Mathematics & Statistics
Strategic Planning Phase III Part II

1 Research and The Faculty

Overview. Over the past two decades, the Department of Mathematics and Statistics has systematically worked toward its overarching goal of becoming one of the top 10 departments of mathematical sciences among public research universities. At least two sets of budget cuts have presented obstacles and forced an unfortunate contraction of the size of the faculty, but thanks to a sustained focus on excellence and a highly successful record of faculty recruitment since 1994, we have already made great strides and stand poised to achieve that goal in the near future. The Department has a long tradition of serving as a unified home for statisticians as well as pure and applied mathematicians, and enjoys the resultant synergies and efficiencies.

In AY2004-2005, concurrent with a restructuring necessitated by a wave of retirements, the Department adjusted the teaching load from the former standard of four courses per year to three courses per year for faculty active in research and service. This move, which was consistent with those made by a number of our peer departments and was strongly endorsed by the 2005 AQAD report, enhanced our competitive position as a research department, from which we anticipated and did in fact experience enhancements in scholarly productivity, external funding and faculty recruitment. In the 2005 AQAD report, the external visiting committee wrote: "Regarding excellence, it cannot be too heavily stressed that the department has done a superb job of recruiting strong young mathematicians and statisticians. Their excellence is a tribute to the leadership of the department. If this strong group of young faculty can be maintained and further developed, the department indeed is in a position to move up a level." Seven years later, this prediction from the 2005 AQAD report could be confirmed: the 2012 AQAD report and the Universitys Doctoral Program Review noted the measurable gain in the NRC estimation of our Department's reputation, in which we moved from the upper 50s in 1995 to the mid 30s among all mathematics departments nationwide, public as well as private.

To maximize its research productivity, impact, and visibility, the Department has employed a strategy of forming vibrant research groups that bring together 3-4 researchers in carefully chosen subdisciplines of mathematics and statistics. All of these groups are focused in areas that are central to contemporary mathematics and statistics and are the drivers of innovation in these fields today. The Department's reputation (including the associated rise in the National Research Council rankings) rests on the strengths and coherence of these research groups and the synergies between them. In many ways, research groups consisting of several faculty members in mathematics and statistics function in the same way that laboratories do in the other sciences. The groups each have their own weekly seminars, which are attended by graduate students, Visiting Assistant Professors (VAPs) and grant-funded postdocs, as well. A number of faculty members have their main home in one such group but collaborate and attend seminars of one or two other groups as well.

Strategy. Maintaining and solidifying the strengths of the existing research groups is of great strategic importance to the future of the Department, and this requires reserving replacement faculty lines for allocation to these areas. The Department seeks, whenever suitable, to make hires that would make fundamental contributions to more than one research group. In the same vein, the Department has also sought, when possible, to prioritize individuals who, in addition to strengthening their home research group within our department, would also make significant contributions to institutes and initiatives outside the Department and even outside the College. For positions which would represent new faculty lines allocated to Mathematics & Statistics, the Department is very much open to the possibility of expanding into new areas currently not covered, as well as cluster hires (faculty who would reside 100% in our Department but who would be affiliated with other Centers or Institutes – we currently have one such hire), and possibly through a small number of joint appointments. We have not had any appointments of the latter type in recent memory and are conscious of the possible complications in filling such positions, including the fact that they are more likely to require multi-year searches, and feel they would be best made at the more senior levels. We have close ties to the Computational Social Science Institute, the newly announced Center for Data Science, and the emerging cross-campus efforts in Cybersecurity. For expansion into areas which do not form part of the Department's current strengths, the allocation of multiple positions, including possibly one at a more senior level, may be a more effective strategy than a piecemeal approach.

Vision for Future Hiring. The faculty devoted considerable time and energy to this discussion. Since the description of the process and outcome is long, it appears in its own stand-alone section below. The areas of focus are 1) predictive modeling (an aspect of "data science" lying at the intersection of applied mathematics and statistics), 2) discrete mathematics, 3) frontiers of geometry and mathematical physics, 4) analysis of dynamical systems and partial differential equations, 5) cybersecurity and cryptography, and 6) Mathematics and Statistics of Life Sciences.

Visiting Assistant Professors. To enhance the research atmosphere in the Department, we employ a certain number of Visiting Assistant Professors (VAPs), a standard practice in the discipline. These young PhDs make significant contributions to the research and teaching missions of the Department: they collaborate in research with faculty members who mentor them, assist in mentoring graduate students, bolster the ranks of calculus teachers, and have proven to be successful teachers of certain upper division courses as well. The number of VAPs was significantly reduced (from 14 in 2002 to 5 in 2014, although the Department is now funding a sixth from its own funds). The reduction in the number of VAPs has made us a bit out of step with our peer departments. An increase in the number of VAPs, as well as the eventual institution of a few (at least 3) enhanced "named" positions (with more money for research and a smaller teaching load) form part of the Departments vision for the future. To explain what we mean by the "named VAP" position, we note that nearly all our peer departments have at least one special non-tenure track postdoctoral position carrying a name (such as the Morrey Assistant Professor at Berkeley, the Doob Instructor at UIUC, the Chowla Research Assistant Professor at Penn State, the Zorn Postdoc at Indiana University Bloomington, etc.). The named positions attract stronger candidates and add greatly to the Department's prestige, at a relatively low cost. As far back as the 2005 AQAD, the creation of such a named postdoctoral position for our Department has been strongly recommended. With appropriate approval by the Dean and Provost's offices, we hope to create these posts immediately and search to fill them as early as Fall 2015.

