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On Constructing a Scientific Archives Network
Exploring Computational Approaches to the Cybernetics Thought Collective

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Résumé de l'article

Les approches informatiques aux archives présentent aux archivistes et aux utilisateurs de nouvelles façons d'entrer en relation avec les documents et leur provenance. De telles approches sont particulièrement utiles pour les archives scientifiques de par la nature collective et collaborative de la production moderne du savoir scientifique. Cet article explore les approches numériques aux fonds numérisés de scientifiques impliqués dans le mouvement scientifique interdisciplinaire de la cybernétique par le biais du Cybernetics Thought Collective: A History of Science and Technology Portal Project en tant que moyen de mettre en lumière la façon dont les cybernéticiens ont développé le concept et débattu d'idées en créant et en échangeant de la correspondance et d'autres documents. Ce projet a expérimenté avec l'apprentissage automatique et des outils de traitement automatique du langage naturel pour générer des données à partir de matériel dans le but de mettre en lumière des liens entre les cybernéticiens et leur correspondance. La cybernétique cherche à comprendre la condition humaine par le biais d'expérimentation avec les machines et, d'un point de vue inspiré par la cybernétique, c'est également ce que font les archivistes qui tentent de comprendre leurs archives à travers l'expérimentation avec les machines. De telles explorations sont importantes pour documenter les réflexions scientifiques collectives comme la cybernétique à l'ère du numérique.

On Constructing a Scientific Archives Network

Exploring Computational Approaches to the Cybernetics Thought Collective

BETHANY G. ANDERSON

ABSTRACT Computational approaches to archives present archivists and users with new ways of engaging with records and their provenance. Such approaches are particularly useful for scientific archives due to the collective and collaborative nature of modern scientific knowledge production. This article explores computational approaches to digitized fonds of scientists involved in the transdisciplinary scientific movement cybernetics through the Cybernetics Thought Collective: A History of Science and Technology Portal Project as a means to reveal the ways cyberneticians have developed concepts and debated ideas through the creation and exchange of correspondence and other records. The project has experimented with machine-learning and natural-language-processing tools to generate data from the materials in an effort to reveal connections between the cyberneticians and their correspondence. Cybernetics seeks to understand the human condition through experiments with machines, and, in a cybernetically inspired sense, so too do archivists seek to understand their archives through experiments with machines. Such explorations are important for documenting scientific thought collectives like cybernetics in a digital age.

RÉSUMÉ Les approches informatiques aux archives présentent aux archivistes et aux utilisateurs de nouvelles façons d'entrer en relation avec les documents et leur provenance. De telles approches sont particulièrement utiles pour les archives scientifiques de par la nature collective et collaborative de la production moderne du savoir scientifique. Cet article explore les approches numériques aux fonds numérisés de scientifiques impliqués dans le mouvement scientifique interdisciplinaire de la cybernétique par le biais du Cybernetics Thought Collective: A History of Science and Technology Portal Project en tant que moyen de mettre en lumière la façon dont les cybernéticiens ont développé le concept et débattu d'idées en créant et en échangeant de la correspondance et d'autres documents. Ce projet a expérimenté avec l'apprentissage automatique et des outils de traitement automatique du langage naturel pour générer des données à partir de matériel dans le but de mettre en lumière des liens entre les cybernéticiens et leur correspondance. La cybernétique cherche à comprendre la condition humaine par le biais d'expérimentation avec les machines et, d'un point de vue inspiré par la cybernétique, c'est également ce que font les archivistes qui tentent de comprendre leurs archives à travers l'expérimentation avec les machines. De telles explorations sont importantes pour documenter les réflexions scientifiques collectives comme la cybernétique à l'ère du numérique.

Introduction

One of the hallmarks of modern science is its collaborative nature. Scientific research is often characterized by networks of colleagues working together and exchanging ideas. Ludwik Fleck describes this phenomenon of social and intellectual interaction in science as a "thought collective," or *Denkkollektiv* – a "community of persons mutually exchanging ideas or maintaining intellectual interaction."[1] From an archival perspective, it is a thought collective – enmeshed within a specific social, political, and intellectual context – that exchanges correspondence, shares data, and circulates drafts of publications to advance scientific knowledge. One of the most notable scientific thought collectives of the 20th century is cybernetics. Emerging out of the big science that characterized the post-war era – and especially a set of 10 meetings known as the Macy Conferences on circular causal and feedback mechanisms in biological and social systems – cybernetics is a transdisciplinary scientific movement that explores questions about behaviour and information feedback for organisms and machines. The Macy Conferences drew participants from a wide variety of disciplines, including information theory, anthropology, physics, psychiatry, and neurophysiology, who laid the foundation for a bold and innovative science. Because of its breadth and fluid disciplinary boundaries, cybernetics has been called both the "new science" and the "universal science."[2] Not only is cybernetics itself influenced by a wide variety of disciplines, but the ideas it advanced continue to inform the theoretical underpinnings of many fields.

The Macy Conferences led not only to the development of a new science but also to the formation of an international network – or thought collective – that established centres for cybernetic research and maintained intellectual interaction through the exchange of correspondence. These cyberneticians corresponded frequently and in ways that led to a dispersed archival record as they developed concepts and debated ideas around information, feedback, and behaviour. Cybernetics presents an opportunity to think critically about the records generated during scientific knowledge production and the provenance of that production. The dispersed nature of scientists' fonds, and the fact that these

1 Ludwik Fleck, *Genesis and Development of a Scientific Fact* (Chicago: University of Chicago Press, 1979), 39.

2 Geoffrey Bowker, "How to Be Universal: Some Cybernetic Strategies, 1943–1970," *Social Studies of Science* 23, no. 1 (1993): 107–27.

fonds represent the work of multiple creators and relationships, underscores the nature of scientific archives as an intellectual, abstract construct.[3] This point is particularly evident in correspondence files themselves, which often include letters and works by multiple individuals and represent myriad relationships. While the arrangement of a fonds may represent the activities of one creator, the intellectual contents often reflect multiple creators and a more complex reality of creation and use. This is especially true of scientists' correspondence, given the overall collaborative nature of science[4] and the fact that such correspondence was the "foundation for the construction of . . . knowledge."[5]

Computational methods of inquiry, in particular, open up explorations of the collective nature of scientific provenance and records creation. Digital scholarship projects that use records and metadata as the basis for visualizations and interfaces to create access to scientific correspondence networks speak to an interest in exploring both the larger context in which individuals worked and developed ideas and to the connections that informed those developments. While these methods have been employed primarily for mapping correspondence networks across geographical boundaries, they have yet to be fully used as a cartography for concept development and idea exchange. At the same time that these interfaces present new ways to engage with digital records, computational approaches to archives are gaining currency as records are datafied – transformed into data through computational processes – to aid archivists in appraisal, arrangement, and description as well as to enable users to analyze archives as data. Indeed, computational approaches signal a significant and even paradigmatic shift for engaging with archives.[6] This shift, and the interest of the history of science community in using computational tools and methods

3 Scientific archives are particularly illustrative of notions about the fonds as an "intellectual construct" and the myriad relationships that comprise its provenance. See Terry Cook, "The Concept of the Archival Fonds in the Post-Custodial Era: Theory, Problems and Solutions," *Archivaria* 35 (Spring 1993): 24–37.

4 For discussions on collaborative science from an archival perspective, see Jennifer Shaw, "Documenting Genomics: Applying Archival Theory to Preserving the Records of the Human Genome Project," *Studies in History and Philosophy of Biological and Biomedical Sciences* 55 (February 2016): 63; and Joan Warnow-Blewett, "Documenting Recent Science: Progress and Needs," *Osiris* 7 (1992): 278.

5 Elizabeth Yale, *Sociable Knowledge: Natural History and the Nation in Early Modern Britain* (Philadelphia: University of Pennsylvania Press, 2016), 3.

6 Devon Mordell, "Critical Questions for Archives as (Big) Data," *Archivaria* 87 (Spring 2019): 145.

on archival records,[7] are likely harbingers for a computational archival future. But these approaches raise a number of questions about implementation in an archival setting: For example, How can archivists generate trustworthy and reliable output from computational processes? How should archivists make that output accessible in user-friendly ways?

This article examines the application of computational approaches to the digitized fonds of cyberneticians and argues that computational methods and tools like machine learning and natural language processing (NLP) can shed new light on the provenance of scientific archives. Between 2017 and 2019, the University of Illinois Archives led a collaborative research project with the American Philosophical Society, the British Library, and the Massachusetts Institute of Technology (MIT) to experiment with computational approaches to the fonds of four founding scientists of the cybernetics movement, as a means to create access to their correspondence network in an archives-as-data vein and reveal insights about the records' provenance. The Cybernetics Thought Collective: A History of Science and Technology Portal Project[8] experimented with technologies to create machine-generated data primarily from the digitized correspondence of these scientists and to provide access in three distinct but interrelated ways: as archival metadata for the digitized records; as reusable data to facilitate digital scholarly analyses; and as the basis for a series of test visualizations of the data to identify connections in this network. While computational approaches are gaining increased traction and are promising in an archival context,[9] one of the project's goals was to determine the specific ways that the output of these approaches could be used to shed light on the thought collective as a "community of records"[10] (and as the provenance for these materials) by using data from the materials themselves. In a circular sense, scientific

7 For example, see Kenneth D. Aiello and Michael Simeone, "Triangulation of History Using Textual Data," *Isis* 110, no. 3 (2019): 522–37; Manfred D. Laubichler, Jane Maienschein, and Jürgen Renn, "Computational Perspectives in the History of Science: To the Memory of Peter Damerow," *Isis* 104, no. 1 (2013): 119–30; and Brian Ogilvie, "Scientific Archives in the Age of Digitization," *Isis* 107, no. 1 (2016): 78.

8 The Cybernetics Thought Collective: A History of Science and Technology Portal Project, 2017–2019 (NEH PW-253912-17) was funded by the National Endowment for the Humanities' Humanities Collections and Reference Resources program (US).

9 Mordell, "Critical Questions for Archives as (Big) Data," 143.

10 Jeannette Allis Bastian, *Owning Memory: How a Caribbean Community Lost Its Archives and Found Its History* (Westport, CT.: Libraries Unlimited, 2003), 3–5.

exchange is key to understanding the circumstances surrounding the creation of the records while at the same time being documented within them. Making the contents of records computationally amenable can reveal insights about the circumstances that surround their creation.

First, this article will provide a brief history of cybernetics and an overview of the Cybernetics Thought Collective project, and then it will situate the project within discussions about provenance and access in the digital age – especially modes of access that are in line with digital projects focused on correspondence networks and computational engagements. It will then describe the project's methodology as an example of the use of computational approaches and dynamic interfaces for description and access. Lastly, the article will use the project's output as a point of departure to explore the utility of computational methods and reimagine access to scientific archives within a computational framework.

Archivists have long debated ways that descriptive practices could be better attuned to capture the provenance of digital records – as Margaret Hedstrom writes, "to link the content of records to the context in which they were created and used."[11] Likewise, archival theorists have recently advocated for dynamic and systems-based interfaces that would respect the complexity of records' context of creation and enable more flexible, user-driven explorations of digital records.[12] As this article illustrates, computational approaches build on these endeavours by opening the contents of records up to discovery in systems and interfaces where new connections and relationships between records, creators, and fonds can be revealed. At the same time, the process of datafying records becomes a part of the history of those records, making it crucial to document that process. These nascent approaches to digital archives open up possibilities not only for creating access to archives as data but also for visually exploring and representing the boundaries and complexity of provenance for modern collaborative science.

11 Margaret Hedstrom, "Descriptive Practices for Electronic Records: Deciding What Is Essential and Imagining What Is Possible," *Archivaria* 36 (Fall 1993): 60.

