Report of the Blue Ribbon Panel Review: Intramural Research Program of the National Library of Medicine

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Executive Summary

The intramural research program of the National Library of Medicine (NLM) has a remarkable track record of research, innovation, and impact, ranging from the development of public resources such as PubMed and the Unified Medical Language System to the individual research contributions of its investigators. With a budget of approximately $40 million per year and a staff of some 150 scientific personnel housed in the Lister Hill National Center for Biomedical Communications (LHC) and the National Center for Biotechnology Information (NCBI), NLM's intramural research program develops and applies computational approaches to a broad range of problems in biomedicine, molecular biology, and health.

This Blue Ribbon Panel (hereafter "the Panel", see Appendix 1: Blue Ribbon Panel Roster) was convened to review NLM's intramural research program and make recommendations about its future research directions, priorities, and organization (see Appendix 2: Charge to the Blue Ribbon Panel). The Panel was charged with assessing the strengths and weaknesses of the program as a whole, including the quality of it research and training programs, the appropriateness of its organizational structure, itins relationship to other Institutes and Centers (ICs) at the National Institutes of Health (NIH), its interactions with NLM's highly regarded and widely used health information services and tools, the effectiveness of its review and evaluation processes, and the suitability of its research facilities. This report summarizes the Panel's findings and recommendations.

The Panel endorses the vision of the Advisory Committee to the Director of NIH that NLM serve as a hub for informatics, data science, and knowledge management at NIH.[1] NLM's mission is consistent with the goal of formulating and executing a large and exciting research agenda that can support the NIH Strategic Plan for Data Science[2] and the NLM Strategic Plan, 2017-2027,[3] and its intramural research program will be critical element of the success of these endeavors. The Panel believes that NLM's intramural research program can play a leadership role in identifying and solving data and data science challenges that will contribute to trans-NIH initiatives, such as the All of Us Research Program, BRAIN Initiative, and Cancer Moonshot, as well as to the larger field of biomedical informatics and data science.

The Panel believes it is absolutely critical that NLM have a vibrant and aggressive intramural research program that reinforces its unique ability, within NIH and the larger biomedical research community, to solve challenges in biomedical informatics and data science. The Panel found that NLM's intramural research program is currently populated with talented scientists who produce high-quality research results and perform at a very high level. Its proximity to NLM's products and services, ability to engage with other NIH research laboratories, deep internal expertise in the biomedical sciences, and stable funding model enable it to conduct important research in biomedical informatics and data science that is not suitably addressed in academia or industry.

[1] See https://acd.od.nih.gov/documents/reports/Report-NLM-06112015-ACD.pdf
[2] See https://datascience.nih.gov/sites/default/files/NIH_Strategic_Plan_for_Data_Science_Final_508.pdf
[3] See https://www.nlm.nih.gov/pubs/plan/lrp17/NLM_StrategicReport2017_2027.pdf

Given rapid changes in informatics and data science and their application to biomedical research, it is essential for the NLM's intramural research program to evolve so that it can maintain the prominent role in the field it has held for the last several decades. The Panel believes that now is an opportune time to grow NLM's intramural research program and rethink how it is structured and led. NLM must be able to allocate more resources to fundamental research activities and to pursue an expansive research agenda that includes high-risk, high-reward research endeavors.

The Panel also believes that to fully leverage NLM's unique resources and capacities at a time when the data science landscape is changing rapidly, NLM must implement a more unified organizational structure that bridges the strengths of its existing research centers and ensures new hiring in the most strategic areas. The Panel sees opportunities to better leverage the strengths of NLM's existing training programs, appropriately configure space to optimize research opportunities, and engage partners across the NIH through joint appointments and mutually beneficial collaborations.

There is an urgency to seize the current opportunity to enhance NLM's approach to informatics research and training in light of the large investments NIH has made in data-intensive research and the innovation that NLM can bring to the formulation of data infrastructures and informatics capabilities across NIH. NIH should not try to outsource these capabilities because it must build a cohort of intramural investigators with deep expertise in these areas. The Panel's specific recommendations for enabling NLM to achieve its potential as a hub of informatics, data science and knowledge management at NIH are summarized below. They are consistent with the goals of the NIH Strategic Plan for Data Science and the NLM Strategic Plan, 2017-2027. Additional details are provided in the body of the report:

Summary of Recommendations

Recommendation 1: NLM must work with NIH to boost significantly its investment in intramural research to support new independent investigators and embrace new opportunities for data science, informatics, and computational biology in biomedical research.

Recommendation 2: NLM should manage its intramural research program as one seamlessly connected, unified intramural research program with a single Scientific Director.

Recommendation 3: NLM should adopt one or more audacious, high-risk, high-reward projects to galvanize research across the organization and inspire the larger scientific community (see Box 3 in main body of this report).

Recommendation 4: NLM's Scientific Director and Leadership should engage in a research portfolio evaluation and strategic plan to align NLM research priorities with the NLM Strategic Plan and the research priorities of the NIH and the broader biomedical research community.

Recommendation 5: NLM should engage in a vigorous program of joint investigator appointments with other ICs to create a cadre of biomedical informatics and data science investigators with specific domain expertise who consider NLM to be their technical home.

Recommendation 6: The leadership of NLM's intramural research program, extramural research program, and engineering services programs should work together to create mechanisms for identifying opportunities for moving research tools into hardened services, including an appropriate and explicit set of criteria for allocating resources to these efforts, based on current need and anticipated impact.

Recommendation 7: NLM should work with NIH to develop specific policies and procedures for optimizing successful recruitments, given the competitive landscape of hiring for informatics and data science, and the attractive grand challenges and compelling data sets available in other sectors.

Recommendation 8: NLM should restructure its intramural research training program into a single, unified training program with a designated Training Director.

Recommendation 9: Assessment of the performance of NLM's intramural research program and its intramural researchers should include broad metrics of scientific outcome, leadership, and impact, in addition to publications and citations.

Recommendation 10: NLM should convene a single Board of Scientific Counselors with sufficient scientific breadth and expertise to evaluate the full set of activity within a unified intramural research program.

Recommendation 11: NLM should work with NIH to renovate and redesign its intramural research laboratories and shared spaces to promote greater collaboration among research groups, optimize collective use of research equipment, and enable 21st century team science.

Introduction

This report presents the results of a Blue Ribbon Panel review of the intramural research program of the National Library of Medicine (NLM) (Box 1). NLM's intramural research program develops and applies computational approaches to a broad range of problems in biomedicine, molecular biology, and health. The program brings together more than 150 scientific personnel with expertise in computer science, library science, engineering, biochemistry, molecular biology, mathematics, statistics, structural biology, medicine, and related disciplines.

NLM's intramural research program supports the mission of the Library "…to assist with the advancement of medical and related sciences and to aid in the dissemination and exchange of scientific and other information important to the progress of medicine and to the public health." It complements other NLM programs and initiatives that collect, organize, and provide access to the biomedical literature; contribute to the growth of molecular biology and clinical research data; and support research, development, and postdoctoral research training in biomedical informatics and data science.

Over the decades since its founding, NLM's intramural research program has produced strong research and impactful software. NLM has helped transform the landscape for collection, analysis and dissemination of biomedical data of all types, and has engaged in several projects that could be done only at the National Institutes of Health (NIH) because of the confluence of mission, resources, vision, and capability. Space does not allow a full listing of the efforts that have provided these transformations, but they include the creation of PubMed, MEDLINE, PubMed Central, the Unified Medical Language System, GenBank, Gene Expression Omnibus, Visible Human, PubChem, and many other resources used by thousands of researchers every day.

The intramural research program has also made fundamental contributions in informatics and data science in the areas of sequence alignment, gene orthology detection, image processing, natural language processing, ontology, and knowledge representation, among others. The Panel notes, in particular, that the free provision of PubMed to the entire world by NLM is among the most compelling, effective and impactful acts of global service and leadership across the entire United States government.

The Panel believes it is absolutely critical that NLM continue to have a vibrant and aggressive intramural research program that leverages its unique ability to advance research in biomedical informatics and data science to solve challenges in biomedical research. Intramural research will be a central element in achieving the ambitions outlined in the NLM Strategic Plan, 2017-2027,[4] which positions the Library as a platform for biomedical discovery and data-powered health. As biomedical research becomes more data-intensive, generating and analyzing growing volumes of data, the demand for fundamental advances in informatics and data science will continue to grow. New approaches will be needed in areas such as data curation at scale, time series interpretation of images, and maximizing use of data contained in electronic health

[4] See https://www.nlm.nih.gov/pubs/plan/lrp17/NLM_StrategicReport2017_2027.pdf

records. Such approaches must be sustainable, generalizable, and reusable across research domains.

