MU Strategic Plan for Bioinformatics

Commissioned by:

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Executive Sponsor of the Task Force

Prepared by:

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Executive Summary

The field of bioinformatics and computational biology is one of the hottest scientific areas nationally and internationally. This field has recently grown out of traditional fields of health informatics, biostatistics, information sciences, computer sciences, molecular biology and genetics. Although the University of Missouri (MU) has historical strength in these classical fields, on the whole, MU has not adapted to the development of bioinformatics as a scientific subdiscipline, a fact that has placed us in a position of competitive disadvantage. Bioinformatics has grown rapidly, due to the enormous amounts of complex data generated by the Human Genome Project and related research and the concomitant need for sophisticated data analysis. Bioinformatics is essential for the conduct of contemporary life sciences research. Thus, bioinformatics is not only an area of primary research, but its technology is also critical for research in all of the life sciences.

Current research funding initiatives from all of the federal agencies (NIH, NSF, USDA, CDC, DOE, DHS, NASA, DARPA, etc.) have a significant and specific focus on bioinformatics. The confluence of these dramatic initiatives illustrates today's enormous research opportunities in the life sciences. Despite its acknowledged strengths, MU will not be able to fully exploit these opportunities or participate in the state-wide I-70 Biotechnology Corridor unless we aggressively build a competitive bioinformatics program. Indeed, to maintain and augment the quality and pace of our existing life sciences research, we must quickly and significantly invest in bioinformatics.

Bioinformatics at MU suffers because it is so multidisciplinary that it does not fit gracefully into traditional department and college structures – there is no organizational structure to foster its growth. Our faculty are scattered in multiple units; we lag behind our peer institutions in educational and training programs; and we have little ongoing funding for critical technical infrastructure and support needs. MU needs to move quickly to establish a structure and the resources so that bioinformatics can play the central role demanded today. Other institutions are aggressively recruiting faculty and staff and building programs. MU needs to do likewise.

These urgent, critical needs are the genesis of this strategic plan. It was commissioned by James Coleman, MU Vice-Provost for Research, and developed by a Bioinformatics Task Force (BITF) of faculty from the Colleges of Arts and Sciences; Engineering; Agriculture, Food and Natural Resources; Veterinary Medicine; and the School of Medicine. (The members of the BITF are listed in Appendix A.) The bioinformatics strategic plan was developed with special attention to critical technical infrastructure and the three central missions of the University: research, education, and service.

Vision

As part of the MU Life Sciences Initiative, we will become recognized and respected for world-class bioinformatics research, education and service.

Goals

Recognizing that research, education, and service in bioinformatics are inherently interdependent and mutually supportive, we have the following goals:

Goal #1: to be a recognized national and international leader in bioinformatics research, leveraging and strengthening the multidisciplinary research faculty who are spread across multiple schools and colleges;

Goal #2: to develop a total package of educational offerings in bioinformatics, including an undergraduate minor, Master of Science, certificate programs, PhD and postdoctoral fellowships;

Goal #3: to develop a user-centered system to support faculty research efforts as they use and develop bioinformatics tools and techniques, independent of physical location of the research;

Goal #4: to maintain a technical infrastructure that allows fast and efficient computation, analysis, modeling, visualization, and retrieval of biological data.

Goal #5: to create an organizational structure that integrates the research, education, and service missions, and to garner requisite institutional resources, leadership, and backing to realize these goals**.**

Critical Needs

MU has critical needs, some overarching and some specific to research, education and service.

Overarching needs:

- A sense of urgency in the senior administration that recognizes that bioinformatics is essential to the future of scientific research at MU and acts accordingly.
- A campus-wide organizational framework to support bioinformatics
- A competitive technical infrastructure, continuously maintained

Specific research needs:

- Faculty positions at all ranks, recruited over several years.
- Seed funding for bioinformatics-experimental collaborations, proposal writing, speakers, and fellowships.
- Centralized space for bioinformatics research.

Specific education needs:

- PhD program and associated administrative support.
- Undergraduate minor.

Specific service needs*:*

- Ongoing, sustainable funding model and funds.
- Faculty and staff with a service mission.
- Assigned space for bioinformatics support, ideally some significant portion in the Life Sciences Center.

Recommended Actions, in Order of Priority

Action #1: Provide immediate seed funding to implement the recommendations of this task force, and develop sustainable, continuing funding for bioinformatics research, teaching, and service.

Action #2: Create a campus-wide Bioinformatics Institute: appoint its Director and associated advisory committees.

Action #3: Develop, within the Bioinformatics Institute, a bioinformatics service facility to support life sciences research. A natural home for this facility would be within the Life Sciences Center.

Action #4: Recruit and hire faculty and staff for bioinformatics research, service, and education.

Action #5: Approve the cooperative bioinformatics PhD degree program that is being developed by the curriculum committee (a subcommittee of the MU-BITF), in coordination with the UM Bioinformatics Consortium.

Action #6: Acquire and continuously maintain the computational, data storage, and networking infrastructure required to support world-class bioinformatics research, education, and service programs.

I. Vision

As part of the MU Life Sciences Initiative, we will become recognized and respected for world-class bioinformatics research, education and service.

The University of Missouri (MU) is strategically positioned to play a leadership role for life sciences in the State of Missouri and beyond. Geographically the University is positioned to bridge the distance along the burgeoning I-70 life sciences corridor to connect a growing list of groups conducting research in the life sciences - from the Donald W. Danforth Plant Science Center in St. Louis to the Stowers Institute of Medical Research in Kansas City.

Columbia serves as a natural connector where synergies among scientists from different fields can exchange ideas, generate new discoveries and work with entrepreneurs who can translate discoveries into products for the marketplace. As a collaborator, MU is positioned, throughout this corridor and beyond, to unite the efforts and provide strong leadership in its role both as a land-grant university and as a viable partner in life science research around the world.

In plant science, animal science and medical science, the University of Missouri has the challenge of playing a leadership role in the life science corridor, benefiting the citizens of Missouri, providing opportunities that foster the economic well-being of the State and be respected for world-class bioinformatics research, education and service. The University of Missouri applauds this challenge and expects to be successful in meeting it.

II. Rationale for Boosting Bioinformatics at MU in 2004

The field of bioinformatics and computational biology is one of the hottest scientific areas nationally and internationally. This field has recently grown out of traditional fields of health informatics, biostatistics, information sciences, computer sciences, molecular biology and genetics. Although MU has historical strength in these classical fields, on the whole, MU has not adapted to the development of bioinformatics as a scientific subdiscipline, a fact that has placed us in a position of competitive disadvantage. It has grown rapidly due to the enormous amounts of complex data generated by the Human Genome Project and related research, and the concomitant need for sophisticated data analysis. It is essential for the conduct of contemporary life sciences research. Thus, bioinformatics is not only an area of primary research, but its technology is also critical for research in all of the life sciences.