12 See Victoria L. Lemieux, "Toward a 'Third-Order' Archival Interface: Research Notes on Some Theoretical and Practical Implications of Visual Explorations in the Canadian Context of Financial Electronic Records," *Archivaria* 78 (Fall 2014): 53–93; Geoffrey Yeo, "Bringing Things Together: Aggregate Records in a Digital Age," *Archivaria* 74 (Fall 2012): 43–91; and Greg Bak, "Continuous Classification: Capturing Dynamic Relationships among Information Resources," *Archival Science* 12, no. 3 (2012): 287–318.

Cybernetic Histories and Connections

Two interrelated events are largely responsible for the emergence and development of cybernetics: the publication of Norbert Wiener's *Cybernetics: Or, Control and Communication in the Animal and the Machine*, in 1948, and the Josiah Macy Jr. Foundation's conferences on circular causal and feedback mechanisms in biological and social systems, which were held between 1946 and 1953. Participants in the Macy Conferences included a broad range of intellectuals of the day, such as anthropologists Margaret Mead and Gregory Bateson; mathematicians and information theorists Norbert Wiener, John von Neumann, and Claude Shannon; and physiologist Arturo Rosenblueth. While the initial two meetings were very focused on applications in mathematics and engineering, Mead and Bateson in particular advocated for increasing attendance among social scientists and linguists to foster more communication between disciplines.[13] Despite the interdisciplinarity that came to define them, the Macy Conferences were not necessarily a unified and harmonious space as these scholars came together to debate and apply cybernetic ideas in their own fields.[14] And indeed, cybernetics itself evolved into a field that transcended disciplinary boundaries, making it difficult for it to be recognized as a unified science. Nonetheless, the many distinct cybernetic concepts that the transdiscipline developed continue to have impacts on many fields.[15]

As a transdisciplinary science, cybernetics explored both the possibilities of machines and computing and what those possibilities said about the human condition. Its futuristic narratives about artificial intelligence led to experimental approaches to bionics and "thinking machines." Though many definitions exist for cybernetics, it is most clearly defined as the science of communication and control or as the study of behaviour.[16] However, the broadness of this definition of cybernetics has also resulted in divergent meanings over time. Research

13 Ronald R. Kline, *The Cybernetics Moment: Or Why We Call Our Age the Information Age* (Baltimore, MD: Johns Hopkins University Press, 2015), 37–38.

14 Tara H. Abraham, *Rebel Genius: Warren S. McCulloch's Transdisciplinary Life in Science* (Cambridge, MA: The MIT Press, 2016), 15.

15 One discipline that cybernetics has influenced is cognitive science. See Jean-Pierre Dupuy, *On the Origins of Cognitive Science: The Mechanization of the Mind* (Cambridge, MA: The MIT Press, 2009).

16 W. Ross Ashby, *An Introduction to Cybernetics* (London: Chapman and Hall, 1956).

in cybernetics initially sought to develop automated defence mechanisms during World War II, but during the 1960s and 1970s, what became known as "second-order cybernetics" fostered the development of utopian and countercultural notions about the role of technology in society, influences of which can be seen in Stewart Brand's *Whole Earth Catalog*.[17] Cybernetics also extended to other sciences such as biology, where cyberneticians Humberto Maturana, Francisco Varela, and Ricardo Uribe developed the concept of autopoiesis – the ability of cellular organisms to self-reproduce and self-regulate[18] – and Lynn Margulis applied systems theory to understanding life on Earth.[19] It has been credited as having given rise to artificial intelligence (AI), though the relationship between the two has been debated.[20] The transdiscipline can be likened to a tree, with different branches sprouting into different disciplines, where it transformed and was itself transformed by the thinking in these fields. While the Macy Conferences were held primarily in New York City, the scientists who participated represented an international group of thinkers. Cybernetics thus spread broadly across the United States, Europe, South America, and the Soviet Union, where it was applied differently in different social and political contexts.[21]

Cybernetics emerged from the Macy Conferences as an international scientific movement composed of an extensive network of scientists. In addition to establishing centres for cybernetics at institutions like the University of Illinois and MIT, it also created a correspondence network, which in part sustained the exchange and development of its ideas. The Cybernetics Thought Collective project (CTC) focused specifically on four individuals who were a part of this network and had key roles in founding the movement: physicist Heinz von

17 Fred Turner, *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism* (Chicago: University of Chicago Press, 2006), 5.

18 Francisco G. Varela, Humberto R. Maturana, and Ricardo Uribe, "Autopoiesis: The Organization of Living Systems, Its Characterization and a Model," *Biosystems* 5, no. 4 (1974): 187–96.

19 Bruce Clarke, *Gaian Systems: Lynn Margulis, Neocybernetics, and the End of the Anthropocene* (Minneapolis: University of Minnesota Press, 2020), 3–4.

20 For examples of the debate about the relationship between cybernetics and AI, see Stefano Franchi, Güven Güzeldere, and Eric Minch, "Interview with Heinz von Foerster," *Stanford Humanities Review* 4, no. 2 (1995): 288–307; and Keizo Sato, "From AI to Cybernetics," *AI & Society* 5, no. 2 (1991): 155–61.

21 Kline, *The Cybernetics Moment*, 7. Cybernetics has been applied in different social and political contexts; an example is Chile's Project Cybersyn. See Eden Medina, *Cybernetic Revolutionaries: Technology and Politics in Allende's Chile* (Cambridge, MA: The MIT Press, 2014).

Foerster, psychiatrist W. Ross Ashby, neurophysiologist Warren S. McCulloch, and mathematician Norbert Wiener. Austrian émigré von Foerster (1911–2002) was part of a familial and social network connected to the Vienna Circle, which included notable intellectuals such as Ludwig Wittgenstein. Although he was educated as a physicist, von Foerster's first influential publication was more philosophical in nature.[22] Von Foerster's essay was read by McCulloch (1898–1969), the chair of the Macy Conferences, who invited him to attend the 1949 Macy Conference. Though McCulloch was known as an American neurophysiologist, his work was truly transdisciplinary in nature; his interest in the relationship between the mind and the brain, and work that itself engaged in computational methods, has had impacts on modern cognitive science as well as on AI and neural nets.[23] Ashby (1903–1972), a British psychiatrist, was interested in applying cybernetic concepts to the nervous system. In 1948, he created the homeostat, an electromechanical device that illustrated self-adapting behaviour, or "ultrastability." Ashby meticulously journaled his thoughts and ideas around cybernetics and the development of the homeostat, creating a rich record of his work.[24] Much of the work of these three scientists, however, was consequential to the work of Wiener, an American mathematician and information theorist. Wiener, who is credited with having coined the word *cybernetics*, developed the idea of cybernetics as a part of his work on anti-aircraft systems during World War II.[25] His development of the notion of cybernetics came to fruition in 1948 with the publication of *Cybernetics*.

As participants of the Macy Conferences, Ashby, McCulloch, von Foerster, and Wiener all shared varying degrees of connections with each other and became enmeshed in this network of scientists. For example, Heinz von Foerster continued to correspond with Warren McCulloch, W. Ross Ashby, and Margaret Mead. In 1949, von Foerster joined the Department of Electrical Engineering at the University of Illinois at Urbana-Champaign, where he established the Biological Computer Laboratory (BCL) in 1958 as a centre for the study of cybernetics. As a foundational centre for second-order cybernetics, the BCL served as an

22 Heinz von Foerster, *Das Gedächtnis: eine quantenphysikalische Untersuchung* (Vienna: Deuticke, 1948).

23 Abraham, *Rebel Genius*, 1–4.

24 Hallvard Haug, "The Thinking Machine: W. Ross Ashby and the Homeostat," *Science Blog*, The British Library, April 20, 2016, https://blogs.bl.uk/science/2016/04/the-thinking-machine.html.

25 Kline, *The Cybernetics Moment*, 11.

important node of this scientific correspondence network. Especially during the 1950s through the 1970s, the notion of cybernetics expanded and spread internationally, all while its participants organized symposia and conferences, hosted each other at their institutions, and exchanged letters. Fleck writes that scientists in a thought collective pass a thought to and from one another, changing it each time, so that the thought in the end “obviously belongs not to any single individual but to the collective.”[26] Cybernetics was a thought collective not only because it consisted of a number of different and evolving concepts but also because it was composed of individuals who collectively created and interrogated those concepts. “Cybernetics is a whole collection of concepts, supported by a whole collection of people,”[27] wrote Paul Schroeder, a former student of Heinz von Foerster. This notion of collectivity is central not only to the creation and advancement of cybernetics’s main concepts but also to the provenance of the cyberneticians’ fonds themselves.

Using the papers of Heinz von Foerster and the records from the BCL as the project nexus, the University of Illinois Archives sought to locate extant papers of cyberneticians with whom von Foerster had closely collaborated and corresponded. Materials for three cyberneticians with close connections to von Foerster and to each other and important roles in founding cybernetics were identified for inclusion in the project: the W. Ross Ashby Papers at the British Library, the Warren S. McCulloch Papers at the American Philosophical Society, and the Norbert Wiener Papers at MIT. Using these fonds as an initial grouping of materials for a pilot project with shared archival bonds, the CTC project endeavoured to build on computational archival science and digital scholarship initiatives that create datafied archives to reveal latent connections in and between digitized archives and to enable their exploration.

Datafying Archives

The recent phenomenon of creating archives as data seeks to transform digital archival materials into data to be analyzed through computational means. This datafication of archives is useful for both archivists and users of archives and

26 Fleck, *Genesis and Development of a Scientific Fact*, 42.

27 University of Illinois Archives, Heinz von Foerster Papers, Record Series 11/6/26, Box 92, Cybernetics [HvF Misc.], “Cybernetics: Words and Images,” by Paul Schroeder, 1987, https://archon.library.illinois.edu/?p=collections/controlcard&id=1020.

is creating a shared space in which archivists and users are converging around methodologies. In this space, the assistance of AI technologies like machine learning[28] and NLP[29] help identify patterns in texts that can be output in the form of structured data. NLP includes a subset of technologies that can, for example, extract and identify specific words and parts of speech as well as perform sentiment analysis.[30] Machines can learn to perform specific tasks, for example, identifying and classifying documents or images into categories and generating data that can be used as metadata.

As archivists manage an increasingly large corpus of digitized and born-digital materials, such approaches appear to be promising as aids to appraising, arranging, and describing materials. Michael Moss et al. contend that the large quantity of digital archival materials makes a "close reading" of those records infeasible,[31] requiring archivists to adopt a macroscopic approach afforded by computational methods. Recent examples of the deployment of these technologies to datafy materials in archival settings indicate their usefulness but also the great degree of preparation and resources necessary for implementation. Rolan et al. describe four case studies of AI initiatives for appraisal and records management.[32] While these examples indicate that technologies like machine learning and NLP are promising, they are not "production-ready 'silver bullet[s]'"[33] but instead require significant preparation to be implementable and useful. At the same time, attempts to use off-the-shelf tools in archival settings

28 Machine learning is defined as "the field of study that develops the algorithms that computers follow in order to identify and extract patterns from data." John D. Kelleher and Brendan Tierney, *Data Science* (Cambridge, MA: The MIT Press, 2018), 97.

29 NLP is generally used "to extract a fuller meaning representation from free text." Anne Kao and Stephen R. Poteet, eds., *Natural Language Processing and Text Mining* (New York: Springer, 2007), 1.

30 Sentiment analysis is "the field of study that analyzes people's opinions, sentiments, evaluations, attitudes, and emotions from written language. It is one of the most active research areas in natural language processing." Bing Liu, *Sentiment Analysis and Opinion Mining* (San Rafael, CA.: Morgan & Claypool, 2012), vi. A notable example of an archival initiative that uses sentiment analysis is ePADD, open source software for appraising, processing, and creating access to email archives. See https://library.stanford.edu/projects/epadd.