Importantly, NIH has recently made long-term commitments to several large-scale and cross-cutting research programs that require deep informatics and data science research and development expertise within the NIH community, including the All of Us program, the BRAIN Initiative, and the Cancer Moonshot. These programs cannot be successful without a robust and vibrant effort in informatics and data science, as each pose major unsolved informatics and data-science research questions that are mission-critical to their success. They also have substantial engineering needs for the creation of software tools. NIH's Strategic Plan for Data Science also establishes objectives that will require substantial improvements in informatics and data science.[5]

NLM's intramural program will be a key contributor to the ultimate success of these programs and the larger informatics and data science future. It offers unique capabilities not available elsewhere in academia, industry, or government. As with other NIH Institutes and Centers (ICs), NLM's intramural research program can pursue research that is strategically important, can be applied at scale, and can address high-risk, high-reward questions without the need to generate preliminary results or exposure to an increasingly conservative and risk-adverse climate of review. As an integral part of the NIH research community, NLM researchers have access to clinical, molecular, imaging, and other types of data from other NIH initiatives, as well as the expertise of NIH's community of principal investigators. The ability for NLM to engage in integrative research that combines these data streams with domain expertise on campus or available through strategic partnerships with industry provides a unique opportunity to that cannot be accomplished elsewhere. NLM researchers have flexibility to quickly re-direct their research efforts when opportunities arise. Importantly, it is critical that NIH have intramural scientists with deep informatics and data science expertise to both respond to new scientific opportunities as they arise and to advise on the appropriate ways to integrate NIH research with academic and industrial capabilities.

In its review, the Panel found considerable strengths in NLM's intramural research program, its scientists, and their science. At the same time, it identified a range of structural issues that require immediate attention for NLM to maintain and enhance the prominent role in the field it has held for the last several decades. The report provides the Panel's recommendations for strengthening NLM's intramural research program; improving its organizational structure and leadership; shaping its research agenda; promoting NIH-wide research collaboration; balancing research, development, and service; recruiting and retaining top talent; training next-generation researchers; assessing outcomes and impact of the intramural research program; enhancing its oversight; and improving its physical space.

The Panel wishes to convey a sense of urgency that effecting change that will require timely decisions and actions so that NLM can best capitalize on the opportunities before it. In doing

[5] See https://datascience.nih.gov/sites/default/files/NIH_Strategic_Plan_for_Data_Science_Final_508.pdf

so, NLM's intramural research program will be forced to "think big" and be galvanized by the challenge to provide robust data science solutions.

Box 1. Blue Ribbon Panel Review

Within the NIH intramural research program, Blue Ribbon Panel reviews are considered an opportunity to tap outside expertise to advise on improvements, some of which may be difficult to achieve without outside support. Prompted by the growing role of informatics and data science in biomedical research, the initiation of several data-intensive research projects at the NIH, and changes in leadership at the NLM, the NIH Director charged a Blue Ribbon Panel (hereafter the "Panel") to review NLM's intramural research program and make recommendations about its future research directions, priorities, and organization. The Panel was comprised of nine external experts in biomedical informatics and data science (see Appendix 1 for a complete roster). Among the issues to be considered by the Panel were the strengths and weaknesses of NLM's intramural research program as a whole, the quality of it research and training programs, the appropriateness of its organizational structure, relationships with other NIH ICs, interactions with NLM's highly regarded and widely used health information services and tools, the effectiveness of its review and evaluation processes, and the suitability of its research facilities (see Appendix 2 for the complete charge). The Panel held a series of five teleconferences and a two-day site visit between February and August 2018 to learn about NLM's intramural research program and its relationships with other NLM programs and NIH ICs and to formulate the findings and recommendations that are captured in this report. The Panel also reviewed the *NIH Strategic Plan for Data Science* and the *NLM Strategic Plan, 2017-2027* to ensure consistency between its recommendations and the elements of those plans related to research in biomedical informatics and data science.

Strengthening NLM's intramural research program

NLM's intramural program had a budget of more than $37 million in Fiscal Year (FY) 2017. This represents about 9% of NLM's overall FY 2017 budget of $406.6 million and is slightly less than the budget of $43 million allocated to NLM's extramural research and training programs. Following a period of growth between FY 2008 and FY 2012, funding for NLM's intramural research program declined from a high of $43 million in FY 2012 to $37 million in FY 2017.

As a result, NLM's intramural research program is not commensurate with the magnitude of the already substantial and rapidly growing challenges and opportunities in biomedical informatics and data science. NLM is greatly under-staffed in the intramural research program, which limits its ability to respond to the great opportunities that arise routinely across NIH. In the academic realm, many universities have created new units (departments, centers, institutes) for informatics and data science and have often associated these with major fundraising initiatives. Similarly, businesses across all sectors have recognized the key strategic importance of informatics and data science to their missions and have created or acquired capabilities in these areas at an astounding pace. Now is hardly the time for the world's leading biomedical research organization to downsize its informatics and data science capabilities, particularly when these capabilities can often amplify the impact and effectiveness of discoveries made across the organization. As in academia and industry, NLM must "go big" in informatics and data science or put its mission at risk.

Recommendation 1: NLM must work with NIH to boost significantly its investment in intramural research to support new independent investigators and embrace new opportunities for data science, informatics, and computational biology in biomedical research.

New investments are needed to expand NLM's intramural research program to match the explosion of data in the biomedical and health sciences and the growing need to analyze and make sense of these data to achieve the vision of the 2015 report of the Advisory Committee to the Director of NIH.[6] NLM requires significant investment in new independent investigators, appropriate space, and financial resources to recruit new scientists, replace retired senior scientists, and match the challenges of the unprecedented projects and opportunities for data science, informatics, and computational biology in biomedical research. A doubling of the number of principal investigators at NLM over the next three to five years would be a great start in reversing the contractions of the last five years. NLM should aim to increase its investment in intramural research within its existing resources, but an increase in NLM's overall budget will be needed to achieve the level of growth the Panel envisions.

In expanding NLM's intramural research program, the Panel makes the follow sub-recommendations:

Sub-recommendation 1.1: *NLM's intramural research program should have a strong focus on basic research in the development and validation of informatics and data science methods and tools that provide sustainable, reusable knowledge.*

As NLM's intramural research program grows, the special capabilities of NLM intramural researchers should remain focused on the creation, validation, and application of novel methods for analyzing biomedical data and turning information into knowledge. These methods must be informed by the application needs of the broader biomedical research community. The research portfolio of every intramural research team should be a combination of methods development based on investigator assessment of current needs and methods development based on collaborative relationships with biomedical scientists at NIH and beyond. This allows both individual creativity and innovation in methods development and application-driven collaborative creation of tools required by application scientists (at the other NIH ICs, for example).

Sub-recommendation 1.2*: NLM should prioritize high-risk research in biomedical informatics and data science, including bioinformatics, attracting the "best of the best" intramural researchers, because of the special opportunities for doing high-risk work at the NIH.*

The choice of research focus by individual NLM investigators must remain with the investigators, who are best qualified to identify important questions that they can handle. In this context, however, the Panel would like to encourage the investigators, when faced with a choice of directions, to prioritize those that provide the highest potential reward, even if they are high risk. Unlike academic investigators who are often under pressure to perform incremental

[6] https://acd.od.nih.gov/documents/reports/Report-NLM-06112015-ACD.pdf

research compatible with preliminary results, previous accomplishments, and existing experimental systems, NIH intramural researchers are empowered to rapidly change directions in response to opportunity, work without extensive preliminary demonstrations of feasibility, and allocate resources quickly. They benefit from stable funding without the need to derive preliminary results prior to a grant application, access to biomedical experts in a broad range of areas, deep bench strength across many areas, and access to a broad range of data streams. The Panel encourages NLM intramural investigators to take advantage of these capabilities whenever appropriate. The Panel also encourages the Scientific Director to support and reward the prioritization of high-risk, high-reward research in the portfolio of the intramural researchers.