Current research funding initiatives from all of the federal agencies (NIH, NSF, USDA, CDC, DOE, DHS, NASA, DARPA, etc.) have a significant, specific focus on bioinformatics. The recently released NIH Road Map defines a framework for the next twenty years of biomedical research in which bioinformatics plays a central role, *e.g.* in developing pharmacogenetics and personalized medicine. The Department of Homeland Security requires bioinformatics-dependent identification of biological weapons, epidemiological and environmental monitoring and prevention and early warning systems for agroterrorism. The NSF's Tree of Life and Biocomplexity initiatives rely heavily on bioinformatics for both data acquisition and analysis. The Department of Energy's Genomes to Life project is developing and using bioinformatics methods and tools to model complex biological systems for use in energy production,

mitigation of global climate change and environmental remediation. The USDA is a key partner in genome projects for food crops and animals, as well as in the development of databases and techniques to track infectious diseases of domestic animals, including zoonotic diseases. The series of reports from the Institute of Medicine on patient safety are centrally positioning bioinformatics in patient care and in the interpretation of the medical record. The CDC, through its Public Health Information Network, is developing a shared vocabulary and technical infrastructure for the rapid and accurate worldwide exchange of information for the detection and monitoring of incipient epidemics. The confluence of these dramatic initiatives illustrates today's enormous research opportunities in the life sciences.

Despite its acknowledged strengths, MU will not be able to fully exploit the current opportunities or participate in the state-wide I-70 Biotechnology Corridor, unless we aggressively build a competitive bioinformatics program. Indeed, to maintain and augment the quality and pace of our existing life sciences research, we must quickly and significantly invest in bioinformatics. This recommendation echoes the strategies documented in the January 2003 Battelle report on "Life Sciences & Missouri's Economic Future" (commissioned by UM System, The State of Missouri, the Danforth Foundation, and the Ewing Marion Kaufmann Foundation). This report highlighted the critical importance of strengthening bioinformatics research and educational offerings as a requirement for optimal, life sciences-related, economic development in the State of Missouri.

Bioinformatics at MU suffers because it is so multidisciplinary that it does not fit gracefully into traditional department and college structures – there is no organizational structure to foster its growth. Our faculty are scattered in multiple units; we lag behind our peer institutions in educational and training programs; and we have little ongoing funding for critical technical infrastructure and support needs. MU needs to move quickly to establish a structure and the resources so bioinformatics can play the central role demanded today. Other institutions are aggressively recruiting faculty and staff and building programs (see summary of four peer institutions in Appendix E). MU needs to do likewise.

These urgent, critical needs are the genesis of this strategic plan. It was commissioned by James Coleman, MU Vice-Provost for Research, and developed by a Bioinformatics Task Force (BITF) of faculty from the Colleges of Arts and Sciences; Engineering; Agriculture, Food and Natural Resources; Veterinary Medicine; and the School of Medicine (the members of the Task Force are listed in Appendix A). The bioinformatics strategic plan was developed with special attention to critical technical infrastructure and the three central missions of the University: research, education, and service.

III. Strengths of Life Sciences and Informatics at MU

MU has a strong reputation and history for providing worldwide service to the plant genetics and genomics communities, especially those investigating maize, wheat, and *Arabidopsis*. Louis J. Stadler pioneered work on the nature of mutations using maize and barley; Nobel prizewinner Barbara McClintock's work at Missouri led to the discovery of mobile genes; Ernie Sears revolutionized wheat genetics and wheat production; and George Redei was instrumental in developing the genetics of the model plant, Arabidopsis. Ed Coe conducted pioneering work on

the genetic mechanisms of maize and is leading the development of the maize database. The development of high resolution, integrated genetic and physical maps of maize began at MU. Researchers have developed strains, databases, mapping algorithms and statistical methods that are essential to the integration of data from thousands of crosses. The work with maize continues today, and has expanded to wheat and soybean. Extending well-past this seminal work on plant genomics, MU has built one of the most comprehensive research programs in life sciences to be found anywhere in the world.

MU Animal and Veterinary Science investigators are participating in national efforts to build genomic and genetic databases for cattle and swine. Investigative teams headed by Randall Prather have developed extensive EST libraries of expressed genomic sequences being applied to a battery of reproductive investigations for cattle (http://genome.rnet.missouri.edu/Bovine/) and swine (http://genome.rnet.missouri.edu/Swine/). Drs. Prather, Riley and Critser have recently been awarded an NIH grant to establish the first National Swine Resource and Research Center (http://nsrrc.missouri.edu/). Prather is leading the way in developing transgenic and knockout strategies in livestock species. MU also houses the only Rat Resource and Research Center in the US, and one of four Mouse Resource and Research Centers, both headed by Critser and Riley and funded by NIH. Gene map work in cattle is headed by Eric Antoniou. Jerry Taylor is working on large scale SNP determination and evaluation in cattle. All these animal genetic programs are heavily reliant on cutting-edge bioinformatics efforts.

There is also considerable genomics and genetic mapping activity in microbial species on the MU campus that relies extensively on bioinformatics expertise. Among the many individual and collaborative efforts, investigators are participating in genome sequencing projects linked to the DOE Genomes to Life Program (J. Wall), to the investigation of plant pathogens (A. Chatterjee, W. Gassmann) and symbionts (G. Stacey, D. Emerich), and to the investigation of animal and human pathogens including select agents (Wise, Calcutt, McIntosh, Reilly, Riley). At least two new bacterial species are under contract with TIGR for sequencing this spring in projects headed by MU investigators. The annotation efforts will require extensive bioinformatics resources. Regional and national consortia underpin these genomics efforts, including the Midwest Regional Center for Excellence in Biosecurity and Emerging Pathogens, centered at Washington University, the MU-based Program for Prevention of Animal Infectious Diseases (involving the DHS/USDA national lab at Plum Island for foreign animal diseases), and the pending Midwest Alliance Homeland Security Center for Foreign Animal and Zoonotic Disease Defense.

At MU, George Smith originated the ideas and developed the first workable system for phage display recombinatorial selection, providing the groundwork for high-throughput methods of combinatorial chemistry, and opening the door to genomewide and multifactorial analysis of binding affinity and specificity of targeted compounds. This technology today underpins the strategies applied to drug discovery in pharmacogenetics, both in the pharmaceutical industry and in biomedical research institutions. MU has also invested heavily in the past 5 years in structural biology and proteomics technologies that have a strong bioinformatics component. MU has a charter membership in the Molecular Biology Consortium, which built an X-ray beamline at the Lawrence Berkeley National Laboratory. Membership gives MU structural biologists and their collaborators guaranteed access to synchrotron beam time on a scheduled regular basis throughout the year. MU also invested >$2M in a Proteomics Center, bringing mass

spectroscopy expertise to campus to allow MU investigators access to peptide fingerprinting and protein modification technologies on a genomewide basis. Analysis of the datasets created by both the structural biology and proteomics activities require a considerable investment in bioinformatics expertise.