31 Michael Moss, David Thomas, and Tim Gollins, "The Reconfiguration of the Archive as Data to Be Mined," *Archivaria* 86 (Fall 2018): 129.

32 Gregory Rolan, Glen Humphries, Lisa Jeffrey, Evanthia Samaras, Tatiana Antsoupova, and Katharine Stuart, "More Human than Human? Artificial Intelligence in the Archive," *Archives and Manuscripts* 47, no. 2 (2019): 179–203.

33 Rolan et al., "More Human than Human?," 195.

present some challenges. To be effective, most technologies must be developed or implemented bearing in mind archival needs and expertise. Tim Hutchinson examined machine learning and NLP for practical use for appraisal, sensitivity review, description, and access.[34] Among Hutchinson's insightful take-aways is that the input of archivists is critical to deploying and aiding further development of these tools in archival settings. To date, the majority of computational archival projects have used these technologies to facilitate appraisal and sensitivity reviews, though there are examples of some projects seeking to machine generate metadata or to use these tools as an aid to arrangement.[35]

Besides being used by archivists to accomplish specific tasks, computational approaches are being harnessed for interdisciplinary projects that seek to extract unstructured data from digitized archival materials to be used as structured data and metadata. For example, the Smelly London project extracted and geo-referenced entities relating to smells in archival materials,[36] while the No More Silence: Opening the Data of the HIV/AIDS Epidemic project based at the University of California, San Francisco,[37] seeks to use machine learning and NLP on records that document the AIDS epidemic. Extracting named entities such as concepts, persons, and places is a means for finding latent patterns of linguistic, historical, and social changes over time that can answer new research questions.

For a user group like historians, the datafication of archives has created a pronounced shift in the craft of history, and according to Ian Milligan, "We

34 Tim Hutchinson, "Natural Language Processing and Machine Learning as Practical Toolsets for Archival Processing," *Records Management Journal* 30, no. 2 (2020): 155–74.

35 Jane Greenberg explored the potential of NLP for information retrieval as a cost-efficient, consistent, and timely "option for indexing and accessing . . . large quantities of electronic archives." Jane Greenberg, "The Applicability of Natural Language Processing (NLP) to Archival Properties and Objectives," *American Archivist* 61, no. 2 (1998): 400–401. Another example is Carnegie Mellon University Archives' use of Stanford NLP and other computational tools to extract data from its digital collections to create metadata; see Kate Barbera and Ann Marie Mesco, "Extracting Metadata from Digital Records Using Computational Methods" (poster presented at Society of American Archivists 2017 Research Forum, Portland, Oregon, July 25, 2017), https://www2.archivists.org/sites/all/files/2017_saa_forum_poster_mesco_barbera.pdf.

36 Deborah Leem, "Smelly London: Visualizing Historical Smells through Text-Mining, Geo-Referencing and Mapping" (paper presented at Alliance of Digital Humanities Organizations conference, DH 2017, Montreal, Quebec, August 8–11, 2017), accessed October 8, 2020, https://dh2017.adho.org/abstracts/537/537.pdf.

37 "UCSF Archives & Special Collections Awarded $99,325 LSTA Grant for Textual Data Extraction from Historical Materials on AIDS/HIV," *Brought to Light* (blog), April 16, 2018, https://blogs.library.ucsf.edu/broughttolight/2018/08/16/ucsf-archives-special-collections-awarded-99325-lsta-grant-for-textual-data-extraction-from-historical-materials-on-aids-hiv/.

are *all* digital historians now."[38] For historians of science, more specifically, "Applying computational methods to understand the history of knowledge is more than just doing traditional history with new tools. It brings novel conceptions of what the nature of knowledge is and how it changes, how it is produced, and how it is connected to other societal domains."[39] The presence of such projects as Archives Unleashed and the HathiTrust Research Center, forums like the Programming Historian, and tools like Text Analysis Portal for Research (TAPoR) and Machine Learning for Language Toolkit (MALLET)[40] are part of this evolution in methodological approaches and indicate a growing interest in using computational methods as a part of the archival research process. The possibility of creating structured data from unstructured data not only presents new methodological developments for studying the history of the creation and evolution of knowledge, but "it also brings with it a new epistemology and ontology of knowledge."[41]

The emergence of digital history as a discipline blurs the boundaries between archivists and historians in new ways, specifically regarding the tools and methods that both use to analyze digital archives. New, computational methods are further recharting these boundaries. In the wake of an increasing array of digital humanities projects, Joshua Sternfeld articulates "digital historiography" as a shared space for engaging with digital archives, but one that should be informed by archival theory.[42] The assertion that archival theory and practice should inform digital history, and digital scholarship more broadly, has been in

38 Ian Milligan, "Becoming a Desk(top) Profession: Digital Photography and the Changing Landscape of Archival Research" (presentation at the American Historical Association Annual Meeting, New York, January 5, 2020), https://www.ianmilligan.ca/talk/aha-2020/.

39 Manfred D. Laubichler, Jane Maienschein, and Jürgen Renn, "Computational History of Knowledge: Challenges and Opportunities," *Isis* 110, no. 3 (2019): 503–4.

40 Nick Ruest, Jimmy Lin, Ian Milligan, and Samantha Fritz, "The Archives Unleashed Project: Technology, Process, and Community to Improve Scholarly Access to Web Archives," in *Proceedings of the ACM/IEEE Joint Conference on Digital Libraries in 2020* (New York: Association for Computing Machinery, 2020), 157–66; HathiTrust Research Center Analytics (website), accessed October 8, 2020, https://analytics.hathitrust.org/; The Programming Historian (website), ProgHist Limited, accessed March 9, 2020, https://programminghistorian.org/en/; TAPoR 3 (website), accessed October 9, 2020, http://tapor.ca/home; "Topic Modeling," MALLET: Machine Learning for Language Toolkit, accessed March 9, 2020, http://mallet.cs.umass.edu/topics.php.

41 Laubichler, Maienschein, and Renn, "Computational History of Knowledge," 504.

42 Joshua Sternfeld, "Archival Theory and Digital Historiography: Selection, Search, and Metadata as Archival Processes for Assessing Historical Contextualization," *American Archivist* 74, no. 2 (2011): 544–75.

many ways a reaction to scholarly digital projects and websites that misuse the term *archives* or decontextualize archival materials. Seeing this as a prime space for collaboration (and perhaps amelioration) between archivists and historians, Alex H. Poole asks, "How can archival principles and practices add value to digital history?"[43] Institutions such as the Library of Congress have accepted this challenge and demonstrated how archives can indeed add value in this space by investing in resources and services to aid computational uses of collections – for example, by enabling bulk downloads of data sets and expanding user services.[44]

Poole questions how archival principles can inform digital history. Perhaps more importantly, how can we create access to datafied archives in ways that are informed by archival principles and practices but that also shed new light on records' provenance? How can computational methods expand our understandings of the broader social and intellectual contexts in which records are created and used? Digital projects can obscure or reveal contextual information about and meanings of records. Emily Monks-Leeson argues that digital archives projects should "reflect certain elements of provenance by maintaining and demonstrating some link to those social factors, functions, institutions, or individuals that constitute their origins."[45] Additionally, the process of datafying archives creates another layer in the strata of records' provenance, making it important for digital projects to also reflect the records' "computational provenance."[46] In light of the datafication of archives, we should not just be "reconceptualizing the archive,"[47] but reconceptualizing it in ways that also respect the nuanced and complex realities of records' provenance.

43 Alex H. Poole, "Archival Divides and Foreign Countries? Historians, Archivists, Information-Seeking, and Technology: Retrospect and Prospect," *American Archivist* 78, no. 2 (2015): 409.

44 Grant Harris, Abigail Potter, and Kate Zwaard, *Digital Scholarship at the Library of Congress: User Demand, Current Practices, and Options for Expanded Services* (Washington, DC: Library of Congress, 2020), https://labs.loc.gov/static/labs/work/reports/DHWorkingGroupPaper-v1.0.pdf.

45 Emily Monks-Leeson, "Archives on the Internet: Representing Contexts and Provenance from Repository to Website," *American Archivist* 74, no. 1 (2011): 54–55.

46 According to Sandusky, the idea of "computational provenance" recently emerged from computer science "to develop systematic, computationally-based processes and standards for capturing, and making available for use, information about who created an object, when it was created or modified and the process or procedure that modified the object." Robert J. Sandusky, "Computational Provenance: DataOne and Implications for Cultural Heritage Institutions," in 2016 *IEEE International Conference on Big Data* (*Big Data*) (Washington, DC: IEEE, 2017), 3267.

47 Moss, Thomas, and Gollins, "The Reconfiguration of the Archive as Data to Be Mined," 131.

As this article will demonstrate, some of these issues can be addressed by carefully documenting the process by which the data are generated and making that process known to users so that they can assess the reliability and trustworthiness of the data. When archivists use computational approaches on archival records, the records are recontextualized in new ways, adding another layer to their provenance.[48] Additionally, providing information about processes that generate data can help facilitate reproducibility and data reuse, things that are becoming more and more important in computational projects.[49] This computational provenance is vital to making datafied archives accessible. At the same time, it is important that the original archival context not be lost in or excluded from these projects. Monks-Leeson astutely notes that

> Archival documents gain their meaning from the preservation of original contexts of creation and use, as represented by the records' provenance. Digital archives, which tend to remove these links and associations in favor of thematic groupings and representative examples, seem to lack the provenancial bonds that archivists take as crucial to a record's meaning and evidential value.[50]

These are important considerations for archivists and users of archives alike, especially when the data are used for digital history and in dynamic new interfaces.

Scientific Correspondence Networks and Provenance

Digital projects count not only among recent examples of the use of archives as data but also among projects that map correspondence networks. A well-known

48 Archivists and archival repositories add their own unique meanings and values to records in their custody as "part of the records' provenancial context." Jennifer Douglas, "Origins and Beyond: The Ongoing Evolution of Archival Ideas about Provenance," in *Currents of Archival Thinking*, 2nd ed., ed. Heather MacNeil and Terry Eastwood (Santa Barbara, CA: Libraries Unlimited, 2017), 39. Digitization decisions by archivists in particular can contribute to "recontextualization." Likewise, I argue that computational approaches are also a type of archival intervention. See also Douglas, "Origins and Beyond," endnote 8, 47.

49 Victoria Stodden, Marcia McNutt, David H. Bailey, Ewa Deelman, Yolanda Gil, Brooks Hanson, Michael A. Heroux, John P.A. Ioannidis, and Michela Taufer, "Enhancing Reproducibility for Computational Models," *Science* 354, no. 6317 (2016): 1240–41.

50 Monks-Leeson, "Archives on the Internet," 39.

example is Mapping the Republic of Letters,[51] which provides access to visualizations of a dynamic intellectual community that transcended geographic boundaries. Similarly, the Cultures of Knowledge project seeks to use "digital methods to reassemble and interpret the correspondence networks of the early modern period."[52] Other projects highlight connections through human-created metadata. The Darwin Correspondence Project's Epsilon, for instance, creates a scientific correspondence network through an XTF-based framework that maps data from correspondence to the Text Encoding Initiative (TEI).[53] What these projects have in common is that metadata about digital archives forms the backbone of the visual representations of these networks. Increasingly, machine-generated data from datafied archives is being used in this vein.