As discussed in greater detail below, the issue of recruiting research talent in informatics and data science is non-trivial because of the simultaneous interest and priorities of industry, academia, and government in these skill sets. Nonetheless, the special opportunities available at NIH and NLM, in particular, should be compelling to a meaningful fraction of scientists with an interest in high-risk, high-reward research and close interaction with those who develop NLM's data resources. These advantages are enhanced by the knowledge that research will lead to fundamental and practical advances that will improve health. Even given these advantages, the NLM (and NIH generally) must consider the realities of recruiting in this area for the foreseeable future and employ innovative ways to create attractive recruitment packages for this cadre of workers. This will require creative solutions to challenges in salary scales, startup packages, space, and job duties.

Improving Organizational Alignment and Leadership

NLM's intramural research program is currently housed in two major centers, the Lister Hill National Center for Biomedical Communications (LHC) and the National Center for Biotechnology Information (NCBI).[7] This separation reflects NLM's legislative history and the statutory mandates of the two centers (Box 2). Within LHC, research is conducted in three major branches--Cognitive Science, Computer Science, and Communications Engineering -- under the leadership of four designated research leaders. Within NCBI, research is conducted within the Computational Biology Branch, with labs that are led by ten Senior Investigators.

Each of NLM's research centers has a strong resume of science and engineering contributions over the last decade and before. Generally (although not exclusively), LHC's research has focused on medical and clinical data, while NCBI's has focused on basic biological data. Each center its own scientific director, and each has its own functional Board of Scientific Counselors (BSC) that helps ensure the quality of the research programs. By usual metrics of informatics and data science research productivity (e.g., publication impact, software artifacts, etc.), the intramural program has performed at a very high level.

This historical split between LHC and NCBI no longer best serves the NLM researchers or the wider scientific community. Operating as two separate programs with independent scientific direction raises the risk of lost opportunities for interaction and barriers to communication and

[7] Appendix C provides a chart of NLM's organization, highlighting the components of its intramural research program.

collaboration that can lead to duplication of research foci, waste resources, and hurt the morale and coherence of the research teams. Moreover, as 'omics' data approach the clinic, with translational research linking clinical entities to molecular entities, it is critical that NLM have a more holistic view of biomedical data, from molecules to patients. In addition, as biomedical research moves towards an era of team science, interdisciplinary research and collaboration (especially for large NIH-wide scientific initiatives), it is critical to ensure that investigators be aware of the activities and challenges of their intramural colleagues to take advantage of opportunities that arise.

There is an opportunity—right now—to enhance alignment between these two research programs and better assure the longer-term integration of NLM's intramural program with the larger NIH signature programs and IC strategies. Alignment with programs such as the All of Us Research Program, the BRAIN Initiative, and the Cancer Moonshot could serve as a change agent and catalyst for enhancement of the overall intramural program.

To take advantage of these opportunities the Panel makes the following recommendation:

Recommendation 2: NLM should manage its intramural research program as one seamlessly connected, unified intramural research program with a single Scientific Director.

Managing NLM's intramural research program as a unified program provides great potential to optimize and concentrate NLM's scarce intramural research resources and to focus on high priority scientific objectives in alignment with NLM and NIH strategies. The Panel understands that there are reasons for the separation of research programs within LHC and NCBI, including their statutory mandates, and recommends that NLM leadership work within those constraints to ensure that the intramural NLM research centers are functionally unified, with a research program that is coherent and synergistic across all scales and all biomedical data types. It must reward collaboration, communication, and open science and avoid internal competition, walled-off research projects, and turf battles.

Essential to the success of this recommendation is to appoint a single Scientific Director to oversee NLM's intramural research program. The Scientific Director should help shape an integrated intramural research program, coordinate research with other NIH ICs, monitor trends in the extramural research environment, and organize and/or facilitate impactful external collaborations. Ideally, the Scientific Director should be comfortable with the entire spectrum of informatics and data science applications from molecular to clinical medicine and health outcomes, and should enable intramural researchers to use their resources, expertise, and position at NIH to optimize their impact. The Scientific Director should also work to ensure that intramural NLM researchers interact regularly and strategically with software engineers and projects that are focused on delivering informatics and data science capabilities to the broader NIH research (intramural and extramural) community. Finally, the Scientific Director should ensure the alignment of the NLM's intramural research with NLM's Strategic Plan, 2017-2027 and with the NIH Strategic Plan for Data Science. Given the sense of urgency alluded to above, the Panel recommends this position be a top hiring priority for NLM.

NLM Leadership, including the NLM Director and Scientific Director, must determine what organizational structure would best align with NLM's mission going forward. NLM's intramural research program will focus on research opportunities in biomedical informatics and data science consistent with NLM's mission. It will also include translational medical research, interactions with large NIH research initiatives, and creating and engineering software tools to be used at-scale by biomedical researchers worldwide. The structure should complement the training mission, which must create investigators who are able to use informatics and data science to make contributions across the spectrum of biomedical research, from molecules to clinical outcomes.

To implement this recommendation, the Panel offers an additional guidance:

Sub-recommendation 2.1*: NLM should consider the optimal allocation of personnel, and any organizational structural changes should include appropriate reassignment of personnel to projects with critical needs.*

NLM's intramural research serves varied stakeholders in the biomedical informatics, scientific, and healthcare communities. It is imperative that a unified intramural research program preserve a diversity of informatics research, especially given the saliency of both the LHC and NCBI research programs to the NIH Strategic Plan for Data Science and their potential to facilitate the success of that plan. There is currently an imbalance in the number of investigators in LHC versus NCBI, which results from a number of historical factors. The imbalance should be evaluated and addressed as necessary, not just in terms of number of investigators and team sizes, but in terms of research expertise that may be missing and necessary to achieve research excellence. This realighment will be a natural result of a joint strategic intramural research planning exercise, which will include appropriate changes to structure, personnel, and resources to match the opportunities and priorities that are identified.

Box 2. Statutory Mandates of the Lister Hill National Center for Biomedical Communications and National Center for Biotechnology Information

The Lister Hill National Center for Biomedical Communications (LHC) was established in 1968 by Public law 90-456 to: 1) design, develop, implement and manage a biomedical communications network; 2) assist the biomedical community in identifying and developing products and services for dissemination through the network; 3) develop networks and information systems to improve health education, medical research and the delivery of health services; 4) apply technology to the improvement of biomedical communications; 5) represent the Department of Health and Human Services in Federal activities related to biomedical communications activities; and 6) serve as the focal point within the Department for development and coordination of biomedical communications, systems and network projects.

The National Center for Biotechnology Information (NCBI) was established in 1988 by Public Law 110-607 to: 1) design, develop, implement, and manage automated systems for the collection, storage, retrieval, analysis, and dissemination of knowledge concerning human molecular biology, biochemistry, and genetics; 2) perform research into advanced methods of computer-based information processing capable of representing and analyzing the vast number of biologically important molecules and compounds; 3) enable persons engaged in biotechnology research and medical care to use the systems and methods it develops; and 4) coordinate, as much as is practicable, efforts to gather biotechnology information on an international basis.

Shaping a Research Agenda

Essential to scaling NLM's intramural research program will be ensuring that its research program generates new knowledge, tools, and methods that will improve the collection, management, and analysis of biomedical and health-related data and information. As noted above, the Panel believes NLM's intramural research program should focus on fundamental, high-risk research in biomedical informatics and data science. In support of these directions, the Panel makes two recommendations for shaping NLM's intramural research agenda.

Recommendation 3: NLM should adopt one or more audacious, high-risk, high-reward projects to galvanize research across the organization and inspire the larger scientific community.

The NLM has a long history of creating such projects. The decision to build the Unified Medical Language System, which has acted as a Rosetta Stone for medical vocabularies, terminologies and ontologies, is a great example of a medical informatics innovation that arose from bottom-up research by NLM scientists with support from NLM Director. Others include the decision to make the contents of MEDLINE available to the world through PubMed. These projects had deep scientific roots and represented difficult engineering challenges that allowed intramural researchers and engineers to work together to create impactful systems.

Bold projects may come in either of two forms. First, they may come from within NLM and represent a challenge that galvanizes researchers across the intramural program and brings in researchers from other NIH ICs. Second, they may come from existing or new NIH initiatives that contain major research challenges that NLM intramural researchers may embrace and take

on as a contribution to the larger initiative. The Panel recommends a combination of the two and highlights several attributes that such projects should possess:

- Integrates multidimensional data including temporally dynamic data
- Impacts many fields of biomedicine (including population health)
- Challenges experts in user interface and user experience
- Represents difficult multi- and interdisciplinary research challenges
- Builds on unique strengths at NLM and NIH
- Provides measures of impact and success
- Requires interactions with other agencies
- Raises profound informatics and data science research questions
- Represents a substantial engineering challenge for scaling and dissemination

The Panel identifies several examples of research projects that display these features (Box 3).