Space & Facilities. The Department does not require expensive laboratory facilities, but it does require appropriately-sized offices and common spaces for faculty/faculty and faculty/student interactions. The former are in increasing short supply, and the latter have been insufficient for a number of years. The Department has experienced no renovation since the mid 70s when it moved to Lederle's upper floors from Arnold House, with the exception of a furniture/carpet acquisition for the large conference/lecture area (Room 1634). The Department has instituted a collaborative policy of allowing other programs and units in CNS access to the room when not being used for Departmental functions. The Department is in active conversation within CNS and with Facilities Planning to add and renovate significant space in the Tower.

Diversity. It is gratifying to report that the percentage of women among math majors has been rising and is about 42%. On the other hand, there are not enough women on the faculty. Currently 5 of the 40 members of the faculty are women (one Assistant Professor, three Associate Professors and one Professor). We would reach the national average if three retiring men are replaced by three women. If, in addition, the Department grows in the long term by adding ten faculty lines and half of those go to women, that would be a realistic way of reaching and exceeding the national average.

Mentoring. The Department has not had a formal mentoring program in place. Starting in the current year, the Department Head has reinstated a practice of meeting with the Assistant Professors as a group, and with the Associate Professors as a group; the chair of the PC and our departmental representative to the College PC join these meetings and provide further information and perspective on the tenure and promotion processes. Additionally, the Head meets with individuals in these groups to discuss their progress toward promotion.

Awards. A recent slate of awards demonstrates the faculty's success and visibility. Since the start of the prestigious Simons Fellowship four years ago, the Department has had one winner each year (Gunnells, Nahmod, Mirkovic, Zhang). We also have three NSF CAREER winners (Kevrekidis, Zhang, Oblomkov) and two Sloan Fellows (Tevelev and Oblomkov). This year, Nahmod was named a Fellow of the American Mathematical Society, and Kevrekidis a Fellow of the American Physical Society. Mathematics & Statistics have fewer awards than many other fields. The Department will step up its efforts to nominate its faculty for University, national, and international awards.

Department Demographic. The Department has relatively few professors due to retire soon, and 95% of the faculty are research-active. For faculty who do contemplate retirement, interest in membership in an institute of advanced study varies; the department has a practice of providing shared office space (about 3 people per office) in the Department for emeritus faculty and this practice has strong support among the faculty. Physical proximity for seminars, easy access to the Science and Engineering Library, and being close to the life of the Department are important considerations that would make maintaining this policy a desired addition to the possibility of an additional home in DuBois.

Summary of Key Recommendations for enhancing Research. Expanding the size of the tenure track faculty is the absolutely crucial investment required for maintaining the path of greater impact within the University and greater visibility in the profession, and essential for meeting the evolving needs of students at all levels. The escalating teaching burden on the faculty resultant from the ballooning enrollment at the upper as well as lower division has been managed up to this point through: 1) doubling of class sizes from 30 to 60 for nearly all lower-division classes; 2) increase in class sizes for many upper division classes from 30 to 40 or even 50; 3) shrinking the number and variety of upper-division and graduate classes; 4) addition of Lecturers. All of these strategies have reached, and are in fact beyond, their saturation point. In order to maintain quality and to be a destination of choice, it is crucial that we maintain and enhance our position as an investment of choice; we can no longer afford half-measures and substitutions for increasing the number of tenure-track faculty. Since the addition of the right number of tenure track positions may have to be staggered over a number of years due to limited resources, a more immediate increase in the number of enhanced or "named" VAPs concurrent with additional faculty lines would be an acceptable compromise in the short term.

2 Graduate Programs

2.1 Overview

The Department offers three graduate programs: MS in Applied Mathematics, MS in Statistics, PhD in Mathematics. The latter includes students who study statistics. Nearly all of the students teach for the Department, thereby contributing to our teaching mission; on the one hand, this is a fairly cost-effective means of teaching some of our lower-division offerings, and on the other hand, it represents a very important component of the graduate students' training. The students we graduate are finding good positions in industry, R&D, finance, and increasingly at strong academic institutions.

2.2 Doctoral Program Review

The Departments graduate programs received a favorable evaluation during the Doctoral Program Review recently conducted by the University. The Mathematics program was rated as Aspirant and the Statistics Program was deemed Good. This agrees with our own self-assessment and that of the 2012 AQAD visiting committee, although in the case of Statistics, the comparison group consisted of nearly all stand-alone Departments of Statistics, which we believe skewed the results somewhat. The doctoral program is rapidly improving, and we have plans that we believe will make us competitive with many of the top programs. We are gratified that the DPR report concurred with our main findings: that the mathematics PhD program should become larger, and that we need to be able to offer more courses. We also agree that student (and faculty) diversity and the completion rate are serious issues where the department needs and hopes to improve.