While correspondence has always been a rich source for archival research and an apt candidate for digitization projects,[54] initiatives such as Mapping the Republic of Letters and Epsilon are part of a shift to reveal deeper connections between people and their letters. Historian of science Brian Ogilvie writes that "correspondence has created and sustained national and international communities of scientists, transmitting ideas and material while sustaining affective bonds between collaborators in the scientific enterprise. Situated between the immediacy of conversation and the finality of publication, it has served an important, if changing, role in the creation of knowledge."[55] Not only does scientific correspondence continue to be of interest, but also the scientific correspondence networks "have recently become distinct objects of historical inquiry in themselves."[56] These networks illustrate how scientific knowledge (including specimens and other forms of data) was collected, exchanged, and spread.[57]

51 "Mapping the Republic of Letters," Stanford University, accessed February 8, 2020, http://republicofletters.stanford.edu/.

52 Cultures of Knowledge, accessed February 8, 2020, http://www.culturesofknowledge.org/.

53 "Darwin Correspondence Project," University of Cambridge, accessed March 5, 2020, https://www.darwinproject.ac.uk/Epsilon.

54 Multiple archival studies of historians' information-seeking behaviour indicate that correspondence is a "good candidate for digitization." See Poole, "Archival Divides and Foreign Countries?," 399.

55 Brian Ogilvie, "Correspondence Networks," in *A Companion to the History of Science*, ed. Bernard Lightman (Chichester, UK: John Wiley & Sons, Ltd., 2016), 359–60.

56 Ogilvie, "Correspondence Networks," 358.

57 For an example of early modern scientific correspondence networks, see Yale, *Sociable Knowledge*.

Manfred D. Laubichler et al. note that "knowing, for instance, how the network of Darwin's correspondence partners changed over time can support various narratives about the development of his ideas."[58] While the shape and size of these scientific networks varied, they have had significant roles in sustaining and shaping scientific institutions, ideas, and disciplines.

The cybernetics thought collective sustained itself through the establishment of centres for the study of cybernetics. But the thought collective may also have perpetuated itself through the correspondence network that emerged from the Macy Conferences. David Kronick uses a term analogous to *thought collective* in the context of correspondence networks, noting that the notion of "invisible colleges . . . serves well to describe the relationship of a group of individuals who were interested in similar ideas, such as a new philosophy, and who communicated with each other by letters."[59] In his 2001 article, Kronick speculates as to whether "computer software" could be used for analysis of invisible colleges via correspondence, undertaking an approach similar to that applied to co-citation studies,[60] which seems to anticipate digital scholarship on correspondence networks. For projects focused on early modern scientific networks, for example, "digital correspondence projects will allow us to establish a clearer cartography of the space of flows of early modern science. . . . they will allow scholars to dig more deeply into how correspondence helped individual scientists or small groups to better coordinate observations, exchange information, and debate interpretations."[61] All of this underscores the indispensable role of correspondence in the development of scientific ideas and the importance of making of that correspondence accessible for study.

Correspondence networks can offer new information for historical research. At the same time, these networks arguably offer insights into the contexts of the records themselves while potentially being able to represent important aspects of their provenance. Identifying connections between records across fonds

58 Laubichler, Maienschein, and Renn, "Computational History of Knowledge," 507.

59 David Kronick, "The Commerce of Letters: Networks and 'Invisible Colleges' in Seventeenth- and Eighteenth-Century Europe," *Library Quarterly* 71, no. 1 (2001): 38. For an in-depth discussion of invisible colleges, see Diana Crane, *Invisible Colleges: Diffusion of Knowledge in Scientific Communities* (Chicago: University of Chicago Press, 1972).

60 Kronick, "The Commerce of Letters," 39.

61 Ogilvie, "Correspondence Networks," 368.

aligns with the idea that provenance exists not for a physical entity but for a set of relationships that surround the creation of records. This resonates with Terry Cook's post-custodial conception of the fonds (in the digital era especially) not as a physical thing that must be reconstructed via arrangement and respect original order but as something enmeshed within myriad relationships.[62] Scientific correspondence networks are especially illustrative of the relationships that surround the creation of records.

Given the collaborative nature of modern science, expanded notions of provenance and the fonds are integral to understanding the larger contexts of creation and the records themselves.[63] This is quite simply because scientists frequently work together to generate new knowledge and build on each other's work. And this collective and collaborative work takes many forms. A famous example comes from a letter by Isaac Newton to Robert Hooke, in which Newton responds to the latter regarding an offer for collaboration: "If I have seen further, it is by standing on the shoulders of giants."[64] As noted previously, correspondence files represent many creators, who exchange letters. Which letters happen to end up in which scientist's fonds is the result of their individual recordkeeping practices, and the order of the correspondence may reflect the activity of a singular scientist. But the thought collective of scientists who maintain intellectual interaction through the exchange of letters is the reason for the existence of those correspondence files, with their fonds forming a distinct community of records.

In the case of scientific archives, a collective can be responsible for the creation of records in the same fonds, or records can share archival bonds with records in different fonds that share this same provenance.[65] The notion of a collective as

62 Cook, "The Concept of the Archival Fonds in the Post-Custodial Era," 33.

63 Expanded notions of provenance take into account both the larger intellectual and social milieu that shapes records and the impact that collectives have on provenance. For example, Joel Wurl has argued for ethnicity as a critical aspect of provenance, and not as a "subject" or "theme." See Joel Wurl, "Ethnicity as Provenance: In Search of Values and Principles for Documenting the Immigrant Experience," *Archival Issues* 29, no. 1 (2005): 65–76, cited in and see Douglas, "Origins and Beyond," 36.

64 Historical Society of Pennsylvania, "Isaac Newton Letter to Robert Hooke, 1675," HSP Discover, accessed November 8, 2020, https://discover.hsp.org/Record/dc-9792.

65 Luciana Duranti defines the concept of an archival bond as "the network of relationships that each record has with the records belonging in the same aggregation." Luciana Duranti, "The Archival Bond," *Archives and Museum Informatics* 11, no. 3–4 (1997): 215–16. But I argue that computational methods make it possible to see bonds between records in different fonds that share the same provenance; in this case the scientific thought collective.

provenance has been recognized, though not without its caveats, in traditional archival representation frameworks.[66] Yet the idea that a collective can shape the records of a fonds is in line with discussions about provenance that articulate the fonds as an abstract instead of a physical entity, which "respect[s] the multitude of relationships that make up that abstraction."[67] This is not a new idea; it has been long understood that a fonds results from a complex set of relationships while also representing those relationships. Debra Barr, for instance, advocated in the late 1980s for a broader definition of the fonds that acknowledges the complex histories of records and the multiple administrative bodies and individuals that comprise their provenance.[68] In the same vein, subscribing to expanded notions of provenance for scientific archives (and correspondence, in particular) acknowledges the multiple entities and relationships connected to the records. While archival theorists have advocated for situating records in their socio-historical contexts,[69] the intellectual contexts in which records are enmeshed also carry significant weight. Further eschewing narrow definitions of provenance, Tom Nesmith describes the "societal and intellectual contexts . . . [that shape] the actions of the people and institutions who made and maintained the records" and the "processes of contextualization and re-contextualization" that records undergo.[70] The fonds is socially situated and contingent, tied to functions and activities of creators, and constituted through multiple relationships relating to creation and use.[71] Jeanette Allis Bastian breathes life into these expanded notions of provenance through her work on collective memory and communities of records in the US Virgin Islands, extending the boundaries of provenance from one creator in one location to place and community.[72] For

66 Michel Duchein, "Theoretical Principles and Practical Problems of *Respect des Fonds* in Archival Science," *Archivaria* 16 (Summer 1983): 64–82, cited in Lemieux, "Toward a 'Third-Order' Archival Interface," 60.

67 Douglas, "Origins and Beyond," 33.

68 Debra Barr, "The Fonds Concept in the Working Group on Archival Descriptive Standards Report," *Archivaria* 25 (Winter 1987–88): 163–70.

69 Douglas, "Origins and Beyond," 35–39.

70 Tom Nesmith, "Seeing Archives: Postmodernism and the Changing Intellectual Place of Archives," *American Archivist* 65, no. 1 (2002): 35, 36.

71 Cook, "The Concept of the Archival Fonds in the Post-Custodial Era," 24–37; Terry Cook, "Fashionable Nonsense or Professional Rebirth: Postmodernism and the Practice of Archives," *Archivaria* 51 (Spring 2001): 14–35.

72 Bastian, *Owning Memory*; and Jeannette Allis Bastian, "In a 'House of Memory': Discovering the Provenance of Place," *Archival Issues* 28, no. 1 (2003–2004): 9–19.

scientific archives, such a framework could be reimagined for a community bounded not by a shared geography but by a specific intellectual milieu.

Visual representations of correspondence networks may be one way in which to represent the connections and relationships between scientists and the provenance of the materials they create and exchange. Given the national and international extent of the cybernetics movement and its transcendence of disciplinary boundaries, the CTC team sought to model a project that would expose the network in which cyberneticians participated. In particular, the project aimed to enable exploration of the ways in which cyberneticians formed and transmitted *ideas* – admittedly, a tall order. While many digital projects represent visualizations of scientific correspondence networks via geography, this project departed from this practice to instead provide visualizations of connections between nodes representing key cybernetic concepts, people, and archival records. Representing these connections via a network graph that connects entities and shows the degree of connection through node size and arc thickness emulates digital projects like the Belfast Group Poetry Networks.[73] The CTC team hoped to provide insight into idea exchange – into who exchanged ideas and the cybernetic ideas they discussed.

Project Methodology

For digital projects focused on correspondence networks to be useful to history of science researchers, Brian Ogilvie writes that they "must create uniform, machine-readable catalogues of correspondence, with appropriate metadata for analyzing intellectual exchange. And they must devise digital tools to query their databases and to present the results visually."[74] From 2017 to 2019, the CTC team sought to use computational tools (1) to generate metadata that would document thought exchange within the collective and (2) to establish ways that users could visually explore bonds between the records. Fortunately, cyberneticians developed a distinct set of concepts and a related vocabulary that could be used as inputs for the computational tools like machine learning and NLP. In

73 "Networks and Maps," Belfast Group Poetry Networks, accessed February 8, 2020, https://belfastgroup.digitalscholarship.emory.edu/network/.

74 Ogilvie, "Correspondence Networks," 368.

order to provide information about the project, the team created a website to serve as a prototype.[75] Throughout the project, the CTC team met with its board of advisors, which comprised scholars of cybernetics and technologists.[76] Focus group testing at the project's end provided feedback on the results to inform future work.

Creating Inputs

Digitization resulted in 61,067 pages of digitized materials,[77] including access PDFs and preservation master TIFF files. Since this was a pilot project, only a select portion of materials from the papers of Heinz von Foerster, Warren S. McCulloch, W. Ross Ashby, and Norbert Wiener was included. For expediency and to align with current descriptive practices, all materials were digitized to the folder level or, for multi-page records, to the item level. A programmer hired for the project used PDFMiner to extract the text from the digitized materials to import into plain text files with the same filenames.[78] Optical character recognition (OCR) software was used to make the materials machine readable. Because OCR results can be inaccurate, a variety of errors needed to be remediated; these errors included merged words (i.e., separate words that had been merged together), extra spaces between characters, and alpha-numeric characters that had been misread as symbols. The programmer wrote a script that identified and remediated some of these errors.[79] In cases where the majority of the documents consisted of symbols instead of alpha-numeric characters, these records were excluded from the corpus due to time constraints.[80] The programmer also briefly experimented with using a Natural Language Toolkit (NLTK) library in combina-

75 See "The Cybernetics Thought Collective: A History of Science and Technology Portal Project," University Library: University of Illinois at Urbana-Champaign, accessed February 8, 2020, https://archives.library.illinois.edu/thought-collective/.