Box 3. Examples of Audacious Projects for NLM's Intramural Research Program

Example 1: "PubMed-NextGen" could become the discoverability engine for the world. As such, NLM should aim to expand PubMed to provide one-stop-shop access to new information types, such as datasets, standards, clinical trials, health resources from other Federal agencies, and methods and tools for data science. PubMed-NextGen should include sophisticated inference capabilities, e.g., developing methods that identify semantic relationships in PubMed-accessible text, and the results of inferencing should be included and discoverable within the resource. Ideally, this would be developed using iterative, user-centered design principles, as is customary in industry. PubMed-NextGen might provide active learning capabilities and insights, and not just hits.

Example 2: NIH's All of Us Research Program provides an unprecedented opportunity for complete integration of molecular, mobile/sensor, environment, behavioral, social, family, and electronic health data, the complete digital footprint. NLM could establish its leadership in creating the data, knowledge, and analytic resources required for discovery and clinical application.

Example 3: The rapid expansion of next generation sequencing of microbial pathogens has provided a vast data stream that, to be useful in protecting the public's health, must be linked to clinical and epidemiological data on both national and global scales. This linking is necessary to provide for rapid detection, identification, and mitigation of the impact of emerging pathogens, pandemics, or malicious attacks. While NLM has taken a leadership role in the collection and annotation of whole genome sequence data for a vast array of pathogens, the creation of new tools for disease surveillance and prediction, combining various disparate data sources and using automated techniques, is a research project that is urgently needed. It could also be a project providing great synergy between NCBI and LHC. Success in this area would be facilitated by a close working relationship with other Federal entities, including the Centers for Disease Control and Prevention, Food and Drug Administration, and Department of Defense.

Example 4: Artificial Intelligence (AI) in medicine. There is a general expectation that the streams of information from electronic medical records, real-time sensing and mobile health, and all facets of genomics will combine to create an opportunity for a learning healthcare system that is able to make precise diagnoses, prognoses, and treatment plans based on large volumes of personal data. One model for this capability is the application of modern AI and deep learning methods to see patterns in data that allow us to recognize new disease subtypes, associations between syndromes and appropriate

treatments, and integration/compression of multimodal data into useful categories that map to the most effective treatments. All these opportunities have been loosely aggregated into opportunities for AI in medicine. In many ways, NLM intramural researchers are in an outstanding position to participate or even lead the research programs necessary to create this future for medical care. All the contributing data streams are (or should be) present at the NLM, as are the informatics and data science capabilities necessary to store, curate, and analyze the data. The surrounding NIH research resources, including the NIH clinical center, provide a perfect testing ground for many of these ideas.

In addition, the Panel sees an important need for NLM to pursue research on aspects of informatics that relate to policy issues that arise in biomedical and health research.

Sub-recommendation 3.1*: NLM should consider creating or catalyzing a national program in technologies and practices for biomedical data security, privacy, and ethics.*

Arguably more than industry or academia, the NIH has an interest and mandate to ensure that biomedical data are managed securely and ethically (including appropriate protections for privacy), and that its uses are governed in a way that is acceptable to the citizenry. These fields are intimately tied to the NLM research mission and services and come up in every major NIH research initiative. They are likely to be front-and-center in any new NLM-initiated projects as well. Thus, NLM should lead an intramural policy research agenda which is supported in parallel to the data science research agenda.

Leading a public discussion of these issues supports Goal 2 of the NLM Strategic Plan, 2017-2027 of "reaching more people in more ways through enhanced dissemination and engagement." In some states, these conversations are already occurring, as is the search for respectful and secure solutions. However, the discourse must ultimately occur at the national level and include both the user community and private industry players. The level of public mistrust is currently high because of several recent well-publicized adverse events. The NLM, as a trusted authority, should act to lead the discussion among all constituencies and find solutions that support valuable research while protecting the privacy of the individual.

Beyond issues of security, privacy, and ethics, NLM should consider developing a policy-oriented research agenda to support data sharing, data management policies, and the principles that data should be findable, accessible, interoperable, and reusable (FAIR). NLM should be recognized as a leader in policy development and dissemination alongside its leadership in the science of data. This policy research agenda should include the development of metrics of data use and utility that can be used both for strategic decision making and the value proposition for the data resources being developed or sustained. It should also include continued work to promote data harmonization and standardization to help make data more interoperable. This agenda would require significant engagement across NIH and with the external stakeholder community. This work would complement NLM's leadership role in the development and dissemination of policies and standards that promote FAIR and widespread data access.

Recommendation 4: NLM's Scientific Director and Leadership should engage in a research portfolio evaluation and strategic plan to align NLM research priorities with the

NLM Strategic Plan and the research priorities of NIH, and the broader biomedical research community.

The Panel believes that it is essential that NLM's Scientific Director lead an effort to evaluate the research portfolio and plan for the expansion and consolidation of research strengths in the NLM intramural program. This effort should involve all intramural researchers, as well as informatics and data science experts from around the NIH with an interest in an expanded robust and vibrant research program at the NLM. This exercise should have a 5- to 10-year horizon and should include identification of strategic scientific areas for hiring and strategic areas for collaboration (e.g. all the big NIH initiatives at a minimum). The effort should also consider opportunities for training, communication, and dissemination, and any structural features of NLM's organization that may need refinement to maximize the chances of success. The goal of this effort would be a roadmap for the expanded size and impact of the NLM intramural research program, including an outward facing functionality that helps make NLM an integral part of the NIH informatics and data science landscape. In doing so, the roadmap should align with the NLM Strategic Plan, 2017-2017 and the NIH Strategic Plan for Data Science. It should also look beyond existing areas of research that are adequately covered by NLM's intramural research program, e.g. to include research on digital health and digital data from devices, apps, phones, and wearables--all of which are undergoing significant growth and use and will be part of the All of Us Research Program and health care delivery.

In putting together a research portfolio, the Scientific Director would need to consider the appropriate balance of targeted vs. curiosity-driven research. The Panel recognizes the difficulty in balancing the bottom-up independence of investigators and the goals of a top-down strategic plan, and the special management skills required of the Scientific Director in this context. To promote a culture of research innovation, investigators must have the flexibility to engage in curiosity-driven research. The Scientific Director could consider opportunities and incentives (e.g. supplemental funding, convening of workgroups, assignment of investigators to high impact NIH initiatives) to encourage NLM researchers to engage in activities that contribute to the goals and opportunities identified in the intramural research strategic plan. The Scientific Director should also ensure that intramural research success in all forms is recognized and rewarded, including research that contributes to the intramural research strategic plan. A major way to advance the goals of the strategic plan is through hiring, allocation of space, and allocation of annual research budgets. The Panel is particularly enthusiastic about the use of application domain experts from around NIH (and more broadly) as *ad hoc* members of the BSC in the evaluation of investigators. These experts could be asked to include an assessment of the research program with respect to compatibility with the strategic plan.

Sitting in close proximity organizationally to the engineers who build data tools and services, NLM intramural researchers are well-situated to identify research questions as part of understanding of how to manage data. NLM researchers can play a critical role in customizing tools and applications for biomedical and biological uses and conduct the fundamental basic research necessary to enable such customization. Furthermore, as an integral part of the NIH research community, NLM researchers have access to the clinical and molecular data from other large NIH initiatives and the expertise of well over 1,200 principal investigators across

camps. The opportunity for NLM to engage in integrative research of these data streams in collaboration with domain expertise on campus, or through strategic partnerships with industry, provides a unique opportunity to combine NLM's data platforms, resources, and expertise in ways that could not be accomplished elsewhere.

Examples of expertise that NLM could contribute to pan-NIH research initiatives include curation at scale, time series interpretation of images, and maximizing use of the data contained in electronic health records. NLM is also uniquely positioned to develop informatics applications that are sustainable, generalizable, and reusable – all of which are further enabled by NLM's commitments to use of open source platforms.

Promoting Research Collaboration

NLM has operated in a relatively isolated manner within the NIH for the last several decades. Consistent with the 2015 report of the NLM Working Group to the Advisory Committee to the Director of NIH, the Panel strongly endorses the need for NLM to begin a new era of outreach and partnership with all NIH ICs and beyond. NLM intramural scientists should actively participate in NIH-wide discussions of informatics and data science and contribute to the development of strategies and plans for data science initiatives. The NLM should partner with individual ICs in creative ways for joint recruitments (e.g. of researchers and post-doctoral fellows) and collaborative projects. NLM should be deeply engaged in the major NIH initiatives of the next decade, both by having those initiatives drive intramural research programs and by having NLM researchers spend time with NIH program officers to help them understand how to approach the various data science and informatics challenges and organize both intramural and extramural responses to these challenges.