Additional key strategic assets that separate MU life sciences research efforts from its competitors include, among many others:

• School of Medicine – with research focusing on cancer, cardiovascular diseases and diabetes, immunology and inflammation, infectious diseases, child health, aging, health care quality, and hospitals for clinical trials.
• MU Research Reactor – the most powerful university research reactor in the world, and a leader in the development of novel radiopharmaceuticals for cancer diagnosis and therapeutics.
• College of Veterinary Medicine – host to NIH-funded Swine, Rat and Mutant Mouse Resource and Research Centers, a recently funded Regional Biocontainment Laboratory for BSL-3 level experimentation with select agents and animal models, and world-renown research on veterinary oncology, and exercise physiology, with a "one medicine" focus on comparative animal and human diseases.
• The Phytonutrient Center – investigating the biological impact of plant products on human health.

These represent only a few of the outstanding life sciences research programs on the MU campus. A more comprehensive summary is available at: http://lifesciences.missouri.edu/whymu.htm More details on some genome projects are available at: http://genome.rnet.missouri.edu

Additionally and significantly, MU faculty have been instrumental in the development of the field of health informatics, to wit:

- Donald A. B. Lindberg, founder of Information Sciences at MU in the 1960's, developed the first pathology laboratory information systems and is recognized internationally as one of the founding members of the field of health informatics.
- Since then we have had federally funded informatics training programs for twenty-five years. Seven MU faculty members have been elected fellows of the prestigious American College of Medical Informatics, recognized as contributing nationally to research in the field, and encompassing research in bioinformatics as well as numerous health fields.
- We have nationally recognized leaders in telehealth systems, electronic medical records, patient safety and health care quality improvement, technical interface standards, and, more recently, bioinformatics.

MU also has a number of researchers representing a wide range of bioinformatics-related expertise (see Appendix B). Specifically, MU has some expertise in the following areas related to bioinformatics:

- Experimental Design
- Bayesian Modeling
- Analyses of Variance and Multiple Testing
- Support Vector Machine
- Biological Networks
- Ontologies and Controlled Vocabularies
- Biological Databases
- Sequence Analysis
- Gene Expression Data Production and Analyses
- Combinatorial Chemistry
- Scientific Visualization and Image Analysis
- Experimental and Computational Structural Biology
- Computational Chemistry
- Information Retrieval and Analysis

Given these strengths, MU faculty are positioned to tackle challenging biomedical informatics problems. However, these faculty do not represent a critical mass – in many instance we are one-deep in specific subdisciplines. The campus will require additional faculty, and their success and productivity would be enhanced by the development of organizational structures and seed funding to facilitate collaborative efforts across campus and beyond.

IV. Critical Needs at MU

Despite numerous strengths in bioinformatics and life sciences research, MU has critical needs in bioinformatics, some overarching and some specific to research, education and service.

Overarching Needs:

Overarching Need #1: **A sense of urgency in the senior administration that recognizes that bioinformatics is essential to the future of scientific research at MU and acts accordingly.**

- MU has not developed a formal, coordinated approach to the development of bioinformatics, despite the widespread acknowledgement by the campus community of the importance of bioinformatics to MU's life sciences initiative.
- This is stark contrast to MU's peer institutions, which rapidly recruiting faculty and staff with bioinformatics expertise to build research programs and associated support centers, and developing educational programs to attract new students. These institutions see the strategic necessity of enhancing bioinformatics as an essential component to enhance their research competitiveness.
- The leading institutions have demonstrated their will to invest and ability to quickly act to position themselves – their success can be measured in competitively acquired research

dollars. These strategic moves enhance their research rankings, and are essential for the development of competitive life sciences research and education programs.

- Summaries of the bioinformatics programs at four of MU's peer institutions are included in Appendix E.

Overarching Need #2: **A campus-wide organizational framework to support bioinformatics**

- Bioinformatics at MU suffers because it is so multidisciplinary that it does not fit gracefully into traditional department and college structures – there is no organizational structure to foster its growth. Our faculty are scattered in multiple units, a situation that is justified based on the specific disciplinary interests of those faculty.
- Bioinformatics requires coordination and collaboration to address most grand challenges and to attract large-scale funding. MU has not provided an organizational structure by which researchers can effectively discover each other and work together. In the 1980s, MU was faced with a similar situation when molecular biology emerged as a prominent area of multidisciplinary research. In that circumstance, MU created the Molecular Biology Program (MBP) to address cross-divisional coordination and support. The MBP is widely acknowledged as a signature program – a solution that has leveraged resources and avoided unnecessary duplication, fostered collaboration and grants and boosted MU's reputation and ranking.
- Bioinformatics is at a comparable point in its relationship to life sciences as whole as molecular biology was during the 1980s. At a 2003 National Institutes of Health Symposium, Nobel Laureate Sydney Brenner told participants that he envisioned a time when – just as the National Academy of Sciences no longer has a section for molecular biology because every biologist is essentially a molecular biologist – everyone is a computational biologist.
- Like molecular biology, bioinformatics is a transforming, catalytic agent in contemporary life sciences research.
- Accordingly, MU needs to create a campus-wide organizational framework to facilitate education, research, and service in bioinformatics.

Overarching Need #3: **A competitive technical infrastructure, continuously maintained**

- Bioinformatics requires high-performance computational, data storage, and networking infrastructure and software. Maintenance of the required hardware and software is made difficult by the rapid rate of change in information technology. It is important to note that this infrastructure is not only absolutely essential to the performance of bioinformatics research, but also can support research and education in diverse academic disciplines (e.g. by supporting high-resolution videoconferencing by faculty and students in distance learning programs).
- Current equipment used for bioinformatics research has been provided primarily by the expenditure of one-time funds, variously derived from UM System (through its investment in the UM Bioinformatics Consortium), MU's Information and Access

Technology Services and federal initiative funding obtained through cooperation with the University's governmental liaisons.

- While minimally meeting current requirements for bioinformatics research, we are increasingly limited in our ability to perform research, train students or recruit new faculty and staff. Moreover, there is little or no continuing funding that would support maintenance and upgrades of existing equipment, in order to ensure continuity of staff, or to expand our base infrastructure and services.
- Our current infrastructure is detailed in Appendix C. To fully support the life sciences as envisioned by our campus leaders, we need to develop processes to ensure that our infrastructure is competitive. This will require a substantial, ongoing investment.

Critical Needs in Bioinformatics Research:

Critical Need #1: **Faculty positions at all ranks, recruited over several years**

While MU currently has a small, excellent core of bioinformatics faculty (see Appendix B), our campuswide bioinformatics efforts are still in the formative stages.

- Existing faculty are heavily engaged in support roles to assist in ongoing life sciences research, a situation that detracts from development of their primary research programs.
- A critical mass of bioinformatics faculty does not currently exist within any individual campus division.
- Additional faculty are required in several bioinformatics subfields to provide depth of expertise for competitive responses to currently available large-scale grant programs.