Size and structure of the program. Our goal is to increase the number of mathematics PhD students from around 34 to around 48, which would bring us close to a 1.5 to 1 ratio of students to faculty. This would require some combination of increasing the number of TA positions and moving some students from TA support to RAs or fellowships for at least part of their career. We hope to obtain external funding for at least part of this increase. We have been actively pursuing such grants: in 2011 and 2012 some applied math faculty submitted proposals for an NSF IGERT grant, and we have submitted three proposals for an NSF RTG (research training grant), in 2007, 2012 and 2013. We note that one area where the reviewers were critical of these proposals was the lack of matching commitments from UMass: for instance, one review of the 2012 RTG wrote that [i]nvestment in this department seems timely, advisable and potentially very rewarding. On the other hand, it seems that while the department has committed funds to match the RTG grant, the university has not really stepped-in, e.g. by committing post-grant funds (as other competing institutions have). If we are to succeed in obtaining these kinds of large training grants, and if they are to have a lasting impact on the department beyond the duration of funding, support from the College and University will be essential. We are gratified that Dean Goodwin has approved our requests for post-grant support on the most recent RTG proposal. The Department is also proposing to create a separate degree program in Statistics; currently students who do doctoral work in Statistics go through an internally separate admission process but enroll in the Mathematics PhD program. This will not require any substantive changes within the program, but will more accurately reflect the students' credentials.

Another avenue we are pursuing which potentially could support an extra graduate student is a Five College Graduate Teaching Fellowship; it has become routine that our more experienced teaching assistants have been asked to fill in teaching shortfalls at one of the other colleges. Since this is a valuable experience to include on their CV, we allow this. The FCGTF regularizes and formalizes that relationship. It is reserved for students with the strongest teaching credentials, and would give them a valuable introduction to teaching in a liberal-arts setting, where many of our students obtain employment. This is now in place for one student, but we would like to expand the program through negotiations arranged through Five Colleges, Inc.

MS programs. For the MS programs in Applied Mathematics and in Statistics, these programs are at about 8 students each; the addition of faculty proposed in the Vision section would allow potentially doubling the size of each program, representing an addition of 16 students. We feel the tuition waivers students receive represent an excellent investment for the University in two ways. First, students who complete the MS programs have historically found extremely lucrative and influential jobs in industry and are an excellent source potential donors to the University. Second, while here, the MS students provide critical teaching help as 10-hour per week TAs. So, we do not recommend elimination of tuition waivers for the 8 students per year in each of these programs. However, there could potentially be a market for international students, particularly from China, who could be recruited to enlarge the program and who would not teach but would pay full tuition.

Recruitment. To increase number of students and still maintain quality, we need to improve our recruiting. Although we have a large applicant pool and thus can be quite selective in making offers, we are not yet competitive with the strongest schools, and our yields among the best and most prepared students are still relatively poor. Recent feedback from some of our applicants have convinced us that our low stipends are a significant problem for recruitment. In particular, in many recent years, the IPOs cost of living adjustment put their minimum financial requirement for international students above our stipend, forcing students to provide a personal financial statement in order to get a visa. This is very embarrassing for the department; we need to make certain that it does not happen in the future. After studying the stipends offered by some of the peer departments we compete with, we feel it is urgent to raise stipends. We plan to do this through the Department's CEI revenue stream, and appreciate matching funds being provided by the Dean, but making a commitment prior to knowing the details of changes to the resource allocation model appears risky. It would also greatly help our recruiting to offer more fellowship support as inducements to the very best applicants. It was an eye-opener to see during this review the much larger fellowship programs that some of our peers have. We have just completed Spring 2015 recruiting successfully; we used Fellowship money we received from the Dean and the Graduate School to offer much more competitive stipends and recruited 13 PhD students, including 5 women and one underrepresented minority candidate. We strongly support the committees finding that the University should increase the size of the graduate fellowship program. It has also been extremely helpful to have a few fellowships which are controlled at the department level and can be reassigned if an applicant withdraws. Finally, another potential source of graduate funding is the NSF graduate fellowships. In the past we have not had many students apply for these, but going forward we plan to be more active in encouraging eligible students to apply and guiding them through the process.

Diversity. Increasing the diversity of our student body is a serious concern for the department. In the last several years we have seen a significant drop in the percentage of female applicants, and we have struggled to enroll enough qualified female students. The worst year was the class of 2010, in which only one of ten new PhD students was a woman. Since then the percentage of women matriculating has stabilized at 25-30%, which is still too low. As a small step to help increase the number of qualified female applicants, we began a policy of waiving the application fee for female applicants from the Five Colleges. We also organized meetings last year with current female students to learn what we can do to make the department more welcoming to women. We received very useful feedback on issues ranging from nighttime safety in Lederle to a lack of transparency in assigning graduate student service roles. We are working to address these and other issues, and hope that by making our current female students happier, they will help us to recruit the next generation of students. We had an especially successful year in AY2013-2014, when we graduated 7 students, 4 of whom were female. Hiring more female faculty continues to be a high priority for us.

Graduate courses. The most important structural improvement we can make to the PhD program is to offer more graduate courses. Under current conditions too much of our graduate instruction beyond the first year is done via independent studies taught by faculty as an overload. While that does allow for more individualized instruction, it is very inefficient, and doesnt foster connections between students within the research areas. To bring us up to the low end of our peers we would need to offer 24 courses per year, an increase of 6 from the current number. We refer to the document Report on Departmental Instructional Needs which we produced for the Dean in 2012 for a broader picture of the department's interrelated teaching needs at the graduate and undergraduate levels. For the most part, offering more graduate courses would require increasing the tenure- stream faculty, although a limited benefit could also come from hiring additional temporary Visiting Assistant Professors (postdoc), since VAPs can teach some upper- level undergraduate courses which would release faculty to teach graduate courses. With all other demands remaining static, the goal of adding 6 graduate courses per year can be achieved by adding 1.5 new VAP positions. We have committed departmental funds (through CEI) for hiring one additional VAP, but unfortunately the new VAP is being used mostly to help cover undergraduate classes due to growing enrollments. Since a VAP is only a 3-year commitment, we felt it was a safe and wise investment. Besides enabling us to offer more regular classes, these extra teaching resources will allow us to implement curricular innovations which would greatly enhance the quality of our program. One example is a proposed one-semester introduction to applied mathematics course which would provide first-year applied students with a broad introduction to applied methods and problems, giving them a broad foundation before they move to more focused and specialized work. Another proposal is to form graduate reading seminars in each major research area which students could take for credit. Students would gain experience reading papers and giving talks. Seminars of this general type have been given in algebraic geometry, representation theory, number theory, and applied mathematics, and the statistics group is planning to create one. In order to ensure that enough faculty are willing to devote the time to run them on a regular basis, we would like to offer a fractional teaching reduction, so that running one for two semesters would give a one-semester teaching reduction in a later semester.

