher's Association.
2. Awards: Halstead Award for Outstanding Research in Software Engineering, 2009; Intel Fellowship, 2008; Department Of Education Graduate Assistance In Areas Of National Need Fellowship, 2004.
3. Program Committees: Java Technologies for Real-time and Embedded Systems, 2010, 2011; Declarative Aspects for Multi-Core Programming, 2012.
4. Journal Referee: Concurrency and Computation Practice and Experience; Software: Practice and Experience.

(Collaborators & Other Affiliations)

Collaborators and Co-Editors

Umut Acar (CMU), Ali-Reza Adl-Tabatabai (Intel), Ethan Blanton (Purdue University, Fiji Systems Inc.), Patrick Eugster (Purdue University), Mathew Fluet (Rochester), Anthony Hosking (Purdue University), Suresh Jagannathan (Purdue University), Bharat Jayaraman (SUNY Buffalo), Demian Lessa (SUNY Buffalo), Petr Maj (Purdue University), Vijay Menon (Google), Filip Pizlo (Apple Inc.), Raghavendra Prasad (Google), Tatiana Shpeisman (Intel), KC Sivaramakrishnan (Purdue University), Jan Vitek (Purdue University, Fiji Systems Inc.), Adam Welc (Oracle)

Graduate Advisors and Postdoctoral Sponsors

Suresh Jagannathan	Purdue University	West Lafayette, Indiana, USA.
Patrick Eugster	Purdue University	West Lafayette, Indiana, USA.
Zihuan Li	Purdue University	West Lafayette, Indiana, USA.
Jan Vitek	Purdue University	West Lafayette, Indiana, USA.

Thesis Advisor and Postgraduate-Scholar Sponsor

Thesis Advisor: (3)
Graduated: none
Current: Shaun Cosgrove, Feng Shen, Yin Yan
Postgraduate-Scholar Sponsor: (0)
none

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
SUNY at Buffalo

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Salvatore Rappoccio

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Salvatore Rappoccio - PI**	0.00	0.00	2.00	**16,000**	
2. **Steven Y Ko - Co-I**	0.00	0.00	2.00	**20,111**	
3. **Lukasz Ziarek - Co-I**	0.00	0.00	2.00	**20,111**	
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	6.00	**56,222**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**1**) POST DOCTORAL SCHOLARS	12.00	0.00	0.00	**50,400**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	**0**	
3. (**2**) GRADUATE STUDENTS				**30,000**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**136,622**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**35,778**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**172,400**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **See budget justification** $ **0**					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**4,000**	
2. FOREIGN				**4,000**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**7,144**	
5. SUBAWARDS				**0**	
6. OTHER				**10,104**	
TOTAL OTHER DIRECT COSTS				**17,248**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**197,648**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 59.0000, Base: 187544)**					
TOTAL INDIRECT COSTS (F&A)				**110,651**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**308,299**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				**308,299**	

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Salvatore Rappoccio

ORG. REP. NAME*

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INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

YEAR 2

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
SUNY at Buffalo

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Salvatore Rappoccio

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Salvatore Rappoccio - PI**	0.00	0.00	2.00	**16,320**	
2. **Steven Y Ko - Co-I**	0.00	0.00	2.00	**20,513**	
3. **Lukasz Ziarek - Co-I**	0.00	0.00	2.00	**20,513**	
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	6.00	**57,346**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**1**) POST DOCTORAL SCHOLARS	12.00	0.00	0.00	**51,408**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	**0**	
3. (**2**) GRADUATE STUDENTS				**30,600**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**139,354**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**36,750**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**176,104**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **$ 0**					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**4,160**	
2. FOREIGN				**4,160**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**7,430**	
5. SUBAWARDS				**0**	
6. OTHER				**11,112**	
TOTAL OTHER DIRECT COSTS				**18,542**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**202,966**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 59.5000, Base: 191855)**					
TOTAL INDIRECT COSTS (F&A)				**114,154**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**317,120**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				**317,120**	

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Salvatore Rappoccio

ORG. REP. NAME*

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 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

YEAR 3

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION
SUNY at Buffalo

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Salvatore Rappoccio

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Salvatore Rappoccio - PI**	0.00	0.00	2.00	**16,646**	
2. **Steven Y Ko - Co-I**	0.00	0.00	2.00	**20,924**	
3. **Lukasz Ziarek - Co-I**	0.00	0.00	2.00	**20,924**	
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	6.00	**58,494**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**1**) POST DOCTORAL SCHOLARS	12.00	0.00	0.00	**52,436**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	**0**	
3. (**2**) GRADUATE STUDENTS				**31,212**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**142,142**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**38,010**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**180,152**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ **0**					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**4,326**	
2. FOREIGN				**4,326**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**7,727**	
5. SUBAWARDS				**0**	
6. OTHER				**12,216**	
TOTAL OTHER DIRECT COSTS				**19,943**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**208,747**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 59.5000, Base: 196531)**					
TOTAL INDIRECT COSTS (F&A)				**116,936**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**325,683**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				**325,683**	