Critical Need #2: **Seed funding for bioinformatics – collaborations, proposal writing, speakers, and fellowships.**

- There are enormous opportunities to attract external funding in bioinformatics. The recently released NIH Road Map defines a framework for the next twenty years of biomedical research in which bioinformatics plays a central role, *e.g.* in developing pharmacogenetics and personalized medicine.
- The Department of Homeland Security requires bioinformatics-dependent identification of biological weapons, epidemiological and environmental monitoring, and prevention and early warning systems for agroterrorism.
- The NSF's Tree of Life and Biocomplexity initiatives rely heavily on bioinformatics for both data acquisition and analysis.
- The Department of Energy's Genomes to Life project is developing and using bioinformatics methods and tools to model complex biological systems for use in energy production, mitigation of global climate change, and environmental remediation.
- The USDA is a key partner in genome projects for food crops and animals, as well as in the development of databases and techniques to track infectious diseases of domestic animals, including zoonotic diseases.

- The series of reports from the Institute of Medicine on patient safety are centrally positioning bioinformatics in patient care and in the interpretation of the medical record.
- The CDC, through its Public Health Information Network, is developing a shared vocabulary and technical infrastructure for the rapid and accurate worldwide exchange of information for the detection and monitoring of incipient epidemics.
- The confluence of these dramatic initiatives illustrates today's enormous research opportunities in the life sciences.
- To compete effectively for these programs, MU's researchers need financial support for pilot studies, assistance with preparation of grant proposals, and graduate student and post-doctoral fellowships.
- Support for seminar series and invited speakers will help develop the campus bioinformatics community.

Critical Need #3: **Centralized space for bioinformatics research.**

- While we expect bioinformatics research to remain disseminated across multiple academic units, collocation of at least some bioinformatics faculty, staff, and students will synergistically enhance the effectiveness of our research efforts. The College of Engineering has recently begun to address this need by providing space in Engineering Building North (the old Student Health Center) for a group of bioinformatics researchers and their teams.
- Even greater gains could be realized by placing some of these individuals in close proximity to life sciences researchers (e.g., within the Life Sciences Center) or medical science researchers (e.g., within the planned Medical Science Research building).

Critical Needs in Bioinformatics Education:

Critical Need #1: **MU needs to develop a total package of educational offerings in bioinformatics, including an undergraduate minor, certificate programs, MS, PhD and postdoctoral fellowships; the PhD degree is the most critical need.**

- MU is facing critical needs and an extreme shortage of bioinformatics professionals. The overall lack of graduate programs is hampering our ability to recruit additional bioinformatics faculty and life sciences faculty overall, and to recruit postdoctoral fellows for research. Specifically:
    - The number of PhD candidates is inadequate to fill the available faculty slots.
    - The number of MS students trained is inadequate to fill the available support positions available on this campus.
    - The lack of a defined undergraduate minor leads to graduate students who require remediation in critical areas and so take longer to complete their degrees.

- The PhD program for bioinformatics is the most critical need. The market data shows that the demand for PhDs is large and growing. Furthermore, our ability to recruit faculty and compete successfully for research grants in all of the health and life sciences depends on having a PhD program in bioinformatics, including postdoctoral trainees. We have trained a handful of people in bioinformatics over the past six years, funded by the NLM Training Program and individual research assistantships, but the paths for training are limited and the training is accomplished one-by-one with existing, cooperative PhD programs and faculty.
- We have a proposed emphasis area defined for bioinformatics in an existing MS degree in the School of Medicine; coursework for this emphasis area is derived from several campus divisions. This emphasis area is currently being reviewed by the MU Graduate Faculty. Beyond this proposed emphasis area, numerous campus divisions have expressed significant interest in developing a campus-wide MS bioinformatics degree program.
- MU lacks a defined undergraduate minor; many students who might be graduate program applicants are hampered by the lack of adequate undergraduate training. MU critically needs rapid definition and acceptance of an undergraduate minor.

Critical Need #2: **The lack of a series of short courses in specific tools is holding back progress on current life sciences research.**

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- MU also has a critical need for short courses in bioinformatics tools and techniques commonly used in health and life sciences research. The lack of these courses often holds up research projects while faculty and staff find an opportunity for training in specific areas. MU needs an ongoing, up-to-date program of short courses to augment semester-long courses and degree programs. These short courses could be offered to the scientific community on-line or on week-ends with a resultant revenue stream within defined certificate programs.
- Administrative support will be required for successful deployment of all of these needed educational and training programs. In particular, we recognize that any successful cooperative PhD program, either in the form of an on-campus Area Program or multi-campus effort, is absolutely dependent upon administrative support.

Critical Needs in Bioinformatics Service:

MU currently lacks a robust bioinformatics support system. Currently a skeleton of a bioinformatics support system is in place, largely pieced together from individual laboratories in conjunction with computational and statistical support efforts provided by individuals in the Computer Science and Statistics Departments and coordinated by Drs. Gordon Springer and Nancy Flournoy, respectively. Infrastructure support is provided by the UMBC and IATS, coordinated by Drs. Gary Allen and Springer. Many more needs for ongoing life sciences research programs are not being met (see Appendix D). A coordinated, campus-wide facility,

with the necessary institutional support, commonly found on many other university campuses, does not exist at MU. It should be noted that the MU Molecular Biology Program's core facilities do not provide bioinformatics support. This critical lack of support has resulted in many investigators looking to other institutions to supply this need via collaboration. The net result has been a loss of funding and resources to the MU campus. MU must address this need to maintain its stature and remain relevant to modern life sciences research and education. The MU leadership needs to support a bioinformatics service facility on the MU campus, to specifically address the following critical needs:

- Ongoing, sustainable funding model and funds.
- Faculty and staff with a service mission.
- Assigned space for bioinformatics support, ideally some significant portion in the Life Sciences Center.

V. Goals and Specific Recommendations

Goals: Recognizing that research, education, and service in bioinformatics are inherently interdependent and mutually supportive, we have the following goals that address the dimensions of our critical needs:

Goal 1. Research

- To be a recognized national and international leader in bioinformatics research, leveraging and strengthening the multidisciplinary research faculty who are spread across multiple schools and colleges.

Goal 2. Education

- To develop a total package of educational offerings in bioinformatics, including an undergraduate minor, MS, certificate programs, PhD and postdoctoral fellowships.

Goal 3. Service

- To develop a user-centered system to support faculty research efforts as they use and develop bioinformatics tools and techniques, independent of physical location of the research.

Goal 4. Infrastructure

- To maintain a technical infrastructure that allows fast and efficient computation, analysis, modeling, visualization, and retrieval of biological data.