Completion rate / time to degree. The time to degree and especially the completion rate of our students has lagged behind our peers; if we are to join the ranks of the top programs they must be improved. To some extent this is already happening, thanks to a revitalized faculty and greater success recruiting strong students. The classes which entered in 2007, 2008, and 2009 have achieved greater than 50% graduation rate, with 2008 and 2009 reaching more than 70%. The time to degree is also improving, with more recent students finishing in five years. Most of the changes discussed earlier in this report should help improve the completion rate and time to degree. We have also made some small adjustments to the qualifying exams to help students progress through them more quickly, and we are considering a more comprehensive overhaul of the exams. We would like to improve the advising and oversight our students get, by moving the primary responsibility for advising students who have not yet chosen an adviser from the GPD to groups of faculty in the various research areas. We have also set up a departmental fund to supplement the graduate school travel grants, helping our students to attend conferences, disseminate their work, liaise with their peers and senior researchers and access the job market. Finally, we plan to start a regular seminar or brown-bag lunch series for our students on professional development. Some possible topics are: - Tools for finding and organizing mathematical literature in the digital age - Strategies for writing longer papers (this is particularly important since some of our students in pure math dont write anything longer than a few pages before their thesis) - How to prepare a talk; matching the presentation and format to the audience - Doing research with undergraduates - Different kinds of academic and nonacademic careers, and what kinds of preparation are necessary for each of them.

3 Vision for Future Strategic Directions

In this section, we describe the areas of growth the Department's strategic planning conversations highlighted as the most important. First, we provide a brief note on the process we used. The Department appointed a *Strategic Planning Committee* in Fall 2014 whose five members represented a cross-section of pure and applied mathematics as well as statistics at the Assistant, Associate and full Professor levels. The Committee composed a "Request For Proposals" for faculty (attached as an Appendix) and received 11 proposals which were evaluated for "Intellectual Merit," "Broader Impacts," and a third category we called "Why invest in Math/Stat?" Of the 11 proposals, the six that rose to the top were presented at a faculty meeting and the write-ups were modified accordingly, and subsequently ratified in a second faculty meeting. It should be noted that *all* of the proposals were deemed first-rate, but the Committee and Department as a whole felt that for the strategic planning to have a greater impact and value, it was necessary to make some difficult choices. Other directions that are not presented here include expansion into numerous disciplines of active research in Mathematics, Statistics, and even Mathematics Education. The six chosen strategic directions are divided into a first group of four expanding existing core research areas, followed by two which would represent entirely new directions for the Department.

Core Research Areas

Subject to availability of appropriate resources, we propose to expand and evolve four core research areas where the Department can leverage a modicum of existing strength and visibility to raise its profile further and expand its reach.

Predictive Modeling

A current exciting direction in the mathematical sciences is fueled by the burgeoning interactions of applied and computational mathematics with statistics and applied probability. This synergy brings together modeling, analysis and simulation of complex systems with the abundance of computational, experimental or sensory/observation data residing at different spatio-temporal scales. Assimilating such data in complex models has the potential to provide reliable predictive computational tools that can help us expedite scientific discovery and "time-to-market" for new products, detect threats, design better experiments, assess risks posed by extreme and rare events, and formulate and understand complex problems in the Life and Social Sciences. Remarkably, predictive modeling aligns tightly with no fewer than four strategic priorities for the University identified in the Chancellor's Phase II Strategic Planning process: 1. Advanced materials and manufacturing, 2. Applied life sciences and health, 3. Data science, computing and analytics, computational social science, and 4. Energy, climate science, sustainability (and most likely 5. Cognitive Science, as well). Thus, investment in predictive modeling has the potential to provide a fundamental foundation and connecting thread for diverse initiatives that emerge across campus through Phase III of the strategic planning process.

The Department has nationally and internationally recognized strengths and a long-standing tradition in this area. For instance, the U.S. Department of Energy supports a $2.3 million current project in uncertainty quantification (Katsoulakis and Rey-Bellet). Statisticians (Gile, Flaherty, Lavine, Liu, and Staudenmayer) have recent and pending awards from NSF, industry (through the UMass Innovation Institute), and NIH (at the R21, R01, and U01 levels). It is important to note that it is relatively uncommon to have a research-based university that has a co-located group of applied mathematicians and statisticians; often those groups are in separate (physically and intellectually) departments. The groups are co-located in the Mathematics and Statistics Department at UMass, and this proposal takes advantage of that structure to create a unique research and education environment for the University and the Commonwealth.