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Salvatore Rappoccio

ORG. REP. NAME*

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 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

Cumulative

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

ORGANIZATION: **SUNY at Buffalo**

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Salvatore Rappoccio**

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Salvatore Rappoccio - PI**	0.00	0.00	6.00	**48,966**	
2. **Steven Y Ko - Co-I**	0.00	0.00	6.00	**61,548**	
3. **Lukasz Ziarek - Co-I**	0.00	0.00	6.00	**61,548**	
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**3**) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	18.00	**172,062**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**3**) POST DOCTORAL SCHOLARS	36.00	0.00	0.00	**154,244**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	**0**	
3. (**6**) GRADUATE STUDENTS				**91,812**	
4. (**0**) UNDERGRADUATE STUDENTS				**0**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**418,118**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**110,538**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**528,656**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ **0**					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**12,486**	
2. FOREIGN				**12,486**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**0**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**22,301**	
5. SUBAWARDS				**0**	
6. OTHER				**33,432**	
TOTAL OTHER DIRECT COSTS				**55,733**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**609,361**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**341,741**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**951,102**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				**951,102**	

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME: **Salvatore Rappoccio**

ORG. REP. NAME*

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Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

BUDGET JUSTIFICATION

Institution : The State University of New York at Buffalo (UB)
PI : Salvatore Rappoccio
Co-I : Lukasz Ziarek, Steven Ko

Personnel

The requested funds of $951,102 USD (for 3 years starting in 2014) would cover two (2) months of summer salary for Profs. Rappoccio, Ziarek and Ko per year for three (3) years ($172,062), the full salary for one (1) postdoctoral fellow for three (3) years ($154,224), and salary plus tuition for two (2) graduate students, totaling $91,812 in salary and $33,432 in tuition. This will also cover $22,300 of computer fees.

If awarded, efforts for Profs. Rappoccio, Ziarek and Ko will be reduced to be in compliance with NSF 2 month policy.

Fringe

Fringe benefit rates are based on the applicable federally negotiated rates published at http://www.research.buffalo.edu/sps/about/rates.cfm.

Travel

This research will require regular travel to conferences and CERN. Hence, the proposal requests $12,486 in domestic travel funds and $12,486 in foreign travel funds for the three years of activity.

Facilities and Administration Indirect Costs

Indirect cost rates are based on the applicable federally negotiated rates published at http://www.research.buffalo.edu/sps/about/rates.cfm

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Salvatore R. Rappoccio

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Startup funds

Source of Support: SUNY Research Foundation

Total Award Amount: $215,000 Total Award Period Covered: 8/15/2012-6/31/2014

Location of Project: SUNY at Buffalo, Buffalo NY / Fermilab, Batavia IL / CERN, Geneva Switzerland

Person-Months Per Year Committed to the Project. Cal: Acad: 5 Sumr: 2

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

U.S. CMS Phase-1 Upgrades

Source of Support: NSF CA award to University of Nebraska, subcontract to SUNY at Buffalo

Total Award Amount: $169,849 Total Award Period Covered: 8/01/2013-07/31/2018

Location of Project: SUNY at Buffalo, Buffalo NY / Fermilab, Batavia IL / CERN, Geneva Switzerland

Person-Months Per Year Committed to the Project. Cal: Acad: 2 Sumr: 0

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

CAREER: Boosting through the hierarchy at the Large Hadron Collider

Source of Support: National Science Foundation

Total Award Amount: $869,953 Total Award Period Covered: 6/1/2014 – 5/31/2019

Location of Project: SUNY at Buffalo, Buffalo NY / Fermilab, Batavia IL / CERN, Geneva Switzerland

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 2

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

High Energy Physics Research at the CMS Experiment

Source of Support: National Science Foundation

Total Award Amount: $578,755 Total Award Period Covered: 5/15/2014-5/14/2017

Location of Project: SUNY at Buffalo, Buffalo NY / Fermilab, Batavia IL / CERN, Geneva Switzerland

Person-Months Per Year Committed to the Project. Cal: Acad: 0 Sumr: 2

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

THIS PROPOSAL : Clustering Jets at the Exascale

Source of Support: National Science Foundation

Total Award Amount: $951,102 Total Award Period Covered: 6/1/2014-5/29/2017

Location of Project: SUNY at Buffalo, Buffalo NY

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 2

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Steven Y. Ko

Other agencies (including NSF) to which this proposal has been/will be submit-

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

CAREER: Systems for Transparency in Personal Devices and Services

Source of Support: NSF

Total Award Amount: $ 498,419.00 Total Award Period Covered: 01/01/14 - 12/31/18

Location of Project: SUNY Buffalo

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1

Support: ☑ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

CI-ADDO-NEW: PhoneLab: A Programmable Participatory Smartphone Testbed

Source of Support: NSF

Total Award Amount: $ 1,322,510.00 Total Award Period Covered: 06/01/12 - 05/31/15