Separate from these large initiatives, there are great opportunities for NLM intramural research to impact the efficiency of translational and implementation science across NIH. As researchers across NIH look for opportunities to move basic discoveries from bench to bedside, NLM intramural researchers in many cases have expertise and skills relevant to translational activities. First, NLM has researchers within its programs that span domains from molecules to human health, and so relatively small teams of NLM research investigators can be assembled to collaborate with other NIH intramural scientists (at other ICs) to address the informatics and data science components of these translational projects. Second, NLM intramural researchers often have specific research expertise and software that may enable or accelerate translational work at other ICs. It will be important for the Scientific Director to consider how NLM scientists serving in this capacity will be viewed by other NIH researchers, that is, as collaborators or as technicians providing a service. The Panel would encourage the Scientific Director to consider ways to ensure the role of collaborator is duly credited and to seek opportunities that advance the research agendas of both NLM and the collaborating IC.

Recommendation 5: NLM should engage in a vigorous program of joint investigator appointments with other ICs to create a cadre of biomedical informatics and data science investigators with specific domain expertise who consider NLM to be their technical home.

The NLM scientific staff have valuable and still relatively rare expertise in biomedical informatics and data science. At the same time, many NIH ICs require this expertise as part of their intramural programs. This raises a problem and an opportunity. The problem is that biomedical informaticians and data scientists need to have a community of other similarly trained technologists with whom they can discuss the nuts and bolts of informatics and data science. At the same time, they often need to be embedded with application scientists to fully understand the problems they are addressing and how informatics and data science can be most helpful. They risk isolation within the NIH application-focused IC and they risk irrelevance if they are cloistered. The opportunity is to create a robust program of joint appointments where investigators are affiliated with both the NLM and an application-focused IC. NLM will provide the technical home with colleagues in informatics and data science to provide collaboration, support, and review. The application IC will provide the deep biomedical problems and access to the data and bench scientists. The Panel is enthusiastic about this idea as both nurturing the jointly appointed scientists and providing a tangible way to raise NLM's profile across all ICs by having a cadre of scientific ambassadors who bring this valuable expertise and can act as conduits for new relationships and collaborations.

The Panel believes that there are already at the NIH many hundreds of scientists with expertise in biomedical informatics and data science, and that these scientists are not sufficiently engaged with or feel membership within the NLM. Thus, the Panel recommends that the NLM create mechanisms for convening these scientists, welcoming them, and engaging them (via journal clubs, speaker series, focused workshops, etc.) so that they see part of their professional identity at NIH through an affiliation with NLM. Along with scientists who are truly jointly appointed, they will create a culture of biomedical informatics and data science at the larger NIH that will accelerate science and engineering, make NLM and NIH better workplaces for informaticians and data scientists, and create capacity for rapidly responding to opportunities. NLM should act as the hub for creating and nurturing this culture, by providing space, activities, and intellectual leadership in order to welcome all NIH scientists with interest/expertise in biomedical informatics and data science.

Sub-recommendation 5.1*: NLM's research mission should be supported, as appropriate and available, by partnerships with external collaborators in academia and industry.*

The recognized strengths of research teams in academia and industry, particularly in the context of limited availability of talent, make it imperative that NLM intramural researchers consider the best way to communicate and collaborate with external scientists. Any review of the peer-reviewed literature and conference proceedings shows that there are robust and effective industrial research groups making state-of-the-art contributions in many fields relevant to NLM and NIH research interests, including automated image analysis, natural language processing, data mining of large medical and claims databases, genomic data storage and analysis, and others. Many of these efforts operate at a scale consistent with the NLM mission of supporting global biomedical research, and so appropriate collaborations, agreements and relationships can be very attractive. Similarly, the extramural community (some but not all of which are supported by NLM extramural program) has outstanding talent and interests that can also be harnessed by NLM researchers to increase their impact and productivity. The Scientific

Director should ensure that NLM intramural researchers are motivated to work with outside groups and receive appropriate professional credit when these interactions are successful.

Balancing Research, Development, and Service

There is a clear expectation at NIH and NLM that NLM exists to serve the public and the world through its research and development and its heavily used information services. Intramural researchers conduct basic research and often engage vigorously with the engineering teams to help deliver production-level software that is used by thousands of scientists worldwide. NLM's two intramural research groups (in LHC and NCBI) have routinely worked with NLM engineering teams to push out impactful software and data resources that have been used by thousands of biomedical researchers. In that sense, the NLM has often acted as a software startup (or series of startups) delivering high quality software that works at scale.

The strong service component of NLM can overshadow the research mission, both in the eyes of the scientific public, as well as among other NIH intramural researchers. Indeed, much of NLM's intramural budget supports NLM's widely used information services (e.g. PubMed, GenBank, ClinicalTrials.gov), not intramural research. In a zero-sum budget, funding to support services can compete with funding to support basic research. The Panel believes that both research and service are critical, but that balance has been lost, and the basic research budget and resources have not kept pace with growing needs and opportunities.

NCBI and LHC have employed different approaches to balance the competing needs of research, development, and provision of services. NCBI's approach has been to segment out the research and engineering components into dedicated branches. LHC's approach has been to merge both poles of the continuum into a single program. Effort will be required to ensure that a union of the two research programs helps transfer culture and disseminate best practices for moving from core discovery to applied science. The panel recognizes that service scientists employ considerable creativity and ingenuity in solving problems and reducing a good research idea to practice. The real challenge is orchestrating this interaction. In reviewing the balance among research, development, and provision of service within NLM's intramural research program, the Panel finds that NLM lacks a well-defined process for identifying basic discoveries that might form the basis for new services and then creating a plan for initial validation, production, and development/implementation. This has been done in a somewhat *ad hoc* manner, and a structure may help both discovery and implementation scientists better understand their roles in this process.

Recommendation 6: The leadership of NLM's intramural research program, extramural research program, and engineering services programs should work together to create mechanisms for identifying opportunities for moving research tools into hardened services, including an appropriate and explicit set of criteria for allocating resources to these efforts, based on current need and anticipated impact.

A regular meeting and discussion forum for NLM's Scientific Director, director of extramural programs, and directors of engineering will be required to make sure that opportunities for new tools and services are identified, prioritized, and implemented. This forum should consider

which tools and services resulting from NLM's intramural research should be transitioned into engineering operations and which challenges from engineering challenges can motivate fundamental research. In addition, NLM should establish processes for transferring research results and tools to the external community if it does not intend to support them or embed them into its own services.

One effective model for the NLM may be to build on the "design/build/test" iterative model used by engineers to continuously improve a tool until it is fit for purpose. In this paradigm, there is not a strict separation of research and service. Instead, there is a continuum of research and development. As an example, the Panel notes approaches successfully used in industry that experiment with different ways of selecting and presenting information, try promising approaches on different subsets of their customers, and measure and continually update their methods based on the results.

Interactions between the research and engineering components of NLM may fall into two categories. In one, research has developed a set of ideas and prototype versions of usable tools that exploit these, but they need to be made robust and scaled to very large-scale use. In the other, engineering has identified technical problems that require basic research advances in order to overcome them. Ideally, these two types of efforts can lead to a synergistic cycle of interaction, based on a "continuous process improvement" model of the development of capabilities. For example, dealing with the extremely large data sets that we anticipate in various signature NIH initiative may require basic research in improved indexing, sublinear algorithms, and data visualization. As researchers develop tools to support such capabilities, engineering can deploy them to users and create a basis for experimental validation of the ideas by measuring the degree to which the tools enable appropriate use of the data. At the same time, research on user experience aspects of the system can try to deploy different variations (as is commonly done in industry) and measure the effects on actual use, leading to ongoing improvement of the tools and to a steady stream of interesting research challenges.

The engineering and software hardening and delivery activities of NLM provide a magnificent potential training environment for junior scientists and engineers who are specifically interested in this kind of work. The skills and knowledge associated with designing, implementing, testing, and releasing code that will be used by thousands of users are valuable and still rare within biomedical informatics and data science. Success requires understanding users' needs, the application domain, the technical details of the underlying software, and the hardware/networking environment in which it will be implemented. As part of the training efforts at NLM, there could be a program that introduces trainees to this process and provides a specialized deep experience for the subset of trainees who want to make this a career emphasis. The idea would be to combine elements of biomedical informatics and data science research training with implementation and engineering training, to produce implementation scientists who can take novel methods and make them routinely available to the scientific community.