Increased emphasis in this area will be synergistic with campus and state initiatives such as the Institute for Applied Life Sciences, the Computational Social Science Institute, and the Massachusetts Green High Performance Computing Center. Undergraduate and graduate education will benefit from an expanded capacity to offer hands-on inter-disciplinary project focused classes, which are faculty-labor intensive. Furthermore, given sufficient investment, a professional degree program could be developed to train graduates, and this program could build off our existing BS degree and MS programs in applied math and statistics.

The highest priorities for hiring in this area include applied mathematicians and statisticians with significant experience/overlap in high performance computing. In applied math, the areas of focus include high-dimensional and multi-scale problems, uncertainty quantification, stochastic / Monte Carlo methods, and inverse problems. In statistics, the foci will include theory and methods for networks, Bayesian statistics, non-parametric as well as $p > n$ theory and methods.

Discrete Mathematics

Discrete mathematics, broadly defined, is important in almost every area of mathematics. Much of the current best work cuts across fields and across artificial divisions into "pure" and "applied" math. For a concrete example, certain special families of graphs, known as expanders, provide not only models of highly efficient telecommunication networks, but also computational tools in Monte-Carlo methods in statistical mechanics. Remarkably, today the only known explicit constructions of optimal expanders use deep results from pure mathematics (specifically modern algebra and number theory). For another example, there are important connections between algorithms in optimization (linear programming) and the geometry of convex polyhedra. Many of the most exciting recent results in mathematics, such as Abel prize winner Endre Szemeredi's study of the subtle balance between the connectivity and disconnectivity of a network, or Fields medalist Terry Tao's major advances in additive number theory, are firmly rooted in discrete mathematics. Investment in discrete mathematics aligns well with the Data science, computing and analytics, computational social science strategic direction identified in Phase II of the University's Strategic Plan.

At present, our department has internationally recognized researchers in many fields with close ties to discrete mathematics. For instance, the subfield of algebraic combinatorics is related to the research programs of several members of the department's algebra group. Graph theory and extremal graph theory are closely related to the work of many faculty members in fields as disparate as number theory, nonlinear PDE and statistical mechanics and span further to cybersecurity and computational social science (analysis of social networks through graph theory). It is difficult to name a research group in the Department that would not benefit from having expertise in discrete mathematics in our department, yet the department currently has no faculty member whose primary expertise is in discrete mathematics.

Adding faculty in discrete mathematics would broaden our undergraduate and graduate student training. Currently we only offer one introductory undergraduate course in discrete mathematics (Math 455, Introduction to Discrete Mathematics). Due to lack of faculty, we have had to combine the traditional two sections of this Integrative Experience course into one large one and close the course to ECE and CS students who traditionally took it and enriched the intellectual breadth of the research projects. Moreover, many students from our department and others would benefit from more advanced discrete math courses, such as computational graph theory, enumerative combinatorics or algebraic combinatorics. The Undergraduate Affairs Committee has expressed strong support for adding a computational component for our pure mathematics curriculum, alongside our existing courses in computational statistics and numerical analysis; adding courses in discrete math would be a great way to do this. Exposing our students to the more concrete and applicable ideas and techniques of discrete mathematics would also help their job prospects, as a significant number of our students end up in non-academic jobs. Having faculty in this area would also aid in recruiting graduate students, since discrete math is a popular choice among undergraduates applying to graduate schools; indeed, roughly 8% of math PhDs are awarded in the field.

The highest priority areas for hiring within discrete mathematics are in algebraic combinatorics and graph theory, and would prioritize candidates whose work is synergistic with one or more of any of our existing research groups from algebra to statistics.

Frontiers of Geometry and Mathematical Physics

The synergy between physics and mathematics has always been a vital source of new ideas in the mathematical sciences. In recent years, topological field theories and related string-theoretic constructions have been gold mines for mathematicians, yet a fundamental understanding of these exotic physical theories is missing. For instance, one of the key tools of the physicist, the path integral, is still awaiting mathematical justification. The methods of derived categories and the algebraic method of analysis are seen by many experts as the most promising avenue to solving these problems, and consequently they have come to the forefront of pure mathematics in recent decades. Related problems of understanding the geometry of algebraic cycles and its connections to arithmetic geometry are among the most important problems in the pure mathematics of 21st century; three of the six as yet unsolved Clay Millennium Prize Problems are centered in this circle of ideas. Especially notable developments of the last five years or so (by Jacob Lurie, Maxim Kontsevich, and Vladimir Voevodsky who share two Fields medals and two $3 million Breakthrough Prizes among them) promise to catalyze new mathematical insights in physics, spawn new understandings of how various parts of mathematics relate to one another (one example being the development of a nascent derived differential geometry), and even range into computer science through a homotopy-theoretic program of computer verification of mathematical results.

Our department has a long-standing tradition of leadership in the frontiers of geometry. To cite only two examples, the Cattani-Deligne-Kaplan theorem is the result closest to the famous Hodge conjecture, one of the Clay Millenium Prize problems (Eduardo Cattani is a research-active Emeritus member of our faculty and a former Department Head); Ivan Mirkovic is co-creator of the Mirkovic-Vilonen theorem, which is fundamental cornerstone of the geometric Langlands program – whose vast aim is to unify number theory and representation theory. Our geometers and number theorists, including the younger generation, have received several recent awards, among them Sloan Fellowships to Tevelev and Oblomkov (who also has an NSF CAREER award), and Simons Fellowships to Gunnells and Mirkovic.