Goal 5. Organization

- To create an organizational structure that integrates the research, education, and service missions, and to garner requisite institutional resources, leadership, and backing to realize these goals**.**

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Goal 1. Research - to be a recognized national and international leader in bioinformatics research, leveraging and strengthening the multidisciplinary research faculty who are spread across multiple schools and colleges.

- Our goal is to create a powerhouse of bioinformatics research which produces high-quality research papers, develops novel bioinformatics tools, and attracts a large amount of research funding from various sources. The research effort will integrate with the educational mission to produce well-trained bioinformatics professionals and substantively contribute to the service mission. The end result will be a bioinformatics research community involving extensive collaborations between the bioinformaticians and life sciences experimentalists across this campus, the state, and the globe.

Specific Recommendations for Research

- Allocate resources for strategic faculty hires in key bioinformatics research areas such as bioinformatics databases for plant sciences, statistical theory and methods for bioinformatics, distributed biocomputing, and clinical bioinformatics. These hires could be accomplished by strategic recruitment, across multiple divisions, to currently open Mission Enhancement positions in both Life Sciences and MOGAIA.
- Identify selected, important research topics and organize campus-wide efforts to address them. Examples of these topics include research areas where huge amounts of data are already being generated (e.g. microarray analysis, proteomics), those which inherently require highly collaborative approaches (e.g. bioterrorism, agroterrorism), and those which align with other campus priorities (e.g. cancer research, comparative medicine). Planning grants for building bioinformatics clusters (e.g. for plant/animal genomics, systems biology approaches and techniques, genomics-based medicine) should be pursued.
- Promote communication among bioinformatics researchers on campus as well as those from other institutions. We should, for example, organize a campus-wide bioinformatics seminar series involving local and outside speakers, and create bioinformatics discussion and email lists to promote discussions among bioinformatics researchers.
- Establish seed funds supporting bioinformatics research to encourage collaboration between bioinformatists and experimentalists, support students who are jointly supervised by faculty from different departments, and encourage planning and grant proposal efforts. We should systematically develop projects in which the MU Prime Fund is used to match proposals submitted to federal agencies. Communications with research leaders in individual schools and colleges research could increase bioinformatics proposals. Additionally, the UM Research Board should be encouraged to establish a category of funding to foster bioinformatics research projects.

- Prioritize bioinformatics research in the new MU Life Sciences Center (LSC) to foster collaboration between bioinformatics researchers and experimentalists. Dr. Michael Roberts, recently named Director of the LSC, has responded enthusiastically to initial discussions in this regard.

Goal 2. Education - to develop a total package of educational offerings in bioinformatics, including an undergraduate minor, certificate programs, MS, PhD, and postdoctoral fellowships.

- Development of a world-class bioinformatics program at MU requires significant enhancement of currently available educational and training programs. Our peer institutions are vigorously adding educational offerings while we continue to discuss the situation. MU needs to take action.
- As stated above, creation of a PhD degree is our most critical need. The PhD should encompass the historic strength in informatics on this campus and provide educational opportunities in both health informatics and bioinformatics. We have an opportunity at MU created in part because of pressures from the UMR and UMKC campuses to join in a UM-wide cooperative effort for an informatics PhD program.
- A PhD program will need funding for administrative, teaching faculty, service personnel, graduate students, and computational and technical infrastructure for the educational programs. Administrative and faculty funding will be especially critical in cooperative (multi-divisional or multi-campus) models; traditional department-based funding will be inadequate. Further, faculty involved in informatics training that are spread throughout multiple schools, colleges and divisions participate in cooperative programs based on support of department chairs; both faculty and their departments need incentives for this essential and ongoing cooperation. An overall governance structure for the cooperative PhD program is required to ensure the program will develop rapidly and with emerging national prominence.

Specific Recommendations for Education

- Move with all speed to establish a PhD degree program, working through the UMBC efforts that involve all UM campuses. The PhD program at MU should be flexible enough to facilitate several emphasis areas in informatics including bioinformatics, health informatics, computational biology, environmental informatics, and other areas that are well defined and with a critical mass of faculty. We should expand the educational subcommittee of the Bioinformatics Strategic Planning Task Force to serve in the capacity as the MU planning group for the PhD program.
- Support the bioinformatics emphasis area within the existing MS program in informatics to accommodate current students with a recognized program of study. Coordination of this emphasis area across multiple schools and colleges requires administrative and faculty support. We should also investigate the feasibility of a campus-wide MS degree program in bioinformatics.

- Develop and deliver a set of short courses in a defined certificate program concentrating on bioinformatics tools and techniques critical for life sciences research. This development will require staff for course generation and delivery.
- Develop an undergraduate minor in bioinformatics; a defined minor would greatly facilitate the preparation of applicants to the graduate programs. Creation of a minor will require faculty advisors and administrative support from relevant divisions.
- Present the needs for educational programs to the Deans' Council and other leadership groups.

Goal 3. Service - to develop a user-centered system to support faculty research efforts as they use and develop bioinformatics tools and techniques, independent of physical location of the research.

- The support needs of existing life sciences researchers is the greatest single driving force on campus related to bioinformatics. Bioinformatics support is largely pieced together by a variety of means. Contributors to this effort include UMBC/IATS RSC headed by Dr. Springer, from the Department of Computer Science, and Dr. Flournoy, from the Statistics Department, grant funded staff, graduate students and post-doctoral fellows, and via inter-institutional collaborative arrangements (both formal and informal). In general, this support is created through individual negotiations among the researchers and contributors. We must develop a strong, centrally funded and managed support system for bioinformatics to address current needs, and to enhance our ability to attract and retain life sciences faculty and funding.

Specific Recommendations for Service

- Establish a computational and statistical bioinformatics support unit, assigned to reasonably sized and equipped space, and modeled after the core facilities maintained by the MU Molecular Biology Program. The support unit will be coordinated through administrative oversight of a proposed Bioinformatics Institute (see below). Discussions with Dr. Michael Roberts indicate that he supports co-locating at least some portion of this function in the Life Sciences Center. Current demand would justify assignment of two faculty (one for computation, one for statistics) and two staff for this unit.
- Establish a training system for conveying bioinformatics techniques and information to the MU research community (i.e., continuing communication about resources, short courses on specific applications). This will need to be coordinated with the educational and training recommendations specified above. Current demand could justify the hiring two, full-time staff people for this function.
- Task the leadership in the Offices of Research, Life Sciences Center, IAT Services, and relevant Schools and Colleges with development of a sustainable funding model for bioinformatics support services.

Goal 4. Infrastructure - to maintain a technical infrastructure that allows fast and efficient computation, analysis, modeling, visualization, and retrieval of biological data.

- MU must develop means to acquire and maintain high-performance computational, data storage, and networking infrastructure and software supporting bioinformatics. This infrastructure will allow secure access to appropriately sized data storage and fast and seamless connectivity to internal and external collaborators and information resources. We are minimally satisfying current demands, but our infrastructure base is rapidly becoming obsolete and underpowered. Perhaps most importantly, our current equipment has been provided primarily by one-time funds. System administration of current infrastructure is being provided largely by the Research Support Computing Group of IAT Services. To position ourselves competitively for life sciences research, we must provide for substantial, ongoing investment in equipment, software, and personnel.