76 For a list of board of advisors, see "Credits," in "The Cybernetics Thought Collective," https://archives.library.illinois.edu/thought-collective/credits/.

77 This amounts to 615 digital objects consisting of materials digitized at the folder level rather than the item level.

78 "jaepil/pdfminer3k," GitHub, accessed March 5, 2020, https://github.com/jaepil/pdfminer3k.

79 For more details on OCR error identification and text normalization, see Bethany G. Anderson, Christopher J. Prom, James A. Hutchinson, Anirudh Chandrashekhar, Brinna Michael, Shreya Udhani, Mark Sammons, et al., "The Cybernetics Thought Collective: A History of Science and Technology Portal Project White Paper" (white paper, University of Illinois at Urbana-Champaign, April 24, 2019), 7–12, http://hdl.handle.net/2142/106050.

80 We hope to address these errors in a future phase of the project.

tion with English dictionaries, but this proved to be a time-intensive and ineffective approach. Because some of this correspondence is in languages other than English, the programmer created a test set of approximately 200 documents in English, German, French, and Italian to test using N-grams (sequences of words that commonly appear together) as an approach to language identification.[81] After the languages had been identified, Google Translate was used to translate the text into English.[82]

This text normalization made the records machine readable and computable. However, an important step toward preparing the materials for analysis is giving the tools instructions for which data or entities to extract from the records. As indicated above, the present state of technologies, and the ability for archival repositories to implement them effectively, indicates that technologies such as machine learning, NLP, and the related named entity recognition (NER)[83] must be adapted to be useful for archives. For these technologies to be useful in an archival context, they must be trained *as archival aids* by practitioners. Thomas Padilla notes that "the viability of machine learning and artificial intelligence is predicated on the representativeness and quality of the data that they are trained on."[84] The tools we employed would not "know" what a cybernetic entity is without instructions and a pre-established vocabulary to draw from. To prepare the digitized materials for computational analysis, the team needed a vocabulary with which to train the algorithm to process the documents (i.e., to extract cybernetic terms and classify the documents into broad cybernetic categories).

81 For a description of N-grams, see Prachi Kumar, "An Introduction to N-grams: What Are They and Why Do We Need Them?" *XRDS* (blog) *Crossroads: The ACM Magazine for Students*, October 21, 2017, https://blog.xrds.acm.org/2017/10/introduction-n-grams-need/.

82 "Googletrans 3.0.0," Python Package Index, accessed March 5, 2020, https://pypi.org/project/googletrans/; given time constraints, the CTC team did not verify the accuracy of the translations, but this is a task that could be undertaken in a later phase of the project.

83 NER, generally considered a subset of NLP, is defined as "the task of identifying and categorizing key information (entities) in text. An entity can be any word or series of words that consistently refers to the same thing." Christopher Marshall, "What is Named Entity Recognition (NER) and How Can I Use It?" *Super.AI*, December 18, 2019, https://medium.com/mysuperai/what-is-named-entity-recognition-ner-and-how-can-i-use-it-2b68cf6f545d.

84 Thomas Padilla, *Responsible Operations: Data Science, Machine Learning, and AI in Libraries* (Dublin, OH: OCLC Research, 2019), 14, https://doi.org/10.25333/xk7z-9g97.

Cybernetics has a distinct vocabulary and set of concepts, which the team sought to use as a basis for identifying entities within the cybernetics materials. To attempt to shed light on the thought collective of cybernetics, it was important to decide how cybernetic concepts would be recognizable in order to reveal how they were exchanged. One approach is to identify terms associated with many of cybernetics's main concepts. However, larger challenges concerning the semantic and linguistic properties of the texts could not be ignored – particularly the difficulty of identifying terms used for concepts as these concepts evolved and changed over time.[85] However, an important first step was to identify the main terms for concepts and other key entities such as persons; proper names; and sensorimotor and other concrete terms that are common within cybernetics vocabulary (e.g., *seeing*, *frog*, *eye*, and *network*).

While the team collectively has a broad knowledge of the history of cybernetics and its fundamental ideas, we needed an authoritative list of the concepts that existed at the time that von Foerster, Ashby, McCulloch, and Wiener were active to supplement this knowledge. The team selected *Cybernetics of Cybernetics: Or, the Control of Control and the Communication of Communication*.[86] *Cybernetics of Cybernetics* is a comprehensive collection of essays on cybernetics, including the ideas of Ashby, McCulloch, von Foerster, Wiener, and other cyberneticians. A digital copy of the text, uploaded to Voyant Tools, was used to generate an initial list based on word frequencies. The terms with the highest number of occurrences generated from Voyant were organized into several categories (table 1). The team also consulted several cybernetics glossaries[87] and shared the list with the project's board of advisors for feedback. As we later realized, many of the terms from the list turned out to be present in the records; thus, the list did indeed anticipate much of the data machine generated from the materials. Yet it is unclear if any cybernetic terms were missed or if any of these terms were false positives. In the future, other ways of identifying entities and employing compu-

85 This issue will need to be addressed with computational linguistics methods and approaches.

86 Heinz von Foerster, ed. *Cybernetics of Cybernetics: Or, the Control of Control and the Communication of Communication* (Urbana, IL: Biological Computer Laboratory, 1974).

87 "The ASC Glossary," American Society for Cybernetics, accessed March 5, 2020, http://www.asc-cybernetics.org/foundations/ASCGlossary.htm; and "Web Dictionary of Cybernetics and Systems," Principia Cybernetica Web, accessed March 5, 2020, http://pespmc1.vub.ac.be/ASC/INDEXASC.html. These glossaries are broad and include more recent terms relevant to systems theory as well, so the CTC team felt it was important to distill the cybernetics vocabulary as it existed approximately during the 1950s to 1970s.

tational linguistics to generate a cybernetics vocabulary should be explored in order to perform quality control on these results.[88]

TABLE 1 *Partial list of cybernetic concepts, terms, and proper names.*

BROAD/ PHILOSOPHICAL/ SCIENTIFIC	MORE SPECIFICALLY CYBERNETIC	TECHNICAL SENSORIMOTOR AND CONCRETE	PROPER NAMES
Abduction	Adaptive	Algorithm	American Society for Cybernetics (ASC)
Action	Adaptation	Animal	Biological Computer Laboratory (BCL)
Affordances	Allo-	Brain	Aristotle
Anatomy	Artificial Intelligence	Cat	Ashby
Art	Auto-	Circuit	Bateson
Auto-	Autonomy	Code	Beer
Autonomy	Autonomous	Component	Bergson
Behavior	Automata	Computer	Günther
Being	Automaton	Ear	Lettvin
Belief	Autopoiesis	Earth	Macy
Biology	Biometrics	Eye	Maturana

Creating a Computational Analysis Pipeline

The CTC project's programmers tested different software libraries to develop a pipeline for extracting data (entities). These included the University of Illinois Cognitive Computation Group's NLP Pipeline software[89] and Wolfram Research's

88 For example, the Smelly London project notes that, in future, it will use "automatic identification of smell terms based on their contextual features to discover new categories that escaped previous classifications." Leem, "Smelly London," 1.

89 Cognitive Computation Group, accessed April 9, 2021, https://cogcomp.seas.upenn.edu/ (now managed by the University of Pennsylvania).

text analysis tools (part of Wolfram Language),[90] especially the WordCounts and TextWords functions.[91] In addition, Python tools spaCy and VADER were used for sentiment analysis.[92] NLP-based sentiment analysis has been used mainly to analyze email archives and social media data, but we thought it would be useful to explore creating sentiment data for other digital archival materials and to see how these data might relate to specific cybernetic concepts and provide further insight into idea exchange. Ultimately, the programmers developed a Python pipeline for text extraction, remediation of OCR errors, translation of texts into English when necessary, analysis, and sentiment entity extraction.[93] Wolfram Language and the NLP Pipeline software presented a number of complications, which led us to test additional software, including various Python libraries that facilitate entity identification and extraction. In addition to the Wolfram Language StopWords function, we primarily used Python NER and NLP libraries due to their versatility and broad community support. During the course of this initial testing, it became apparent that the data in the texts required additional normalization. The programmer thus removed articles, conjunctions, pronouns, prepositions, and other words unrelated to cybernetics to reduce noise. Wolfram Language's StopWords function[94] proved useful for removing words like *the*, *and*, *you*, and so on.

The programmer experimented with Wolfram's WordCounts[95] and TextWords[96] to identify N-grams as well as strings of words that contained related cybernetic terms. We experimented with 2-grams, 3-grams, and 4-grams. For example,

90 "Text Analysis," Wolfram Language and System Documentation Center, accessed March 5, 2020, http://reference.wolfram.com/language/guide/TextAnalysis.html.

91 Stephen Wolfram, founder and CEO of Wolfram Research, was a member of the advisory board and generously donated technology resources toward the project. Wolfram Text Analysis Tools proved to be particularly useful for the project.

92 "cjhutto/vaderSentiment," GitHub, accessed March 5, 2020, https://github.com/cjhutto/vaderSentiment.

93 Available at the project's GitHub repository, "cybernetics-thought-collective/Project_Files," GitHub, accessed March 5, 2020, https://github.com/cybernetics-thought-collective/Project_Files.

94 "DeleteStopwords," Wolfram Language and System Documentation Center, accessed March 5, 2020, https://reference.wolfram.com/language/ref/DeleteStopwords.html.

95 "WordCounts," Wolfram Language and System Documentation Center, accessed March 5, 2020, https://reference.wolfram.com/language/ref/WordCounts.html.

96 "TextWords," Wolfram Language and System Documentation Center, accessed March 5, 2020, https://reference.wolfram.com/language/ref/TextWords.html.

3-gram results of "((‘sensorimotor’, ‘program’, ‘online’), 84)" and "((‘state’, ‘system’, ‘would’), 84)" indicated that these strings of three words appeared together 84 times.

While the N-grams still contained a great deal of noise, especially frequencies of words that did not appear germane to cybernetics, some cybernetic terms that appeared frequently together (e.g., *neuron*, *impulse*, *measure*) did surface. After removing stop words, the programmer used the cybernetic terms/inputs to further refine the list of entities to be used in the machine-learning phase to classify the documents. The next step was to extract entities that include these cybernetic terms and the names of associated persons, such as individuals mentioned in the documents (figure 1).

1106026_51_LOFGREN_1975_EXTRACTED_FEATURES.TXT

Action | Art | Auto | Behavior | Belief | Cause Effect | Cognition | Concept |
Construction | Theory |
Description | Design | Domain | Doubt | Dream | Engineering | Environment
| Error | Evolution | Experiment | Experimental | Flow | Future | Human
| Hypothesis | Methods | World | Nature | Information | Knowledge |
Laboratory | Law | Learning | Man | Mathematics | Mechanism | Meaning | Mind |
Model | Nervous | System |
Observation | Observing | Order | Organism | Organization | Paradox | Perception |
Physics | Process |
Reality | Science | Scientific | Space | Structure | System | Systems | Thinking | Time |
Theory | Truth |
Uncertainty | Value | Allo | Auto | Automata | Communication | Complexity |
Cybernetics | Distinction |
Emergence | Information | Laboratory | Engineering | Order | Purpose | State |
Trivial | Animal | Brain | Cat |
Code | Computer | Ear | Eye | Function | Hand | Hear | Map | Program | Reflex |
Sun | Biological | Computer |
Laboratory | Wittgenstein

FIGURE 1 *Extracted entities from Heinz von Foerster’s correspondence.*

Statistical analysis was conducted to identify which words, or entities, appeared to be most "important" in the corpus. We felt this would be useful for comparison against the original cybernetic inputs generated from *Cybernetics of Cybernetics*. We used term frequency–inverse document frequency (TF–IDF) on the documents to determine the most prominent entities.[97] This analysis examined how often a word appeared in a file-level document as well as how frequently it appeared throughout the entire corpus. However, because document length varied considerably across the corpus, these results ended up not being useful. Future experimentation with TF-IDF will require normalization of document length, which may be difficult given the diverse nature of archival records.