Our faculty members in these areas run active graduate seminars, organize the Valley Geometry Seminar and Five College Number Theory Seminar, as well as the nationally recognized NSF-funded biannual AGNES conferences in algebraic geometry. The group's engagement in the undergraduate major has been especially notable, and in the past five years we have seen phenomenal impact: for instance, the UMass Putnam team, coached by members of the group, was ranked number 24; numerous undergraduates who have done REUs and senior theses within the group have been accepted to the top graduate programs, including MIT, Harvard, Brown, UT Austin, including two of our undergraduates who received NSF graduate fellowships. Undergraduate Morgan Opie who began studying algebraic geometry with Tevelev as a junior, received a Churchill Scholarship to attend Cambridge University, the first such award for a UMass Amherst student in any discipline and will pursue a Mathematics PhD at MIT.

Hiring in derived geometry, arithmetic geometry and modern homotopy theory are the highest priorities of the group. A homotopy theorist with the knowledge of topological field theory would tie together our algebraic geometry group with the topology group via string topology and mirror symmetry studies. An arithmetic geometer would link our number theory and algebraic geometry groups. An expert in derived categories would provide a further expansion of the scope of the group and generally broaden our geometry group.

Analysis of Dynamical Systems and Partial Differential Equations

Many exciting current advances in science involve complex, high (or infinite) dimensional systems, which are predominantly non-linear, often evolve under random rule and are sometimes non-local. Examples of such complex systems are ubiquitous and include social systems such as financial markets, materials and fluids, models of climate, and physical phenomena such as Bose-Einstein condensation. In all these problems, stochastic and deterministic partial differential equations (PDE), dynamical systems, nonlinear dynamics and ergodic theory, stochastic homogenization and statistical mechanics provide the mathematical and conceptual underpinnings needed to unravel and analyze the complex cooperative phenomena. For example harmonic analysis and geometric and probabilistic techniques are currently used in innovative ways for image processing and data analysis. Thus, investment in this area is aligned with the Phase II strategic priority in Data science, computing, analytics, computational social science.

The Department has a deep, internationality recognized, cluster of excellence in Dynamical Systems (for example, Panos Kevrekidis is a recipient SIAM J.D. Crawford Prize, Hongkun Zhang received an NSF CAREER award) as well as in Analysis and Partial Differential Equations (for example, Andrea Nahmod is Fellow of the American Mathematical Society and she and Luc Rey-Bellet are co-organizers of the Jumbo program on New Challenges in PDE: Deterministic Dynamics and Randomness in High and Infinite Dimensional Systems, at the Mathematical

Sciences Research Institute, Berkeley, Fall 2015). The group as a whole has an excellent, long track record of federal funding for their research programs.

Some of the best graduate students in the department in recent years have been mentored in this field and have gone on to successful careers both in academia (in first-rate research universities) as well as in industry. From a teaching and mentoring point of view however, at both graduate and undergraduate level, in pure and applied analysis, the existing group is severely understaffed. Providing proper training in pure and applied mathematics requires maintaining a PDE, analysis and probability faculty of appropriate size that is at the forefront of these emerging cutting edge topics.

An investment of positions in harmonic analysis and its applications, in dynamical systems, as well as in stochastic, fully nonlinear, non-local partial differential equations are the highest priorities in this area. These topics are among the most vital research areas in contemporary mathematics (these topics are directly connected to 3 of 4 Fields medals awarded in 2014). The group's current stature ensures that these hires would be at the highest level of achievement and visibility and would make possible the invigoration of a cluster of excellence at UMass capable of forging new synergies within as well as beyond the department.

Expansion Research Areas for Future Investment

If the University's strategic planning process results in the allocation of resources for increasing the size of the faculty in Mathematics & Statistics, the Department proposes two strategic directions for expansion into areas currently not represented in the Department.

Cybersecurity and Cryptography

While the implementation of cybersecurity systems lies primarily in the domain of computer science and electrical engineering, the design of all computer security systems ultimately rests on a mathematical foundation. For instance, the RSA and elliptic curve cryptosystems, which have secured online commerce since the inception of the internet, are based on fundamentals of number theory and algebra. The security of these systems rests on the current intractability of certain problems of computational number theory, such as factoring large integers. As theoretical as well as computational advances devise faster integer factorization routines, current encryption standards must be upgraded and indeed in the not-so-distant future must give way to fundamentally new encryption schemes. The possible development of quantum computers adds further urgency to the search for new mathematical tools for cryptosystem design. Thus, alongside efforts by computer scientists and engineers to improve implementation of current cybersecurity technologies, there is a pressing need for mathematicians with cutting-edge knowledge in theoretical mathematics to work on the problem of creating new cryptosystems and verifying the security of existing ones. The increasing acuity of the need for new mathematical ideas in security research can be gleaned, for instance, by the introduction of the Secure and Trustworthy Cyberspace (SaTC) program within the Division of Mathematical Sciences at the NSF, and the proliferation of new conferences on the mathematics of cryptography sponsored by research centers such as ICERM (`icerm.brown.edu`) and the Naval Postgraduate School CISR (`cisr.nps.edu`). On another front, statistics plays an increasingly important role in the monitoring of large flows of data across computer systems. Statistical modeling, machine learning, graph theory, and network analysis techniques will play an important part in the development of tools for advanced cyber situational awareness. Investment in this area aligns extremely well with national, state, and Phase II priorities in Data science and Cybersecurity.