Specific Recommendations for Infrastructure

- Develop processes and funding to flexibly and quickly increase MU's Internet1 and Internet2 bandwidth as demand requires. In order to accommodate the Life Sciences Week 2004 activities, MOREnet has already committed to raise the campus Internet2 bandwidth from 45 to 60 megabits per second. Current demand from the campus would support an additional increase from 60 to 100 megabits/second. Accomplishment of this goal will require funding and policy negotiations among MU IAT Services, UM System, and MOREnet.
- Increase computational and data storage facilities to accommodate bioinformatics and life sciences researchers. Both MU and UMBC-supported resources are targeted for enhancements, in part by anticipated federal initiative funding (~$2 M) derived from NASA in FY04. It is anticipated that sizable Linux cluster dedicated to bioinformatics research will be procured by those funds. Additionally, IT infrastructure planning for the Life Sciences Center (LSC) will includes acquisition and deployment of additional computers and storage supported in part by funding derived from IATS. Provisioning the LSC also includes a laboratory information management system (LIMS) to support the Proteomic Center. Through funding provided by the UMBC, we are acquiring a microarray data analysis software package. As with network capacity, we need to develop means to flexibly and quickly increase computational and storage capacity as needed. Major computational equipment purchases should be undertaken in such a way as to minimize duplication, and to optimize use of shared resources. The purchases should be accompanied by identification and dedication of funds required for that equipment's timely depreciation (typically, 3 years). Discussions aimed at development of sustainable funding models for research infrastructure support is ongoing between IAT Services and the MU Office of Research.
- Recruit and hire additional support personnel commensurate with the infrastructure enhancements mentioned above. Additional computer system administrators, particularly those with expertise in clustered and other high-performance computational environments, and in very-large-scale storage systems, will be needed to support these devices. Additional personnel will be required as application specialists supporting specific research software (e.g. LIMS, microarray analysis, proteomics).

Goal 5. Organization - to create an organizational structure that integrates the research, education, and service missions, and to garner requisite institutional resources, leadership, and backing to realize these goals.

- The multifaceted nature of bioinformatics, coupled with the diverse needs of the campus community, demands a central organizing and coordinating framework. MU needs to create a campus-wide organization to facilitate education, research, and service in bioinformatics.

Specific Recommendations for Organization

- A campus-wide organizational framework, modeled after the Molecular Biology Program, but extended to include administration of academic degree programs. This framework, which might take the form of a Center or Institute or Program of Bioinformatics, would include the following components:
    - Director, who would report to the appropriate Officer(s) of the Provost's staff, and would supervise administrative, fiscal, and grant-writing support staff.
    - Associate Director(s) of graduate, undergraduate and post-doctoral studies
    - Associate Director of support services, who would (co-)supervise statistical, computational, and infrastructure support staff
    - Advisory committees (campus-wide and external)
    - Operating budget
    - Predoctoral and postdoctoral stipends, perhaps jointly administered with the Molecular Biology Program and the NLM Training Program.

Recommended Actions, in Order of Priority

Action #1: Provide immediate seed funding to implement the recommendations of this task force, and develop sustainable, continuing funding for bioinformatics research, teaching, and service.

Action #2: Create a campus-wide Bioinformatics Institute: appoint its Director and associated advisory committees.

Action #3: Develop, within the Bioinformatics Institute, a bioinformatics service facility to support life sciences research. A natural home for this facility would be within the Life Sciences Center.

Action #4: Recruit and hire faculty and staff for bioinformatics research, service, and education.

Action #5: Approve development of a cooperative bioinformatics PhD degree program in coordination with the UM Bioinformatics Consortium.

Action #6: Acquire and continuously maintain the computational, data storage, and networking infrastructure required to support world-class bioinformatics research, education, and service programs.

VI. APPENDICES

A. Members of the MU Bioinformatics Task Force

B. Current MU Bioinformatics Research Faculty

C. Summary of Current Infrastructure

D. Partial List of Bioinformatics Support Needs from MU Life Sciences Researchers

E. Related activities at four of MU's Peer Institutions

Appendix A. Members of the MU Bioinformatics Task Force

Joyce A. Mitchell, chair of Task Force
Professor, Health Management and Informatics, School of Medicine
UMC Bioinformatics Coordinator for the UMBC

Gary K. Allen, Associate Professor, College of Veterinary Medicine
Executive Director, University of Missouri Bioinformatics Consortium

Nancy Flournoy, Professor and Chair, Dept of Statistics, College of Arts and Sciences

Toni Kazic, Associate Professor, Dept of Computer Sciences, College of Engineering

Marc Linit, Professor and Coordinator of Plant Sciences Unit, College of Agriculture, Food and Natural Resources

Mark McIntosh, Professor and Chair, Dept of Molecular Microbiology and Immunology, School of Medicine

Satish Nair, Professor and Associate Dean for Research, College of Engineering

Henry Nguyen, Professor, Dept of Agronomy, College of Agriculture, Food and Natural Resources

Thomas Quinn, Professor, Dept of Biochemistry, School of Medicine

Gordon Springer, Associate Professor, Dept of Computer Sciences, College of Engineering.
Scientific Director, University of Missouri Bioinformatics Consortium

Gary Stacey, Professor, Dept of Plant Pathology, College of Agriculture, Food and Natural Resources

John Walker, Professor, Dept of Biological Sciences, College of Arts and Sciences
Director, Proteomics Center

Judy Wall, Professor, Dept of Biochemistry, College of Agriculture Food and Natural Resources and School of Medicine

Dong Xu, Associate Professor, Dept of Computer Sciences, College of Engineering

Jim Coleman, Vice Provost for Research, Executive Sponsor of the Task Force

Appendix B. Current MU Bioinformatics Research Faculty

Department/Research areas	Computer Science	Health Informatics	Statistics	Physics	Biochemistry	Pathology	Education	Agronomy	Electric Engineering
Sequence analyses	Springer				Forrester	Caldwell		Coe, Polacco	
Ontology/gene function prediction	Shyu, Springer, Xu, Zhuang	Mitchell, Patrick							Keller
Comparative genomics	Xu							Coe, Polacco	
Molecular dynamics simulation				Kosztin	Quinn				
DNA/RNA structure modeling and prediction				Chen					
Protein Structure analyses and predictions	Shyu, Xu			Chen, Kosztin	Quinn, Zou				
Gene expression analyses	Shyu, Kazic, Springer, Xu		Flournoy, He, Hearne, Sun, Thombs			Caldwell			
Biological semantics	Harrison, Kazic, Shyu							Coe, Polacco	
Biological network analyses	Kazic, Harrison								
Biological pathway prediction	Xu								
Computational proteomics	Xu		Speckman						
Biological databases	Kazic, Shyu, Springer	Mitchell, Patrick				Caldwell		Coe, Polacco	
Retrieval and analysis of biomedical literature	Kazic	Mitchell, Patrick					Sievert		
Parallel biocomputing				Kosztin					

Appendix C. Summary of Current Infrastructure

Databases

Access is provided campus-wide to a variety of international databases (e.g., Genbank). Access is also available to a variety of specialty databases (e.g., those developed here [swine database], as well as those housed at other locations [TIGR databases, maizeDB]). Remote access is provided to databases both in a site-specific manner (e.g., linked to MU based websites) or general (e.g., TIGR databases). The MU Research Network (RNet, see below), also provides Internet2 high-speed access for those projects needing this support. Pipelines for data storage and analysis have been developed (e.g., swine EST project, maize root EST project, soon bovine project) and can be adapted to future needs.