This process resulted in two text files per file-level document: one containing the extracted entities and the other consisting of the normalized document. The former outputs would be used as archival metadata for each file and as inputs for the machine-learning classification algorithm, to reveal how all these documents are related via their entities and other characteristics and thus which documents share connections across and between the cyberneticians' archives. One of the project's aims was to find ways to determine how the documents primarily connected to each other: What intellectual groupings would emerge? Would these groupings provide insights about the materials' provenance? In order to answer these questions, the next step was to decide how to approach machine learning in order to classify the documents into distinct categories and, specifically, whether to use a supervised or an unsupervised approach. A supervised learning approach would require training an algorithm to perform a specific task and to identify outputs that correspond to training set inputs.[98] An unsupervised approach, on the other hand, would employ a clustering method, whereby the algorithm would be given entities from documents to create its own categories, or clusters.[99] The documents in a particular cluster would presumably share similarities with other materials grouped into that cluster. The algorithm would still be provided with direction – for example, by being pointed to entities around which to cluster documents.

97 As another example of the application of TF-IDF to archival records, María Esteva explored its application where documents were very similar. María Esteva, "The Aleph in the Archive: Appraisal and Preservation of a Natural Electronic Archive" (PhD dissertation, University of Texas at Austin, 2008), 109–10, https://repositories.lib.utexas.edu/handle/2152/3840.

98 Ethem Alpaydin, *Machine Learning* (Cambridge, MA: The MIT Press, 2016), 38–42.

99 Alpaydin, *Machine Learning*, 111–12.

The CTC team decided to adopt a supervised approach given both the project timeframe and the unpredictability of unsupervised output; pursuing an unsupervised approach might be worth exploring in a future phase of the project, when the team has more time and resources to analyze the results. Nonetheless, a supervised approach can be (and was) labour intensive. The team manually created a training set of 154 documents, which were manually tagged and grouped into four broad categories: mathematics/logic; computers/machines; psychology/neuroscience; and personal. The three disciplinary categories were created since they encompass many of the terms generated from *Cybernetics of Cybernetics*.[100] We also thought it was important to include a category for correspondence that did not explicitly relate to cybernetics, since many cyberneticians had personal relationships with each other and exchanged correspondence relating family and personal news.

The classification workflow consisted of running the extracted entities, along with the normalized documents from the training set, through the machine-learning classifier, which produced statistical probabilities per category and classified the documents. Entities were extracted from the training set according to these categories to classify the rest of the records in the corpus. Following the initial testing of normalization and extraction approaches, we solidified a machine-learning pipeline that automatically converted PDFs to plain text, normalized the documents, removed files with significant noise, extracted entities and determined the language of the documents, and then classified the documents and percentage of certainty for each class (figure 2).

The programmer tested several classifiers but ended up using Naïve Bayes,[101] which yielded promising results. Naïve Bayes is part of a family of flexible, well-known probabilistic machine-learning classifiers used for supervised models. Despite reassurance that the entities as inputs were relevant to the corpus as a whole and the percentage of accuracy was rather high, the team was able to produce only a relatively small training set, and thus the results indicate room for improvement. For example, the classification of some documents (such as technical reports) as "personal" did not seem entirely accurate. Therefore, yielding more reliable results in a future phase would require creating a larger

100 Ideally, we would have created categories based on more specific cybernetic concepts, but we decided broader disciplinary concepts would be more useful for initial testing of these methods – especially since many of the records might feasibly contain terms that overlapped with multiple cybernetic concepts.

101 "codebox/Bayesian-classifier," GitHub, accessed March 5, 2020, https://github.com/codebox/bayesian-classifier.

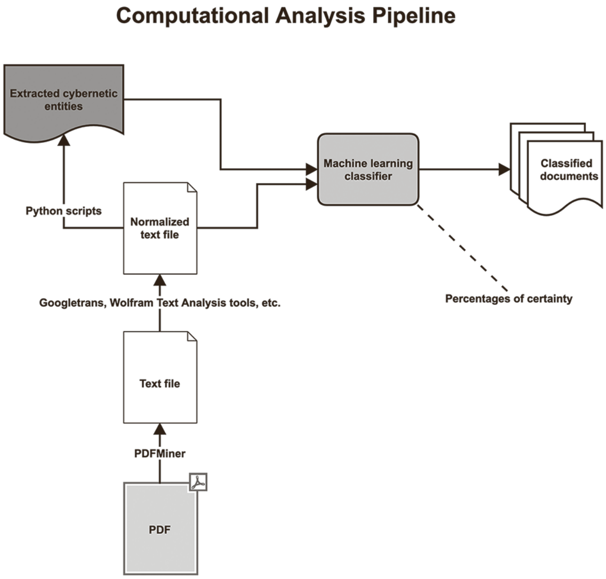

FIGURE 2 *Extraction and classification pipeline. Source: Diagram courtesy of author.*

training set and ensuring that the algorithm could more intelligently parse through records that vary in form and length. However, for the purposes of the pilot project, it was important to understand these results so that the team could make adjustments to refine the training set and workflow moving forward. The team sought to gain further insight into these results – in order to understand the ways in which the entities related to particular documents to produce a ranking of the entities – in an effort to further reduce noise.

Weka,[102] a graphical user interface (GUI)-based machine-learning toolkit, was used to understand the reliability of the training set. Weka enables chi-squared analysis to determine the relevancy of the entities in the overall classification process. The metrics revealed that the classification model[103] yielded a result

102 Weka (website), UoW Machine Learning Group, accessed March 5, 2020, https://www.cs.waikato.ac.nz/ml/weka/.

103 In machine learning, a model is "a computer program that encodes the patterns the machine learning algorithm has extracted from a dataset." John Kelleher, *Deep Learning* (Cambridge, MA: The MIT Press, 2019), 253.

of 71.1% true positives (i.e., those that it had classified correctly) and 4% false positives (i.e., data that it had incorrectly classified at this rate) and, overall, indicated a 93.4% confidence in the classification model's accuracy in distinguishing between true positives and false positives. Weka seemed to indicate that the entities as inputs corresponded to the contents of the documents themselves. The chi-squared analysis enabled us to determine how likely the entities were to be found in the documents based on their classification category. Names of persons appeared to match up most consistently with four classification categories, followed by cybernetic terms. From this ranking, we were able to eliminate some of the entities as inputs that had lower rankings to further reduce noise. This work enabled us to perform some quality control on the training set to improve the machine-learning results.

Machine Learning, Certainty, and Reliability

The experimental exercise described above generated output with the ultimate goal of creating a data set that could be used both to describe the materials and to visualize relationships between them but could also be reused for computational analyses beyond those performed by the project team. Like the archival records from which they were generated, machine-created data should also be reliable and trustworthy.[104] For the machine to produce accurate results is thus paramount. The exercise raised questions about how to ascertain accuracy and how to best refine the training set and process at a later phase in order to produce more accurate and trustworthy results.

An important part of creating a reliable and trustworthy record of computational processes and the data they produce is to provide users with information to help them interpret the results for themselves and understand the computational provenance.[105] In other words, it was important to provide information about

104 In the same way that records should be evaluated for reliability, computational output should be likewise assessed for whether it "is capable of standing for the facts to which it attests." Reliability is related to the completeness of form and information about a record's creation and the procedures responsible for its creation. Heather MacNeil, *Trusting Records: Legal, Historical and Diplomatic Perspectives* (Dordrecht: Kluwer Academic Publishers, 2000), xi, 100–101.

105 Sandusky, "Computational Provenance," 3267; See also Claudio T. Silva and Joel E. Tohline, "Computational Provenance," *Computing in Science and Engineering* 10, no. 3 (2008): 9–10.

the origins of the data and the workflow employed. We thus made certain that we created access to information about how the training set and resulting data were produced to help users gauge the accuracy of those results. The CTC team provided open access to all code and software used during the project and also a brief summary of the process in a readme file.[106] We also sought to provide algorithmic transparency by indicating the percentages of certainty about the results.

One interesting result of the project was that the correspondence did not necessarily *always* lend itself to being logically grouped into a specific category. The preliminary results indicate deeper nuances in the materials. These percentages of certainty are made available through the metadata profile for each folder of correspondence in the University of Illinois Library's digital collections (figure 3).

CYBERNETIC CLASSIFICATION (MACHINE GENERATED)	MATH
Classification Certainty (Machine Generated)	Math, 59.17% Psychology, 27.92% Machines, 8.23% Personal, 4.67%

FIGURE 3 *Example of classification certainty provided via the metadata profile for the materials in the Cybernetics Thought Collective.*

While some of these percentages illustrated nuances in the materials worth further study, a manual review of the classification results raised a few questions about the overall reliability and accuracy of some of the output. For example, a folder of correspondence between Heinz von Foerster and Herbert Brün (a fellow faculty member at the University of Illinois whose own work had cybernetic leanings) was classified as 100 percent "personal." However, the correspondence also contains an intellectual discussion between von Foerster and

106 "README_Cybernetics_Thought_Collective_Data.txt," Illinois Library Digital Collections, accessed March 5, 2020, https://digital.library.illinois.edu/items/3cd33c50-8c95-0138-729a-02d0d7bfd6e4-8.

Brün on Noa Eshkol and Avraham Wachman's work on movement notation.[107] Despite the presence of some personal content in the correspondence, it was surprising to see this folder classified as overwhelmingly personal. This points to a number of possibilities: the training set needs to be larger to produce more accurate results; we may need to normalize document length; and we may need to perhaps analyze materials at the item level as opposed to the folder level moving forward. The machine-learning algorithm seemed to produce more nuanced and accurate results for folders of correspondence that contained fewer pages (i.e., up to 10 pages). Folder-level material longer than 10 pages tended to result in more questionable results. Refining the inputs and training sets and devoting more resources to analyzing the results as part of a later phase of the project will be helpful in indicating when the machine produces trustworthy, reliable results and when it does not.

The team created a web portal as proof of concept to provide unified access to the materials, the data, and the machine-learning results. As originally conceptualized, the portal was meant to facilitate exploration of the relationships among the data through user-generated visualizations. At the same time, it was important to ensure access to the digital surrogates and machine-generated metadata in established archival systems that would enable users to understand the context and relevance of the materials.[108] Providing linkages between the original materials, their machine-generated data, and the visualized data is not only important to the team, so as to preserve the original provenance and context of materials within the project, but it is also important for tracing the origins and procedures that created the machine-generated data as a record in and of itself, as a way to illustrate reliability. In an archives-as-data spirit, all machine-generated data and original inputs were also made available for download as CSV files to aid further computational research and analysis.[109]

107 University of Illinois Archives, The Cybernetics Thought Collective (Digital Surrogates), Record Series 35/3/99, Box 5, Heinz von Foerster Papers, Correspondence with Herbert Brün (1 of 3), 1967–1970, 1973–1974, https://digital.library.illinois.edu/items/60a9bca0-29ac-0136-4d81-0050569601ca-f.

108 The need to build authentic digital infrastructures that enable humanities scholars to seamlessly access digital content and to readily ascertain context and relevance is an important consideration. See Alexandra Chassanoff, "Historians and the Use of Primary Source Materials in the Digital Age," *American Archivist* 76, no. 2 (2013): 463–64.

109 The data and inputs, along with a readme file that provides further context, are available here: https://digital.library.illinois.edu/items/3c80ad40-8c95-0138-729a-02d0d7bfd6e4-b.