Our Department has strong research groups in algebra, number theory, and algebraic geometry, three sub-disciplines whose basic objects of study have proven to be the richest source from which cryptographic protocols are created. These are also the fields whose theories are used to try to attack cryptosystems. Given the accelerated pace at which cybersecurity has become a priority for the US government, and the increasing need of a workforce which is trained in the mathematical underpinnings of cryptography, the Department of Mathematics & Statistics foresees an opportunity and a need to develop a number of new courses and indeed of new programs for undergraduate as well as graduate students. The need for such courses is in no way limited to students housed in our Department.

The University has significant strengths in many aspects of cybersecurity, in particular in Computer Science. Our Department does not currently have mathematicians/statisticians whose work directly impacts cybersecurity. In order to create a more complete and coherent cybersecurity profile for the University, a number of cluster hires in Mathematics and Statistics who would interact with other Institutes or Centers on campus are recommended. The highest priority areas are computational number theory and algebra as well as the intersection of data science with information theory.

At the graduate level, these new faculty lines would allow the addition of a cybersecurity component to the Masters Programs in Applied Mathematics and Statistics. It would allow students studying pure mathematics to learn about applications of algebra and geometry to cryptography, expanding the scope of jobs available to them. Moreover, the Masters program in Electrical and Computer Engineering, which has an enrollment of 180 students would potentially benefit greatly from one or more courses in cryptography to be offered by our Department. At the undergraduate level, a sufficient number of new hires would make possible the creation of a new Cybersecurity/Cryptography concentration for math majors, which would require a number of new courses to be designed and offered yearly. We also note a potential synergy between the existing Actuarial and the putative Cybersecurity/Cryptography concentrations, especially in relation to our existing ties with Mass Mutual since this company has an interest in both of those areas. The Department could contribute also to courses at the 100 level designed to provide the business leaders of tomorrow with a basic knowledge of open-key cryptography and signature schemes so that they can be well-informed about the mathematical fundamentals of these issues.

Mathematics and Statistics of Life Sciences

There is an ever increasing need for mathematicians and statisticians to contribute to the explosion of contemporary research in the biological and medical sciences. While Mathematical Biology is an established interdisciplinary field that applies mathematics to biology, ecology and medicine, nowadays the interface between the mathematical sciences and the life sciences is expanding and its emphasis is rapidly changing. For instance, the genomics revolution is generating huge data sets that require new and different methods of statistical analysis and inference. Similarly, areas of core mathematics that have not traditionally been associated with biological applications, such as geometry and topology, are now being invoked in biological modeling; for example, tools from knot theory and 3-dimensional manifolds are being used to predict the action of enzymes needed for replication and protein synthesis. It is possible that, just as physics has stimulated the development of modern mathematics for over two centuries, 21st century bioscience will become a key driver of innovation in both mathematics and statistics. Even existing techniques in mathematics, statistics and allied computational algorithms are impacting how biologists cope with their modeling challenges and their proliferating experimental data. For instance, dynamical systems theory supplies the conceptual framework for building deterministic models of spatial and temporal evolution in multiple contexts ranging from intracellular dynamics in molecular biology to the spread of diseases in epidemiology. But nowadays researchers insist that uncertainty and stochasticity be included in their models, and they are therefore turning to applied probability and statistics for ideas. In the future, as-yet-unknown approaches will be conceived, and novel quantitative methodologies will develop in parallel with the bioscience disciplines themselves.

While the department has never conducted a targeted search in the fields of mathematical or computational biology, several faculty from Mathematics and Statistics have established expertise in these areas. For instance, our applied mathematicians (Kevrekidis, Whitaker) have collaborated with colleagues in Veterinary and Animal Sciences and the BayState Medical Center. To an even greater extent, many of our statisticians (Conlon, Lavine, Liu, Staudenmayer) have ongoing interactions, joint publications and grants with faculty in Biostatistics, Kinesiology, and Microbiology, among others. The Department's latest two hires, Li and Flaherty, study probability theory and statistics, respectively, and to varying extents contribute to problems stemming from the life sciences. Interdisciplinary cluster hiring of faculty, would have the potential of catalyzing these interactions with other disciplines and would create a strong nucleus of activity in this field. Such collaboration across science departments would place our faculty in a truly competitive position in the funding arena; potential sources include: NSF, NIH, NSF and NIH joint programs, Big Data initiative, Mathematical Science Innovation Incubator Awards, and non-governmental sources (J.S. Mc Donnell Foundation, Keck Foundation, Simons Foundation – Mathematical Modeling of Living Systems).

An expansion effort through cluster hiring in this area would align our department with ongoing initiatives on campus and within the Five Colleges in the biological sciences. These include IALS (Institute for Applied Life Sciences) but could also be influential in reinvigorating the ICB3 (Institute for Computational Biology, Biostatistics and Bioinformatics). Naturally, investing in this area would also be in accordance with two of the priority areas identified in Phase II of the University Strategic Plan, on Data Science and Applied Life Sciences. From the educational perspective, the University has had no involvement in the Four College Biomath Institute funded by NSF's Interdisciplinary Training Program for Undergraduates in Biological and Mathematical Sciences (UBM). Once faculty are dedicated to this area, there would be consequent developments in undergraduate and graduate courses in mathematical and statistical bioscience. We anticipate that such offerings would be hugely popular with students, who themselves perceive the burgeoning career opportunities in this field. Former mathematics major and Goldwater Scholar, Heather Harrington (B.S., 2006), now a Fellow at Oxford University (`www.maths.ox.ac.uk/people/heather.harrington`) is one example.

The 21st century's biological revolution is in full swing. The department proposes to seize the opportunity to expand in this timely and relevant area and to expand not only its research profile but also its curriculum and its interconnections with the life sciences throughout the University.