Sub-recommendation 6.1*: NLM should consider a single, unified engineering/services unit that matches the unified intramural research program and preserves the level of connection necessary to fuel innovation in an intramural research program.*

Separate from the intramural research program, the NLM has large engineering operations that work to deliver products and services to the world. (The Panel was not asked to evaluate these units but learned about them during discussions with the intramural scientists and with NLM leadership.) The engineering operations staff also engage in hardening particularly useful and impactful research software to make it robust, scalable, and reliable for use by researchers outside of the NLM. There are numerous examples of successful identification of new capabilities that have led to the transfer of software innovations out of the research units into the engineering delivery units. All these success stories involve strong and frequent communication between the intramural researchers and the engineering teams. NLM needs to maintain a special and explicit relationship between its engineering efforts and its intramural research efforts through a regular and standing process of research tool evaluation and prioritization. The engineering/service organizations need to support the transition of all appropriate fruits of research, regardless of the internal organizational unit from which they arise. They need to work closely with researchers as both agents of technology transfer and as sources of user experience engineering to allow researchers to test the efficacy of ideas on which they work.

Although it falls outside its charge, the Panel recommends that NLM consider unifying its engineering/service units to facilitate interactions with the research program. Such consolidation would bring greater attention and consistency to procedures for translating research outputs into new or improved services and for channeling experience-based insight back into the research program. The engineering division would need a leader who understands business development as well as salient user and resource constraints, and who can work with the intramural Scientific Director to identify and prioritize resources to the most important tools. This will enhance service delivery and reduce redundancy.

Recruiting and Retaining Top Talent

The Director of NLM and the Scientific Director must address the vision and strategy for hiring intramural scientists. The Panel notes that retention and recruitment of data scientists is challenging at NLM given competition from industry and academia in terms of pay and benefits in the informatics sector. The types of scientists NLM needs for its intramural research program are highly trained in data science and bioinformatics. This means that for any given recruitment there is a great deal of competition from both industry and academia. This is also a problem for retention particularly with the current salary gaps between industry and academia in the computer sciences fields.

The recruitment issue for workers with skills in informatics and data science may be more acute for NLM than other NIH ICs because it is still a rare skill set and a current high priority not only for other academic institutions but also for aggressive industry powerhouses. NLM needs policies and procedures that are specifically optimized for such recruitments. It also needs to create recruiting channels that are not currently well-developed. For example, enhancement of NLM's interactions with universities would facilitate recruitment of graduate students by NLM

scientists. Another solution is to create mechanisms for hiring programmers and other specialized technical staff into NLM's intramural laboratories, similar to the way technicians are hired into wet labs by NLM research groups. Recruiting technical staff would liberate NLM's scientists and postdoctoral trainees from routine tasks, making research positions at NLM more appealing.

With an anticipated increase in the size of NLM intramural research staff, there will be important decisions about the relative merits of open searches versus targeted searches. In open searches, all candidates are invited across all fields to compete for a position; the search committee selects those who they expect to have the most exciting and impactful research program. In targeted searches, candidates are drawn from a particular field that the leadership has identified as mission-critical. There are arguments for both these approaches, and it is likely that a mix of search strategies will yield the best program. In all cases, however, it is critical to find scientists with deep technical skills in informatics and data science, who also understand the biological domain-specific subject matter and can tune their methods development to the special features of these domains. The Scientific Director must also consider the market for talent, particularly in hot areas of informatics and data science (such as deep learning methods) and create a plan for creating an attractive environment and offers for these scientists so that they can compete with academic and industry groups based on the compelling NIH mission, the nature of NIH funding, special access to data resources, and overall impact of NIH work.

The Panel emphasizes that special efforts have to be made to engage scientists from under-represented minority groups early in their careers with data science and informatics. NLM has participated and engaged in a variety of committees and outreach programs but with limited success. Out of the 101 members of NLM's intramural research staff, only six are Hispanic and two African American. NLM has a special opportunity to lead in this area as part of the NIH Diversity Initiative and should make the increase in staff members from under-represented minority groups one of its highest priorities. Recruiting graduate students from the historically black colleges and universities can be a first step.

Recommendation 7: NLM should work with NIH to develop specific policies and procedures for optimizing successful recruitments, given the competitive landscape of hiring for informatics and data science, and the attractive grand challenges and compelling data sets available in other sectors.

The Panel recognizes that there are limitations in Federal hiring rules and regulations that must be accommodated. Nonetheless, it urges the leadership of NLM and NIH to consider ways to ensure that a cadre of dedicated scientists in biomedical informatics and data science be recruited and retained for the important work in these areas. This could serve as a model for creating a critical mass of expertise to work on problems across the agency and the larger Department of Health and Human Services, encourage communication and collaboration and become the basis for a strong workforce for decades to come. To the extent possible, recruitment and staffing plans for NIH's intramural research program should be aligned with the NLM Strategic Plan, 2017-2027 and NIH Strategic Plan for Data Science.

In addition, NLM should pursue specific efforts to strengthen its recruiting efforts as it begins to build up its intramural research program.

Sub-recommendation 7.1*: NLM should create recruiting channels that are not currently well-developed, such as partnerships with universities, focused NIH-based training programs, and other novel mechanisms for hiring research programmers and technical staff.*

In particular, NLM should consider recruiting using professional societies focused on underrepresented minorities in biomedicine, such as the National Medical Association, the Association for Women in Science, the American Association of Hispanics in Higher Education, to enrich the applicant pool for both its scientists and post-doctoral fellows. There are opportunities to work within NIH and academia on novel models for training that could make NLM the go-to place for early career training in biomedical informatics and data science. These trainees would be in great demand nationwide and would also be outstanding ambassadors for the NLM intramural research program and its scientific staff.

Training the Next Generation of Researchers in Biomedical Informatics and Data Science

NLM's intramural research program provides opportunities for training and career development in biomedical informatics and data science. NLM's program attracts a mix of trainees at all levels. Those completing post-doctoral training programs find positions in academia, industry (e.g., health care organizations, information technology companies), and government. Some become part of NLM's intramural research program, as staff scientists or contractors.

The postdoctoral training programs of the LHC and NCBI operate independently and display some important differences. The LHC program is more formalized with an official training program and corresponding website that can be found in the training link from the NLM main page[8] and with specifically designed bi-annual training for the whole cohort. The NCBI program is more informal with recruitment flowing more from direct contacts with PIs. Both the NCBI and LHC have a clear commitment to summer internships that train diverse sets of trainees, from high school students to post-docs, although it appears that the number of applications from high school and college students has decreased in recent years.

The scientific aspects of the training program are of high quality, and soft skills training is provided by NIH's Office of Intramural Training and Education. The trainees that met with the Panel identified many strengths of the training programs in both LHC and NCBI, including: 1) relatively easy access to data; 2) faculty and other trainees with research experiences that cover many facets of biomedical informatics; 3) flexibility and freedom to pursue the interests of the trainee; and 4) internationally diverse trainee population (being one of the few such program available to scientists from many countries).

The trainees who met with the Panel also identified a number of opportunities for improvement in the programs, including: 1) more varied and consistent mentoring and guidance in navigating

[8] https://lhncbc.nlm.nih.gov/biomedical-informatics-training-program

NLM and NIH to take advantage of opportunities beyond those available in their assigned lab; 2) more career skills training, including both hard skills, such as those that improve their competence as informatics professionals, and soft skills that improve the quality of their work life (e.g. time management, writing, presentations); 3) more opportunities to meet and work together across NLM (i.e., bridging the divide between labs and between LHC and NCBI); and 4) more freedom to pursue research aims rather than conduct purely technical work. Because of the difficulty in hiring biomedical informatics engineers (the equivalent of technicians in wet labs), post-doctoral fellows can end up doing considerable technical work. The Panel cautions against relying too heavily on post-doctoral fellows as a research workforce for the intramural program.

The Panel endorses the goals of the NLM Strategic Plan, 2017-2027 in the area of expanding "training initiatives for informatics and data science research to build a workforce to drive the future of biomedicine." The Panel also recognizes the catalytic process fueled by the ability for post-doctoral fellows in the intramural labs to execute research envisioned by the investigators. However, the Panel is also aware of the varied ways the NLM may execute this goal without expanding the intramural training program. It may be possible for the NLM to use its extramural programs in a way that creates a pipeline for specific sub-disciplines of informatics and focusing the intramural training program on mission-critical research and trainees with pre-existing research expertise. The Panel encourages the NLM Director to work across NLM's intramural and extramural programs to achieve a suitable balance that is responsive to its strategic plan.