Representing Machine-Generated Data

The CTC project sought to create three different but complementary types of access: (1) access to digital surrogates and metadata through the University of Illinois Library's digital collections platform; (2) access to data visualization to enable exploration of the machine-extracted data and machine-learning classification of the documents; and (3) access to the inputs and machine-generated data itself. Creating different user pathways to facilitate access to the materials would provide traditional archival access in established systems as well as in ways that would be in concert with digital scholarship needs. As noted below, providing access to machine-generated metadata proved more successful, whereas the visualizations presented several challenges.

Metadata Profile and Digital Library Access

All digitized records, along with their machine-generated and classification data, were ingested into the University of Illinois's preservation service, Medusa, and made accessible through its front-end digital library interface.[110] The digital library provides curators the ability to create customized metadata application profiles for digital collections based on either Dublin Core or *Describing Archives: A Content Standard* (*DACS*). The metadata application profile allows for both aggregate and file-level description and, thus, the flexibility to include customized metadata elements and entities as part of this experimental project. For the CTC project, we used the DACS-based standard profile developed for the University of Illinois Archives but included additional elements to accommodate machine-generated metadata. The latter is identified as "Machine Generated" in the metadata profile.[111] The metadata application profile includes a browsable folder directory that mirrors a computer file system as well as an embedded IIIF image viewer. The interface enables users to explore the content in a more traditional mode, by browsing content through a box-folder structure that mimics the experience of perusing physical materials in a reading room.

110 "Medusa," University Library, University of Illinois at Urbana-Champaign, accessed March 9, 2020, https://medusa.library.illinois.edu/; and "Digital Collections," Illinois Library, accessed March 9, 2020, https://digital.library.illinois.edu/.

111 For an example of the profile, see https://digital.library.illinois.edu/items/3f775a00-29ac-0136-4d81-0050569601ca-f; each field in the profile is also described in the readme note that is provided along with the downloadable data: "README_Cybernetics_Thought_Collective_Data.txt," https://digital.library.illinois.edu/items/3cd33c50-8c95-0138-729a-02d0d7bfd6e4-8.

Visual Representations

A series of test visualizations were created to enable exploration of the machine-generated data and their connections[112] and to see how this data could be made accessible in ways that align with digital scholarship methods. These visualizations, it was hoped, would provide insights not easily gleaned from browsing the records and their metadata in the digital library. Specifically, we explored open-source visualization software for representing relationships between the data. One of the chief difficulties we encountered was that many of the network visualization technologies were unable to coherently display large quantities of machine-generated data. To mitigate this problem, we selected a small sample of the data to form the basis of test visualizations. We also recognized the limitations of this approach since the data could not be more effectively displayed and explored through an interface that enabled users to query the data to produce different entity maps. It was especially important to make sure we included the filename (hyperlinked to the digital surrogates when possible) as a node so that the original archival context – the arrangement in the original fonds – was discernible.

Given the aim of the project to represent correspondence networks and intellectual exchange around cybernetic ideas, network visualization software that could illustrate connections between correspondents and cybernetic entities was important. To experiment with different views of the data, we also tested other types of visualization software, such as RAWGraphs,[113] a web-based open-source visualization software that generates vector-based data visualizations based on the D3.js JavaScript library and works with tabular data that can be imported as a spreadsheet via a web-based application.[114] While RAWGraphs provides a diverse array of visualizations, these are static and do not afford the kind of interactivity that we sought. In searching for more dynamic interfaces, the team explored chart- or grid-based visualizations through Plotly,[115] which also uses D3.js and includes a chart studio that provides different options to create interactive visualizations, such as heat maps and timelines. While these visualizations were

112 These visualizations are available under "Data Visualizations" on the CTC portal: "The Cybernetics Thought Collective," https://archives.library.illinois.edu/thought-collective/.

113 RAWGraphs (website), accessed March 9, 2020, https://rawgraphs.io/.

114 See "densitydesign/raw," GitHub, accessed March 9, 2020, https://github.com/densitydesign/raw. RAWGraphs can also be run locally.

115 "Dash Enterprise," Plotly, accessed March 9, 2020, https://plotly.com/

easy to implement and embed in the prototype portal site, they are limited in terms of the number of nodes/entities that can be displayed in any one visualization (generally no more than three at a time). These visualizations did illustrate some interesting trends, however, such as which cybernetic terms appear most frequently in select correspondence from a specific year. We also tested the visualization software Tableau to visualize classifications of the materials and the percentages of certainty. Tableau can display multiple nodes, but it does not have the capacity to illustrate the complexity of interconnections between people, concepts, and materials that might be possible with a network interface.

After trial and error with tools to visualize networks, we came across Onodo,[116] an open-source network visualization and analysis tool that enabled us to illustrate more broadly the correspondence network and multiple entities/nodes together. Onodo is not only interactive but also able to illustrate degrees of strength between connections (through the thickness of arcs between nodes) while making it possible to provide direct links to the digital surrogates in the digital library. The tool also works with data via a spreadsheet import function. As with the other software we tested, we could only use a select amount of data in Onodo, especially if we wanted to display connections among more than two nodes. The data set for these visualizations has been made available to enable additional exploration.[117]

These visualizations presented a number of pros and cons, and the CTC team ultimately realized that they were intended for simpler datasets. Most off-the-shelf visualization software is not created with archives in mind but would need to be further developed for use on archival data to provide information about provenance and original files. What is notable from these visualizations, particularly those using Onodo, is that they illustrate connections among materials within and across different fonds. But the utility of these visualizations and the insight they can offer are limited in terms of the ways in which they can currently be queried, interrogated, and integrated with current archival systems. Thus, the data are also made available to enable broader analyses beyond these test visualizations.

116 Onodo (website), Fundación Ciudadana Civio and Eurecat, accessed March 9, 2020, https://onodo.org/.

117 A sample data set for visualizations is available here: "Onodo_Test-Data.xlsx," https://docs.google.com/spreadsheets/d/1zfY0bKovXWMti7aNGLKYvpqkamSc__jP_iXGoNzp5tQ/edit?usp=sharing.

In a future phase of the project, we hope to provide access to all data through an interactive network interface that enables users to query the data to produce different entity maps. Likewise, information about the computational provenance of the data and the connections among them should be readily evident to users so they can assess the reliability of the data. Providing information about the computational provenance and about the original archival context and enabling users to reproduce the process or reuse and run the materials and/or the data through their own computational analyses pipelines is a step toward providing access to trustworthy computational archival projects.[118] But even with users having access to this information, the output of a machine-learning pipeline is only as good as its input.[119] As the above questions about the accuracy of the machine-learning process indicate, this will need to continue to be refined.

User Perspectives

Near the end of the project, a focus group comprising advisory board members and science and technology studies scholars was assembled to inform future project development. Preliminary feedback from this group indicated that access through machine-generated metadata and visualizations can complement traditional archival access. However, these modes of access should not necessarily be seen as a replacement for current archival access systems. Focus group participants voiced an interest in having links to digitized archival materials more seamlessly integrated into visualizations and in being able to explore digitized content through traditional means that mimic hierarchically ordered box and folder listings. It became apparent that the original context of archival records still matters to users. In other words, being able to situate a record in its original archival arrangement is critical to understanding both the record and its significance. Such context is important both for understanding the materials and for

118 In the context of digital libraries, Lucie C. Burgess discusses provenance as key information for a multiplicity of purposes for digital objects but also for reuse and reproducibility. Lucie C. Burgess, "Provenance in Digital Libraries: Source, Context, Value, and Trust," in *Building Trust in Information: Perspectives on the Frontiers of Provenance*, ed. Victoria L. Lemieux (Cham: Springer International Publishing, 2016), 81–91.

119 Anthea Seles, "Artificial Intelligence and Archives, June 9, 2020," Session 1 of Emerging Technologies, Big Data and Archives Webinar Series, YouTube video, posted by Council on Library and Information Resources, June 10, 2020, https://youtu.be/noxwKS-cPh0.

knowing how to formulate queries in the first place.[120] In a future phase of the project, we will consider how to better situate digitized content in network visualizations within its original context (in terms of placement in box-folder hierarchies), while also allowing for deeper explorations of provenance.

The focus group expressed the need for users to have more control over the data and visualizations, so that the presentation of records could be better tailored to the nature of a particular inquiry. The possibility of exploring the materials through a more fluid network speaks to discussions about access in the digital age that eschews hierarchical aggregations in favour of user-driven constructions of materials. In this vein, transforming paper correspondence into digital form opens up the possibility of multiple (re)orderings of the materials. Geoffrey Yeo articulates a vision that, "Instead of preordaining the groupings our users will encounter, we can employ technologies that make it easy to organize materials into multiple collections that reflect users' individual interests."[121] We intend to conduct a more formal assessment in a future phase of the project to evaluate the utility of such interfaces and the ways they can more cohesively be integrated, particularly those that incorporate machine-generated metadata.

Conclusion: Reimagining Archives in a Computational Framework

Cybernetics sought to understand what it could learn from machines as much as it sought to understand how machines learn. Similarly, archivists are seeking to understand what we can learn about archives from machines as much as we seek to understand how machines can "learn" archives. There are fundamental questions here for archivists: What can users learn about archives through AI and machine learning that could not be easily gleaned otherwise? Do new and different stories surface? Do computational methods result in more efficiently, accurately (or even better) described records? Do digital scholarship frameworks provide useful and insightful access to records? Can we create access to trustworthy and reliable output from computational processes? And how feasible are these approaches given the complexities of implementing current technologies in an archival context?

120 Sternfeld, "Archival Theory and Digital Historiography," 556–57.

121 Yeo, "Bringing Things Together," 58.

This pilot project raised more questions than it answered. The classification of materials into intellectual groupings, for example, proved challenging, indicating that a larger training set as well as a method for determining the quality and usefulness of the results would be needed in the future. Indeed, authors may discuss a range of subjects in any one letter, not to mention in a series of correspondence. The exercise raised questions about how neatly correspondence can be grouped into one classification over another and about what is more valuable to represent: an overarching single classification or the varying shades of classifications. Including percentages of certainty is crucial to that end. But the exercise also raised the question of how well these methods shed light on the provenance of scientific activity. The project indicated that connections among materials could be identified and groupings of materials could be made in a preliminary sense. How meaningful these patterns are in broadening our understanding of the larger context of records creation is undoubtedly subjective, but the patterns arguably do illustrate that records are created within a complex set of relationships and bear connections to records beyond their own fonds, which also result from the same contexts.

This is a work in progress, and the tools and models we employ need reconfiguring and refining. Domain-specific models are conceived of as one way to understand specific vocabularies and linguistic features.[122] Using a cybernetic-based vocabulary is a step toward a domain-specific model, but understanding linguistic features, including changes and the evolution of vocabularies, requires training a model that can parse these elements and their overall significance in the exchange of ideas. More importantly, archives-specific models are needed to address the challenges of normalizing documents and understanding the results, bearing in mind the complexity and uniqueness of archives. Specifically, it will be useful to investigate models that can employ partial membership latent Dirichlet allocation (PM-LDA)[123] as part of a topic modelling approach[124] to illustrate how

122 Andrew Janco, "What Natural Language Processing Reveals in a Corpus of 400,000 Russian Diary Entries" (presentation at the University of Illinois Library, February 27, 2020), https://slides.com/andrewjanco/deck-aa9819#/42.

123 Chao Chen, "Partial Membership Latent Dirichlet Allocation" (PhD thesis, University of Missouri, Columbia, MO, 2016), https://github.com/GatorSense/Publications/blob/master/chen2016partial.pdf.