4 Concluding Remarks

The rapid technological changes of the last two decades have catalyzed a "quantification" of disciplines throughout academia and the workplace. This month, the Huffington Post reported that "Math skills are a requirement for most of the top ten jobs, according to the latest report from `careercast.com`." Locally, we experience this shifting landscape through unprecedented enrollment pressure in upper-division courses, which has been managed primarily through means that lower the quality of what we can offer. The ability to collect and store large amounts of data and to perform large computations on them quickly have led to the wise decision for the University to invest heavily in Computational Sciences. For the moment, the focus is on the computer science and engineering aspects of the shifting landscape. Any strategic planning process looks to sift out the tremors in the landscape that presage what is to come. As the software and hardware innovations run up against their natural boundaries, it appears inevitable that the focus will shift increasingly to the need to make use of innovations in the methods that underlie software programming; the latter are the province of mathematics and statistics. For these reasons, we believe investment in faculty hiring in Mathematics & Statistics at this time is crucial for accomplishing the University's mission, and is moreover further supported by a number of conditions and trends.

- Research in the mathematics and statistics does not require the expensive physical and human resource infrastructure which is a must in most, if not all, related disciplines.

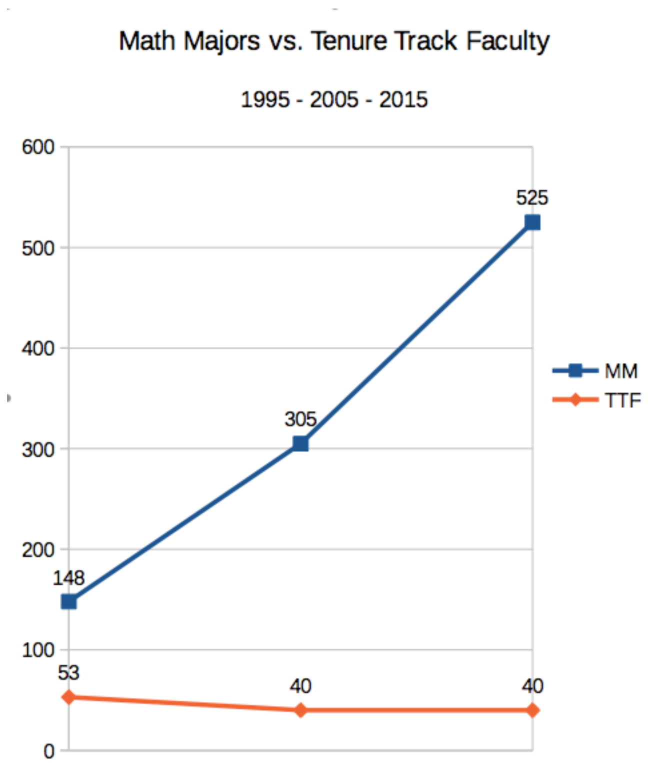
- In addition to being core subjects of study at every college and university, Mathematics & Statistics are fundamental modes of thinking, and ones on which related disciplines, from physics to economics, rely at an ever accelerating pace.

- The Department of Mathematics & Statistics is likely in a unique position in that support for its initiatives outlined here contributes to every one of the Strategic Directions highlighted in Phase II of the University's Strategic Plan in relation to the intersection of campus strengths and state/regional/national priorities.

- Mathematics & Statistics faculty at all levels yield a high return on investment not only through federally supported sponsored research, but also through to the consistently high volume of teaching they deliver, as measured either by student credit hours, or numbers of organized sections taught. Mathematics & Statistics courses support huge numbers of students at the lower division level; as well, an increasingly large number of upper division courses in the Department have heavy enrollment from outside the Department and even outside the College of Natural Sciences, creating an unprecedented teaching bottleneck with significant consequences for graduation rates across the University.

- The variation in the number of majors in the Department juxtaposed with the number of tenure track faculty members over the past two decades tells a dramatic story:

- In 1995, there were 53 tenure track faculty members serving 148 majors
- In 2005, there were 40 tenure track faculty members serving 305 majors
- In 2015, there are 40 tenure track faculty members serving 525 majors.



- As indicated above, over the last twenty years, the number of math majors has grown at the rate of 350% while the tenure track faculty has shrunk by 33%. The increase in the number of math majors is accelerating: it rose from 475 in Spring 2014 to 525 in Spring 2015, a 10% jump in only one year. At the same time, a burden of much larger magnitude, as measured by number of students, is providing lower division courses in (among others), Calculus, Linear Algebra, and Differential Equations, which serve many CNS and Engineering majors. From AY2009-2010 to AY2013-2014, enrollment in these courses grew from 3392 to 4585, an increase of 35%. Without significant investment in additional faculty lines within the next two years, the Department will need to decide whether to cut back on lower division courses in order to facilitate 4-year graduation pathways for math majors, or to cut back on upper-division courses to support 4-year graduation pathways for all other majors.

- The Department's Doctoral Program Review supports greater investment in and an expansion of the graduate program.

- The Department has an excellent record of Faculty hiring spanning two decades, as noted in 2005 and 2012 AQADS; in AY 2014-2015, both tenure track searches succeeded in recruiting the top candidate, and the Department also filled five Visiting Assistant Professor positions with the top five candidates who were still available at the time our offers were made.

- The Department's rise in the NRC rankings indicates that a relatively modest investment in increasing the size of the Tenure Track faculty could edge the Department from the top 20 among peer departments at public research universities to the top 10 in a relatively short time span.