Recommendation 8: NLM should restructure its intramural research training program into a single, unified training program with a designated Training Director.

For the same reasons that the Panel is enthusiastic about a unified intramural research program, it is also enthusiastic about a unified training program for undergraduates, graduates and post-doctoral fellows. A combined program will allow NLM to pool its training resources to greater effect and provide a greater range of opportunities for trainees. The training program can include an optimal balance of centralized programmed elements and distributed apprentice training with the scientific hosts. Flexibility becomes increasingly important as training moves from undergraduate to post-doctoral training programs.

The Panel is convinced that the existing training opportunities and the potential for expansion require a dedicated leader who is part of the intramural research program and can think about how to best configure the scientific and engineering training for the NLM trainees. This leader should consider ways to engage trainees in other ICs who likely will be very interested in adding more biomedical informatics and data science research skills. It is important to emphasize that this training director would be focused on training biomedical informatics and data science professionals, and not in training biologists or clinicians in the use of NLM tools.

In support of this recommendation, the Panel has identified additional ways in which an integrated intramural research training program could be operated to maximize its benefits to NLM and the trainees.

Sub-recommendation 8.1*: NLM should provide trainees with regular opportunities to work collaboratively and to learn from each other, regardless of the laboratory in which they work.*

With the growth and emphasis on team science, NLM trainees should be encouraged and given opportunities to work together during their training. This can occur by having regular research colloquia where the trainees hear about other projects and may form new collaborations. It may also occur by creating project classes or hackathons where, separate from their core research projects, trainees work on a group project in order to get all the experiences associated with group collaborations. There are many other approaches, but the key is to help trainees meet and work with each other as they begin to form their professional networks for the rest of their careers. It may also be a way for trainees to get research experience in a second area, different from their primary project with their primary research mentor. Clearly, research mentors must support these activities and be enthusiastic about their goals, so that they do not feel that the trainees' time is being unproductively taken away from their primary research project.

Sub-recommendation 8.2*: NLM trainees should have opportunities to work jointly with other NIH ICs to gain exposure to methods development, and the application needs of specific application domains.*

The Panel believes that there would be great value in having NLM trainees who are jointly appointed in another IC, likely with dual mentorship from scientists who would serve as co-advisors. It would be important to identify the scientist with primary responsibility for the trainee, but if appropriately executed, joint research mentorship could produce trainees with a deep understanding of both the domain application needs and the biomedical informatics and data science methodologies that are required. In addition, this approach would allow the trainees to become ambassadors from the NLM to the rest of the NIH community. It may also be useful to consider internships in industry or academia, particularly in the setting of ongoing collaborations with NLM and NIH scientists where a short stay in a new environment would expose the trainee to new technologies or approaches to science.

Sub-recommendation 8.3*: NLM should consider providing educational content that includes core technical and domain skills, as well as soft skills necessary to conduct research in a wide range of environments.*

Research training is primarily an apprenticeship model, particularly for senior graduate students and post-doctoral fellows. The primary goal for the trainee is to work in the laboratory of a senior scientist PI to ask and answer important novel scientific questions. Recognizing that trainees come to NLM with varying levels of expertise and diverse educational experiences, the Panel believes there is an opportunity for NLM to provide some core curriculum as part of the training experience at NLM. This could be a core set of technical skills, or a core review of the application areas with special needs for biomedical informatics and data science. It could also include broad exposure to other areas of research conducted at the NLM. In making this recommendation, the Panel understands that there must be flexibility in designing the training experience for each trainee, and so a core curriculum must be flexible and not onerous for the trainees and scientific staff.

The Panel recognizes the prime importance of the mentored research experience for trainees; nonetheless, the Panel also believes that an available curriculum for general research and professional skills—such as grant writing, oral communication (giving a talk), writing and reviewing papers, networking, and creating a compelling poster—would be useful and welcomed by trainees. This training in soft skills must be flexible and not take excessive time away from the primary mentored research project.

Sub-recommendation 8.4*: NLM should advertise its training program more broadly to attract trainees with a broader array of backgrounds, interests, and capabilities.*

A program of aggressive advertisement for NLM's training opportunities would serve two purposes. First, it would attract a broader array of applicants and increase the quality and diversity of the training programs. Second, it would serve as a general outreach mechanism to remind professional colleagues (in industry, academia, and across NIH) about the exciting activities and opportunities at and with the NLM.

Sub-recommendation 8.5*: NLM should aim to lead NIH in training and recruiting under-represented minority staff in informatics and data science as part of the NIH diversity initiative and to establish a pipeline of talent for all NIH ICs.*

Strategies could include recruitment of under-represented minorities at colleges and universities with high levels of minority populations. The major challenge of recruiting staff from under-represented minority populations is the relative paucity of interested and well-qualified candidates. Many NLM training programs now invite summer interns to engage in research at their programs. Relevant professional societies also provide opportunity for these interns to showcase their work during the major conferences and symposia. These interns are the future of data science and biomedical informatics and may benefit from more explicit connections to the NLM, such as through paid visits to the campus or NLM-staff outreach to these summer programs. In addition, the NLM could provide resources, such as access to its scientists or data, to these programs, thereby allowing trainees to become familiar with NLM programs and software services.

Assessing Outcomes and Impact

Assessing the outcomes and impact of research in biomedical informatics and data science is challenging. Such research produces not only discoveries and new knowledge that can be captured in research publications but also important engineering and methodological outcomes. Entrepreneurship and the translation of research products into tangible outputs are also part of the goal of intramural science. These varied outcomes make traditional measures of research output less well-suited to biomedical informatics and data science than to other fields of science.

Standard outcomes of academic research include publications, graduated PhD students, and mentored post-docs. Evaluation of impact related to publication must rely not solely on quantitative measures such as citation count or h-indices, but also on the role of the scientist in accomplishing the published work and how the work has influenced the field; this evaluation relies upon securing external letters of evaluation. The evaluation of students and postdocs

must be based on placement at the end of their training period and subsequent accomplishments. NLM and NIH should be aware that first-class, highly impactful research publications in data science (especially AI and machine learning) and informatics (especially computer science) often are found in conference proceedings, not just in journals.

Non-standard, yet important scientific outcomes for data science and computer science include data sets, software tools, and platforms. The impact of these outcomes can be measured by numbers of downloads, accesses, and users, and most importantly, what scientific outcomes were produced with them. In the future, a new kind of outcome may also become important: knowledge models derived through machine learning. Current practice involves considerable parameter-tuning to train models, often on large computing clusters, to produce a model with good predictive power. Because of its access to large and unique data sets, NLM could greatly contribute to the research ecosystem by making well-annotated models available to the broader research community.

The impact of scientific research in biomedical informatics and data science is also evidenced by technology commercialization such as patents and start-ups. These outcomes measure the amount of technology transfer the research community provides the innovation ecosystem. NLM researchers do not enjoy the same flexibility as their academic counterparts to participate in start-ups, consulting, or other commercialization activities. Nevertheless, they are encouraged to patent and license their inventions to the private sector and to make use of research results in NLM's own service offerings.

Recommendation 9: Assessment of the performance of NLM's intramural research program and its intramural researchers should include broad metrics of scientific outcome, leadership, and impact, in addition to publications and citations.

To suitably measure the scientific output and productivity of NLM's intramural program, NLM and NIH will need to adapt the criteria for assessing researcher and overall program performance. Ideally all contributions to scientific progress should be recognized. The spirit of this recommendation is to give intramural researchers credit for impact that may not be best measured by standard academic metrics. Measures will need to account for the wide range of valuable outputs from research in biomedical informatics and data science, including not only journal publications and citations, but peer reviewed conference proceedings, shared data sets, adopted software and tools, and successful commercialization activities. These are the same types of research outputs and outcomes that NIH is beginning to recognize more broadly across the scientific enterprise but will be especially important to include in assessing research and researchers in biomedical informatics and data science. Assessments might also capture measures of collaboration with researchers in other NIH ICs, such as through joint publications or development of software and tools for use in particular research domains.