Computational Hardware

Beagle

- Compaq/HP AlphaServer SC
- Two AlphaServer ES45 nodes. Each node has 4 1-GHz Alpha processors and 4 GB of RAM. A high-speed Quadrics switch connects the nodes. Each node has a gigabit Ethernet adapter for an external network connection on MU Rnet.
- A dual processor DS20 AlphaServer acting as a management server for the AlphaServer SC complex.
- Data Storage Resources
    - Fibre Channel SAN with two Compaq/HP HSG80 controllers.
    - Approximately 3.8 terabytes (unformatted) disk space.
        - 60 36-gigabyte disks
        - 24 72-gigabyte disks

Darwin

- Two Compaq/HP AlphaServer ES40 nodes. Each node has 4 Alpha processors and 4 GB of RAM. One node has 500-MHz processors and the other has 866-MHz processors. A high-speed Memory Channel connects the nodes.
- Data Storage Resources
    - Fibre Channel SAN with one Compaq/HP HSG80 controller.
    - Approximately 1.3 terabytes (unformatted) disk space.
        - 6-gigabyte disks on the SAN
        - 7 36-gigabyte disks in a RA3000 RAID array, connected only to node 0.

Networking services

MU has two, autonomous networks (TigerNet [TN], and the MU research network [Rnet],). Rnet is provided by subscription/application to IATS/Research Computing group only for those units that specifically require it. Currently, there are around 50-60 machines campus-wide connected to Rnet. TN and Rnet are interconnected and are also connected to MORENet, which then links to the outer world.

MU is connected to Internet2 via a 45mbps network connection to the Internet2 Abilene Network at the Great Plains Network Gigapop in Kansas City. All MU users have access to Internet2 sites regardless where their machines are located on the Columbia campus. The MU Rnet supports

servers and systems that regularly interact with other I2 sites, support large volumes of incoming/outgoing traffic (e.g., data repositories and the like), or utilize evolving networking protocols not supported on the campus network (e.g., Ipv6, etc). The high performance servers and services such as those located on *Beagle* and *Darwin* are located on the Rnet, and serve both MU users as well as the external community in a seamless fashion.

Currently, MU subscribes to 110 megabytes/second (Mb/sec) of commodity (Internet1) bandwidth 45 Mb/sec over the Internet2 system. By comparison, Purdue University subscribes to 600 Mb/ sec over Internet1 and 655 Mb/sec over Internet2. The four UM campuses are part of the Great Plains Network system. Cost for the 45 Mb/sec is ≥$240,000 per year. The last Missouri Life Sciences Week (and attendant high-resolution videoconferencing) consumed all of our available bandwidth capacity supporting presentations to and from the Danforth Plant Sciences Center and UMKC. MORENet has recently indicated that MU's Internet2 bandwidth will be increased from 45 to 60 Mb/sec.

Institutional funding

UM System – Over the past three years, UM System has provided a total of $750,000 to the UM Bioinformatics Consortium (UMBC) in one time funding. The System commitment for the current year is $130,000. The UMBC is line for $2,000,000 in one-time congressional funding from NASA's budget..

MU – Information and Access Technology Services funds an estimated ≥$250,000 per year for bioinformatics. In addition, there is approximately $180,000 per year that comes from soft money (grant support) that is exclusively used for personnel support.

Personnel

3	System administrators responsible for hardware and networking services, etc.
½	Mark Ellersieck (of the Statistics Dept.) provides statistical support for experimental design for field experiments (bioinformatics in a broad sense).
11	Gordon Springer's staff – provide service to a variety of projects.
1	USDA Mary Polacco.

Physical facilities

Computer hardware, networking services, etc. are decentralized. A summary (with square footage estimates) is provided below:

Telecom Building (hardware)	~36 ft^2
Locust St. Building (offices)	~500 ft^2
Engineering Building	
North	5000 ft^2
West	600 ft^2
East	300 ft^2
North Node Room	5 ft^2
TOTAL	6441 ft^2

Statistics services

Important changes have transpired since the ME proposal and the Winship report were written and Nancy Flournoy came to chair the Statistics Department at the University of Missouri in August 2002.

IATS transferred management responsibility for Statistical Software support to the Statistics Department in Winter 2003. With this transfer, Ray Bacon and Margie Gurwit, statistical software experts, joined the SSSC under Dr. Thombs' direction. The Statistics Department successfully recruited Lori Thombs for Fall 2003 to direct the Social Science Statistics Center (SSSC) as part of the statistics ME initiative. Dean Schwartz contributes two Graduate Research Assistants to the SSSC, one who is studying in the Statistics Department and another who is studying in the Psychology Department.

During academic year 2002-2003, CAFNR transferred management responsibility for their Experimental Station Statistics Unit to the Statistics Department. Dr. Mark Ellerseick, statistical consultant, and Ahma Afsaw, statistics programmer, staff this Unit. To replace Gary Krause, who was administratively in CAFNR, CAFNR is funding ½ FTE for two tenure-track positions within the Statistics Department; each position has ½ FTE from an ME position in A&S. These searches are underway.

Leonard Hearne, Ph.D. was recruited for academic year 2003-2004 with ½ FTE funded by CAFNR to do consulting and ½ FTE by A&S to teach. Motivated by research in Animal Sciences, he has spearheaded efforts within the Statistics Department to get up to speed on microarray analysis techniques. In addition, to consulting with CAFNR faculty, Dr. Hearne initiated a study group of interested Statistics Department faculty and bioinformatics postdoctoral fellows around campus to study recent literature in this area.

In addition, Drs. John Hewett and Dick Madsen, retired faculty from the Statistics Department, provide statistical consulting out of the Office of Medical Research. Two masters level statistics work with Drs. Hewett and Madsen. They focus on research in the health sciences.