124 See, for example, Simon Hengchen, Mathias Coeckelbergs, Seth Van Hooland, Ruben Verborgh, and Thomas Steiner, "Exploring Archives with Probabilistic Models: Topic Modelling for the Valorisation of Digitised Archives of the European Commission," in 2016 *IEEE International Conference on Big Data* (*Big Data*) (Washington, DC: IEEE, 2017), 3245–49.

words, and also the materials from which they derive, can be simultaneously associated with multiple categories or topics. And exploring this through partial membership models will be crucial to that end,[125] so that these nuances in correspondence can be more fully explored. This will be useful not just for archival materials but especially for correspondence, which can discuss a considerable range of topics.

The methods employed by the CTC team revealed that software libraries and tools could be utilized to a degree in an archival context. However, even with extensive reconfiguring of tools, Tim Hutchinson's observations about the importance of integrating archival knowledge into computational analysis pipelines rings true.[126] Archival records vary greatly in form, length, and content. This is not to say that other texts on which NLP and machine-learning tools are used do not pose their own unique challenges but that not all materials in an archival corpus are created equally. A machine-learning and NLP pipeline must account for a wide array of variants across records and their contents in archives. At the same time, it became clear that it is vital to document the process for generating the data and to find ways to communicate that process to users. While the process is largely documented through a white paper and a readme note, in hindsight, some of the decisions the team made should have been noted in more detail. For example, offering users information about which records were excluded and why would help them better understand any gaps in the output. This is important not only for accountability but also for understanding the results and computational provenance, especially because the process by which they are created is so opaque.[127] Without documentation of process, any archival project employing computational methods risks becoming obscured through a process akin to a black box, from which one can view only the inputs and the outputs and cannot ascertain the trustworthiness of the latter.

Thomas Padilla reasons that "attempts to use algorithmic methods to describe collections must embrace the reality that, like human descriptions of collections,

125 Katherine A. Heller, Sinead Williamson, and Zoubin Ghahramani, "Statistical Models for Partial Membership," in *Proceedings of the 25th International Conference on Machine Learning* (New York: Association for Computing Machinery, 2008), 392–99.

126 Hutchinson, "Natural Language Processing and Machine Learning as Practical Toolsets for Archival Processing," 162.

127 Anthea Seles emphasizes the importance of documenting the process for employing AI, especially because of the "black box" phenomenon. Seles, "Artificial Intelligence and Archives."

machine descriptions come with varying measures of certainty. This should come as no surprise given that algorithms are the product of explicit and latent biases held by humans."[128] Any claims that machine-learning results are objective or neutral risks obscuring even further what is already an opaque process. As with description or classification of any object, "description delineates the world, yes, but in doing so it informs what's seen with ourselves, our ways of seeing."[129] The machine, here, is an extension of the archivist and delineates the archivist's way of seeing the world, not to mention that of the software developers who created the tools. The results of the CTC project in creating this pipeline are inflected with human subjectivity because we ourselves interacted with the records via the algorithms. Devon Mordell sagely cautions against viewing archival data produced through computational processes as objective and neutral.[130] But this is true of *all* archival description, regardless of the methods and tools used. On reflection, the distinction between machine- and human-generated data is somewhat blurry and tenuous, and one must resist the temptation to attribute complete agency and autonomy to the machine. A more honest and transparent approach would be to acknowledge the different methods and tools that created the data by refusing to make arbitrary claims about different (i.e., human and machine) agents responsible for their creation.

Despite these caveats, the project demonstrated the possibility of finding connections between archival records, across different fonds, using the data within the materials themselves as connecting nodes. These data also show promise in being deployed as metadata. While the Cybernetics Thought Collective serves as an example of local adoption of machine-generated metadata, wider conversations are needed across the archival community to discuss interoperability and how to present and share these metadata. These methods also raise the possibility of more efficiently (and authentically?) describing materials. David Bearman argued that "archivists should find, not make, the information in their descriptive systems."[131] Bearman discussed the importance of using metadata derived from native information systems within which records

128 Padilla, *Responsible Operations*, 13.

129 Mark Doty, *Still Life with Oysters and Lemon* (Boston: Beacon Press, 2001), 64.

130 Mordell, "Critical Questions for Archives as (Big) Data," 149.

131 David Bearman, "Archival Methods," Archives and Museum Informatics Technical Report no. 9 (Pittsburgh, Archives and Museum Informatics, 1989), http://www.archimuse.com/publishing/archival_methods/.

are created and used, and he lamented the creation of metadata that may not adequately capture records and their provenance. However, the practice of using data from the records themselves as metadata may run counter to Bearman's premise of describing the records' context of creation rather than their contents. Using extracted data as metadata in an archival and recordkeeping context is not new.[132] And using data from records as metadata, rather than having archivists create that metadata themselves, is in line with the spirit of capturing metadata from the systems in which digital records are created.[133] This approach works as the reverse of a macro approach by using the contents of records to recreate their context in a way that respects the intellectual activities that created the records. The notion that records' contents (and forms) can serve as representations of their contexts has been articulated by archival theorists, though not without speculation on the limitations of doing so.[134] But computational engagements with records may also generate new meanings through the records and even new contextual information.[135] The extent to which machine-generated metadata can adequately describe the records themselves – and, through shared connections between them, also provide new insights into their provenance – is a question raised by this project and one that merits further discussion.

Revealing links between records across fonds builds on discussions of communities *as* provenance – in this case, the community or collective of cyberneticians who articulated and refined their ideas through these records. Archival theorists such as Chris Hurley, Nesmith, Bastian, and Cook,[136] as well as Laura Millar and

132 See, for example, David Walling and María Esteva, "Automating the Extraction of Metadata from Archaeological Data Using iRods Rules," *International Journal of Digital Curation* 6, no. 2 (2011): 253–64; and Kyle R. Rimkus and Christopher J. Prom, "A Research Interface for Digital Records Using the IIIF Protocol" (presentation at the IIIF Conference, Washington, DC, May 24, 2018), http://hdl.handle.net/2142/100056.

133 Hedstrom, "Descriptive Practices for Electronic Records," 58–59.

134 Lemieux, "Toward a 'Third-Order' Archival Interface," 59.

135 Sternfeld, "Archival Theory and Digital Historiography," 552.

136 Chris Hurley, "Parallel Provenance: Part 1 – What, If Anything, Is Archival Description?" *Archives and Manuscripts* 33, no. 1 (2005): 110–45; Chris Hurley, "Parallel Provenance: Part 2 – When Something Is Not Related to Everything Else," *Archives and Manuscripts* 33, no. 2 (2005): 52–91; Nesmith, "Seeing Archives," 24–41; and Tom Nesmith, "The Concept of Societal Provenance and Records of Nineteenth-Century Aboriginal–European Relations in Western Canada: Implications for Archival Theory and Practice," *Archival Science* 6, no. 3–4 (2006): 351–60; Bastian, *Owning Memory*; and Cook, "Fashionable Nonsense or Professional Rebirth," 14–35; and Cook, "The Concept of the Archival Fonds in the Post-Custodial Era," 24–37.

Brien Brothman,[137] have broadened our understanding of provenance to extend beyond a single creator and to recognize the larger context of creation and use. The evolution and broadening of the notion of provenance relates to long-standing questions about the utility of the notion of the fonds.[138] Digital projects add another layer to this discussion about evolving notions of provenance and the fonds and open up questions about how to represent and apply provenance in digital projects.[139] At the same time, the digital world has seemingly rendered the fonds as even more abstract and less bound to hierarchical systems, thus opening up experimental and visually driven possibilities for access.[140] Given the collective nature of scientific work, exploring scientific archives through computational methods and more dynamic interfaces resonates with these expanded ideas about provenance.

These shifts in our understandings of the fonds and provenance favour more fluid and dynamic orderings that reflect the more complex reality of provenance.[141] Different users will undoubtedly have different needs, and being able to order materials in ways that meet a variety of needs will require that we move away from "fixed boundaries and linear ordering."[142] Victoria Lemieux explores this possibility further in the construction of dynamic archival interfaces that represent and visualize records through a systems- or network-based model.[143] Notions about dynamic interfaces speak to the recognition that records are created in complex environments and result from a complex set of relation-

137 Laura Millar, "The Death of the Fonds and the Resurrection of Provenance: Archival Context in Space and Time," *Archivaria* 53 (Spring 2002): 1–15; Brien Brothman, "Orders of Value: Probing the Theoretical Terms of Archival Practice," *Archivaria* 32 (Spring 1991): 78–100.

138 See Peter J. Scott, "The Record Group Concept: A Case for Abandonment," *American Archivist* 29, no. 4 (1966): 493–504.

139 Monks-Leeson, "Archives on the Internet," 45; Douglas, "Origins and Beyond," 44.

140 Jefferson Bailey, "Disrespect des Fonds: Rethinking Arrangement and Description in Born-Digital Archives," *Archive Journal* 3 (2013), https://www.archivejournal.net/essays/disrespect-des-fonds-rethinking-arrangement-and-description-in-born-digital-archives/, cited in Douglas, "Origins and Beyond," 44; Yeo, "Bringing Things Together," 43–91.

141 Victoria Lemieux provides an overview of many of the critiques of hierarchical and reductionist representations of records that do not respect the complexity of provenance. See "Toward a 'Third-Order' Archival Interface," 59–64.

142 Yeo, "Bringing Things Together," 91.

143 Lemieux, "Toward a 'Third-Order' Archival Interface," 53–93.

ships; the ability to visualize and understand these relationships respects the complexity of archival fonds. A select number of repositories and projects have begun reimagining archival access by integrating finding aids with visualizations of data, perhaps as an acknowledgement of this complexity.[144] While these projects focus on human-created metadata, they illustrate what is possible. These examples are valuable for illustrating how to successfully combine new and established ways of providing access. The CTC project's focus group feedback also indicated the importance of not discounting traditional archival access in a network-based framework as well as of enabling new orderings and ways of exploring records and their provenance.

Ada Lovelace tempered the fascination with Charles Babbage's "analytical engine" with the practical insight that "it can do whatever we *know how to order* it to perform."[145] In other words, the machine does what we tell it to do based on what we know how to do. Archives are not just any kinds of texts; archives are diverse and unique in content and form, and they are created and used in a complex array of contexts. Machine-learning and natural-language-processing technologies employed for computational approaches to archives will not learn the particularities of these materials without guidance from archivists. While software libraries and tools can be harnessed and refined in an archival context, this requires significant labour and preparation. The Cybernetics Thought Collective project indicates the need for easily implementable archives-specific models as well as for domain-specific models that can be deployed to analyze thought collectives. As these methods and tools are implemented and used, documenting the computational processes is vital for enabling users to assess and use machine-generated data and metadata, especially since computational methods become part of the history of the records and their provenance. These are necessary considerations if we are to cultivate affordances for digital scholarship and reconceptualize archives in a digital age.

Archival standards and access mechanisms are evolving to meet new research needs for dynamic and flexible interfaces for accessing digitized and born-digital

144 A relevant example is the New York Public Library's Archives and Manuscripts terms explorer tool: http://archives.nypl.org/terms/. A consortial example is the Social Networks and Archival Context (SNAC) project: https://snaccooperative.org/. And, as noted above, the Darwin Correspondence Project's ϵpsilon provides an example for scientific archives.

145 Quoted in James Essinger, *Ada's Algorithm: How Lord Byron's Daughter Ada Lovelace Launched the Digital Age* (Brooklyn, NY: Melville House Publishing, 2014), 172. (emphasis in original)

archives. These possibilities open up new ways of engaging with records. Computational approaches to datafying archives also open up potentially new ways to ascertain the records' contexts and explore the provenance of collaborative science through the records themselves. But to explore these new territories in relation to scientific thought collectives like cybernetics, users must be provided coherent maps that lead them back to the materials' origins, from which new pathways and contexts can be forged.

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