Enhancing the Board of Scientific Counselors Process

In general, BSC members and NLM leadership seem to agree that even though they have different foci, each of the BSCs does a thorough evaluation of the work of all PIs and senior scientists. The BSC review program provides meaningful input to individual scientists' programs of research. The LHC and NCBI BSCs differ in terms of their role in tenure process. The NCBI BSC regularly evaluates tenure track faculty midway and at the end of the tenure process and makes recommendations that go the tenure committee. LHC has fewer tenure track scientists than NCBI, and its BSC does not routinely make recommendations related to tenure. The LHC BSC conducts a thorough evaluation of individual LHC scientists' work, assesses trajectories of research, and makes recommendations related to future research directions. Additionally, the LHC BSC regularly evaluates the LHC training program and makes recommendations related to recruitment and programming.

Recommendation 10: NLM should convene a single Board of Scientific Counselors with sufficient scientific breadth and expertise to evaluate the full set of activity within a unified intramural research program.

The Panel recognizes the great challenge in creating a unified BSC with the full range of expertise required to evaluate work at the (current) LHC and NCBI. This work ranges from medical records to imaging to biological sequences and functional cellular measurements and many other areas. Nonetheless, the Panel is confident that a distinguished set of scientists can be assembled who will feel comfortable looking at this broad array of activities and evaluating the quality of work. It is important the BSC not be a confederation of narrow experts in individual fields but scientists with a broad vision who can understand and evaluate the NLM intramural program in the context of the major trends and needs within biomedical science, as well as informatics and data science. As such, it may be important to include in the newly constituted NLM BSC *ad hoc* reviewers (from other NIH ICs or outside NIH) who can provide meaningful input in relation to highly specialized areas of research.

As a unified BSC begins its operations to review and evaluate NLM's intramural research program, the Panel believes that certain improvements could be made to its functioning:

Sub-recommendation 10.1*: NLM should evaluate and refine mechanisms for feedback to the BSC on the consequences of BSC evaluations and recommendations to research programs.*

One missing link in the current evaluation process is the lack of a mechanism for feedback to the BSC on the consequences of their evaluations. Within NCBI no such feedback is typically provided, with the exception of tenure, for which the NCBI BSC is usually informed verbally at the subsequent meeting. At LHC, there is no systematic update to the BSC on changes to research programs; however, the board receives occasional *ad hoc* updates on selected projects that demonstrate responsive follow-up to board recommendations. In recent years, the LHC BSC has evaluated investigators and their programs of research without reference to an overall strategic plan, as no recent strategic plan for research was available. Now that NLM's recent strategic planning efforts are complete, we anticipate that the BSC(s) will be able to

provide more targeted and effective input to individual investigators and their research programs in the context of NLMs strategic priorities

Sub-recommendation 10.2*: The BSC reviews should be aligned with the mission of the NLM and NIH strategic planning efforts.*

The NLM leadership and intramural scientists would benefit from having the BSC reviews include an assessment of alignment with NLM and NIH strategic plans, as well as the NIH Strategic Plan for Data Science. The Panel suspects that intramural scientists will be most motivated to play leadership roles within large NIH initiatives if this activity and its outcomes are explicitly evaluated on a regular basis. Similarly, their collaborative work with other ICs, the quality of the mentored-research training experiences they offer, and many of the other activities stressed in this report must be included in their evaluation. Thus, the Panel recommends that in addition to using the usual metrics of research productivity, that the BSC have a structured evaluation of the degree to which activities of the NLM program (including individual investigators activities) are consistent with these strategic planning documents. The Panel recognizes that the degree of engagement will vary across investigators but believes that the sum total of activities should be consistent with institutional priorities, as detailed in these planning documents.

Improving NLM's Physical Space

The Panel assessed the physical plant in which NLM's intramural researchers conduct their work. Physical work space is highly relevant to the success of research programs and impacts the quality of work in important ways. The physical plant should provide the necessary space and equipment for an NLM intramural research workforce that must expand and increasingly interact in multidisciplinary teams. It should also help facilitate innovation and collaboration. There needs to be appropriately configured space not only for individual investigators, but also for team meetings, random interactions between colleagues (e.g. over coffee and lunch), and for special task forces assigned to solve mission critical engineering or science problems.

The Panel found the current NLM intramural research program office spaces to be outdated, poorly maintained, not conducive to creative random collisions, and insufficient to allow meaningful growth of the current NLM research enterprise. Both LHC and NCBI research programs are housed in the Lister Hill Center (Building 38A) on the NIH campus. With 27,700 square feet of space, current available space is filled to capacity, particularly in the summer when the interns arrive. Offices badly need renovation, and the general atmosphere is far from what would be considered today a high-tech creative environment. Most meeting rooms have been replaced by cubicle spaces to accommodate staff. In general, there is no space designed to promote informal or formal interactions among staff or among trainees. The NLM leadership could visit the spaces of similar research groups in academia and industry to see potential options for redesigning NLM intramural space.

Recommendation 11: NLM should work with NIH to renovate and redesign its intramural research laboratories and shared spaces to promote greater collaboration among

research groups, optimize collective use of research equipment, and enable 21st century team science.

The central role of NLM as hub of data science requires its intramural research program to remain on campus. NIH should put NLM's office space high on the NIH priority list for renovation and provide the resources necessary for needed renovations. The current layout of the NLM intramural research program exacerbates the challenges of collegial coordination and integration across all elements of the program. Renovations to space for the NLM's intramural research program should provide spaces for random collisions and informal meetings that will promote interaction among staff within the NLM and attract collaborators from around the NIH intramural program.

Many of the recommendations in this report involve NLM taking a more outward-facing role at the NIH. These include recommendations for joint appointments, joint trainees, and increased engagement with the larger NIH biomedical informatics and data science community, serving as a physical, as well as intellectual, hub for the field. All these recommendations will require allocation and design of space that supports the lively intellectual interactions that will help build a culture of outstanding biomedical informatics and data science at NIH, all with NLM as the hub. Ensuring that NLM's intramural research laboratories provide well-designed space to enable team science will be essential to its success in this endeavor.

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Appendix 1: Blue Ribbon Panel Roster - Review of the Intramural Research Program of the National Library of Medicine

Chair

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Jeanette Wing, Ph.D.
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Appendix 2: Charge to the Blue Ribbon Panel

The Blue Ribbon Panel will review the intramural research program of the National Library of Medicine (NLM) and make recommendations about future research directions, priorities, and organizational structure. The output of this review will inform efforts to strengthen NLM's intramural research program and position it to maximize its value to the NLM, the NIH, and the larger biomedical research enterprise. Specifically, this Panel is asked to:

- Review strengths and weaknesses of current NLM intramural research and training initiatives for the period 2008-2018;
- Consider the optimal balance of and interaction among research (basic and applied), development, and provision of services and tools used by the biomedical community;
- Identify priority areas of biomedical informatics and biomedical data science research that NLM's intramural research program should pursue to advance biomedical research and health, considering relevant research activities in academia, industry, and elsewhere at NIH;
- Recommend ways in which NLM intramural research program can best support training to advance the fields of biomedical informatics and data science;
- Recommend (as warranted) changes to NLM's organizational structure, budget, staffing, internal and external partnerships, or other factors that could enhance the ability of NLM's intramural research program to advance NLM's mission in the next 5-10 years;
- Suggest approaches NLM can use to assess the outcomes and impact of its intramural research and training investments.
- Consider how to align NLM's intramural research activities with the goals articulated in NLM's Strategic Plan 2017-2027, the NIH Strategic Plan for Data Science, and the recommendations of the 2015 report of the Advisory Committee to the Director of NIH.

The Panel may also consider additional factors used in the review of intramural research programs at other NIH Institutes and Centers such as: innovation and impact of research; uniqueness of the resources and skills of the program; basic organization of the intramural program (laboratory and branch structure); effectiveness of the Board of Scientific Counselors review process; funding balance between intramural and extramural; space and location issues; quality of post-doctoral training (career development); recruitment issues, including under-represented groups and missing areas of expertise; and interactions with other parts of NIH (e.g., Office of the Director, Office of Research Services, Clinical Center, Center for Information Technology, other Institutes).

The review takes place in the context of the dynamic, evolving research environment at NIH and in the extramural community, including growing interest in biomedical data science. It should consider NLM's Strategic Plan for 2017-2027, as well as the recommendations of the Advisory Committee to the Director, NIH working group on the Future of the National Library of Medicine and NIH's Strategic Plan for Data Science.

APPENDIX 3: NLM Organizational Chart

(Components of NLM's Intramural Research Program highlighted in blue)