Location of Project: SUNY Buffalo

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1

Support: ☐ Current ☑ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Clustering Jets at the Exascale (This Proposal)

Source of Support: NSF

Total Award Amount: $ 951,102 Total Award Period Covered: 6/1/14 - 5/29/2017

Location of Project: SUNY Buffalo

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 2

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Lukasz Ziarek	Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: SHF : Medium : Collaborative Research : Robust Distributed Systems by Design

Source of Support: NSF

Total Award Amount: $ 599,806 Total Award Period Covered: 08/01/14 - 07/31/17

Location of Project: SUNY Buffalo

Person-Months Per Year Committed to the Project. Cal: 0.00 Acad: 0.00 Sumr: 2.00

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: II-EN: Collaborative Research: Positioning MLton for Next-Generation Programming Languages Research

Source of Support: NSF

Total Award Amount: $ 381,640 Total Award Period Covered: 08/01/14 - 07/31/17

Location of Project: SUNY Buffalo

Person-Months Per Year Committed to the Project. Cal: 0.00 Acad: 0.00 Sumr: 1.00

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Clustering Jets at the Exascale

Source of Support: NSF

Total Award Amount: $ 951,102 Total Award Period Covered: 06/01/14 - 05/29/17

Location of Project: SUNY Buffalo

Person-Months Per Year Committed to the Project. Cal: 0.00 Acad: 0.00 Sumr: 2.00

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Facilities, Equipment and Other Resources

Center For Computational Research

UB has a large computational research center, CCR, which is a Linux-based cluster on the Open Science Grid, and also has a large GPU cluster for possible parallel processing developments.

Office

The faculty, postdoctoral fellows and graduate students all have office space at UB.

Data Management Plan

The data that are produced from this proposal will be in the form of software algorithms and procedures. The format and content will be as source files (typically `C++`). There will be no data nor metadata collected.

The algorithms that are developed with this research plan will be integrated into the main `fastjet` software framework for distribution among collaborators (both experimental and theoretical) worldwide (`http://fastjet.fr`). This software is open-source, freely available, and continually maintained by the `fastjet` maintenance team under the GNU Public License V2 [35]. The web pages related to this project are stored on machines at the "Laboratoire de Physique Thorique et Hautes Energies" (`http://www.lpthe.jussieu.fr/spip/?lang=en`).

The `fastjet` team has indicated their willingness to integrate improvements into the main `fastjet` package for worldwide distribution.

Postdoctoral Fellow Mentoring

One postdoctoral fellow will be funded on this project. There are extensive postdoctoral fellowship mentoring activities at UB, as well as via the CMS Experiment at CERN. These include guidance in career paths, work/life balance discussions, and technical skill development such as writing grant proposals, etc. Specific elements are highlighted below.

- **University at Buffalo (UB)**
  - The UB Office of Postdoctoral Scholars offers diverse services for postdoctoral fellows, including the *"Postdoc Survival Skills Workshops"*, targeted seminars and symposia for postdoctoral fellows, social functions, and logistical assistance.
  - The UB Physics Department offers several services to our postdoctoral fellows, including a biweekly Journal Club for particle physics and cosmology, weekly seminars and colloquia, and weekly social functions inside the department.
- **CERN**
  - The opportunities for a postdoctoral fellow at CERN are extensive. There are also a plethora of workshops, seminars, conferences, etc, at CERN. There are also smaller weekly avenues for networking possibilities, as well as seminars for postdoctoral fellows to gain visibility for their work.
  - It is also worth pointing out that, because of the world-class nature of CERN, it often attracts very high-level members of the particle physics community on a regular basis. Such opportunities for visibility among the top-tier scientists in the world (including Nobel and Milner Prize winners, etc) are hard to understate.

In all, the postdoctoral fellow that will be supported by this proposal will have ample opportunities for professional advancement and development, as well as a myriad of opportunities for a community of peers in both professional and social settings.

Letter of Collaboration for “Clustering Jets At The Exascale”

To Whom it May Concern :

The work by Prof. Rappoccio and colleagues will be complementary to efforts of the FastJet project so far, and will focus on research and development of applying parallelization techniques to existing FastJet algorithms. The FastJet authors would be happy to consult and, if appropriate, collaborate with Prof. Rappoccio and colleagues on this work. Should these techniques prove useful, they would then be considered for dissemination in the standard fastjet package (distributed to thousands of theorists and experimentalists worldwide).

Regards,

Gavin Salam
Matteo Cacciari
Gregory Soyez