Appendix D. Partial List of Bioinformatics Support Needs from MU Life Sciences Researchers

Department /Research areas	Agronomy	Plant Microbiology and Pathology	Biochemistry	Chemistry	Radiology	Physics	Biology	Molecular Microbiology & Immunology	Obstetrics	Animal Science
Sequence analyses	Nguyen	Stacey								Taylor
Ontology/ gene function prediction	Nguyen, Davis	Stacey								Antoniou, Taylor
Comparative genomics	Nguyen, Davis	Stacey								Antoniou, Roberts
Molecular dynamics simulation			Beamer, van Doren	Tanner, Wong						
DNA/RNA structure modeling and prediction			van Doren							
Protein Structure analyses and predictions	Nguyen, Davis	Stacey	Beamer, van Doren, Sharma	Tanner, Wong						
Gene expression analyses	Nguyen, Davis	Stacey	Folk				Birchler, Booth, Murfett,	Mcintosh, Pintel	Sharpe-Timms	Antoniou, Prather, Lucy, Green, Taylor, Roberts, Garverick, Smith, Spiers, Fritsche, Lubahn, Safranski, Lamberson, Keisler
Pathway prediction and modeling	Nguyen	Stacey								Antoniou
Computational proteomics	Nguyen, Davis	Stacey		Greenlief, Thelen						Taylor, Antoniou, Green
Biological databases	Nguyen	Stacey								Antoniou
Parallel biocomputing										
Bio-Image Analyses					Volkert	Yu				
Bioinformatics visualization										
Combinatorial chemistry							Smith			

Appendix E. Related Activities at Four of MU's Peer Institutions

University	Teaching	Research	Services/ Facilities	Other Notes
UC - Davis	▪ PhD students can opt for Designated Emphasis in Biotechnology which includes internship. ▪ Variety of short courses. ▪ Advanced Degree Program for corp. employees ▪ NIH Training Grant in Biomolecular Technology	▪ New Genomics Center will unite faculty from Med., Vet. Med. Ag. & Environ. Sciences, Biological Sciences, Mathematics and Physical Sciences and Engineering. ▪ Other centers related to bioinformatics include: Center for Image Processing and Integrated Computing, and national Center of Excellence in Nutritional Genomics	▪ New 211,000 sq' foot facility for Genomics Center open June 2004. ▪ numerous corporate affiliations ▪ Several Biotechnology affiliated Research Centers and facilities www.biotech.ucdavis.edu	▪ 270 faculty engaged in biotech-related research ▪ Spin-off life science consulting & venture capital firm - davisbioscience.com ▪ Biomedical Engineering campus-wide program with 30 year history.
Iowa State	▪Interdisciplinary PhD program in Bioinformatics and Computational Biology ▪MS or PhD program with major or minor in genetics - 13 participating departments. ▪ New Summer Institute funded by NIH and NSF ▪ 3rd Ann. Joint Bioinf. Workshop with U of Iowa. ▪ Computational Molecular Biology training group funded by $3M NSF grant (IGERT - Integrative Grad Education & Research Traineeship) ▪ Computational Biology for Animal Agriculture Training Group established through USDA grant. The group is comprised of over thirty faculty, and offers Multidisciplinary Graduate Education Training which features interdisciplinary mentoring and internships with Federal laboratories, industry or international labs.	▪ List of nearly 80 faculty research projects in bioinformatics and related fields can be found at www.bioinformatics.iastate.edu /research/bioinformatics.html ▪ Genome projects in maize, soybeans. ▪ Livestock animal genome mapping projects in horse, sheep, cattle, pig, and chicken supported by National Animal Genome Research Program (USDA). ▪ Fellowships in Bioinformatics and Computational Biology provide $10,000 six-month research assistantships plus tuition, benefits, and fees	▪ Comp Sci Artificial Intelligence Research Lab. ▪ Plant Science Unit has Baker Center for Bioinformatics and Biological Statistics, plus 7 other related centers.	Office of Biotechnology has impressive list of faculty indexed by research interest: http://www.biotech.iastate.edu/Current_Research/faculty_by_interests.html Plant Pathology Dept has its own bioinformatics facilty

Appendix E. continued

University	Teaching	Research	Services/ Facilities	Other Notes
NC State	▪ Genomic Sciences offers: MS in bioinformatics (non-thesis). Co-major in bioinformatics, PhD in Bioinformatics. Minor in bioinformatics for PhD (not masters). ▪ Statistical Genetics offers MS in bioinformatics. ▪ PhD students can co-major in statistics and genetics ▪ Summer Institute in Statistical Genetics funded by NIH and NSF ▪ Bioinformatics Seminar Series ▪ NSF funded IGERT (Integrative Grad Education & Research Traineeship) fellows receive $27,500 plus benefits & fees for 3 years, plus funds for remainder of graduate program.	▪ The Bioinformatics Research Center (BRC) was established August, 2000. Variety of industry partners including: Paradigm Genetics, Quintiles, NIEHS, SAS Institute, GlaxoSmithKline. ▪ Genomic Research Centers: Genome Research Laboratory, Fungal Genomics Laboratory, Center for Biology of Nematode Parasitism, Forest Biotech Group, Center for Computational Biology	Interesting curriculum on Genomics and Bioinformatics for High and Middle School students at: http://www.ncsu.edu/kenan/fellows/2001/kporch/	▪ List of 42 bioinformatics faculty (11 with offices at Bioinformatics Research Center) can be found at: http://statgen.ncsu.edu /sisg/people.php ▪ 124 faculty (inc. 30 of the 42 above) are listed as Core Genomic Sciences Faculty at: genomics.ncsu.edu/ facult.html
Virginia Tech	▪ Interdisciplinary PhD program in Genetics, Bioinformatics and Computational Biology ▪ "Departmental Options" in bioinformatics with masters and PhD programs	▪ Dozens of research projects are described, and 50 publications since 2000 listed, at: http://research.vbi.vt.edu/ ▪ An example: EST Database & Analysis Pipeline (ESTAP) software co-developed by U Nevada-Reno, and VA Bioinformatics Institute with support from the Samuel Roberts Noble Foundation. ▪ Institute for Computational Genomics (INCOGEN) relocated corp. offices from S. Carolina to VA as result of $6.6 million bioinformatics collaboration funded in part by $3.2 million from VA's Commonwealth Technology Research Fund (Tobacco $).	▪ Core Laboratory Facility ▪ Core Computational Facility ▪ Collaborative project with Forest Biotech Group at NC State: Grid It - Resources for Microarray Technology detailed at: http://www.bsi.vt.edu/ralscher/gridit/	▪ VA Bioinformatics Institute (VBI) established in July 2000 and leveraged $30 million in first 2 years. ▪ VBI has 52,000 Sq ' with 6 wet labs and 2 core facilities building underway includes 15 additional wet labs. ▪ Dec. 2003, 100 of VA Bioinformatics Institute's employees moved into new 59,000 square foot, on-campus facility named Bioinformatics Facility I

U of Missouri Bioinformatics Consortium (D. Oerly) February 2, 2004