The Cybernetics Thought Collective Project: Using Computational Methods to Reveal Intellectual Context in Archival Material

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Abstract—**This paper discusses "The Cybernetics Thought Collective: A History of Science and Technology Portal Project," a collaborative effort among four institutions that maintain archival records vital to the exploration of cybernetic history—the University of Illinois at Urbana-Champaign, the American Philosophical Society, the British Library, and MIT. With recent grant funding from the NEH, the multi-institutional team is developing a prototype web-portal and analysis-engine to provide access to archival material related to the development of the field of cybernetics, which influenced the development of modern computing and provided a common language to articulate similar questions about behavior across disciplines—regardless of whether the subject of study was animal, machine, or social group. The project is also enabling the digitization of the personal archives of four founders of cybernetics—Heinz von Foerster, W. Ross Ashby, Warren S. McCulloch, and Norbert Wiener. Using computational methods based on advanced machine-learning algorithms to yield network and entity relationships maps from the digitized texts, this project seeks to create access to archival material that enables humanities scholars to better understand the development of cybernetic ideas and to enable scientists and engineers to reuse and access cybernetic data.**

Keywords—digital archives, cybernetics, named entities, natural language processing, machine learning

I. Introduction

Cybernetics emerged during World War II as the science of communication and control systems as applied to automatic antiaircraft systems, but it gradually became a vehicle through which scientists, engineers, humanists, and social scientists studied the complexities of communication and self-organizing systems. Regarded as one of the most influential scientific movements of the 20th century, cybernetics developed at a time when postwar science had become highly compartmentalized. Countering the trend of specialization, cybernetics epitomized the interdisciplinarity that has become emblematic of innovative research in the modern era. Given its broad appeal as a science and philosophy, the interdisciplinary science has been employed by anthropologists, philosophers, mathematicians, computer scientists, artists, and cognitive scientists to explore questions about behavior.

University of Illinois electrical engineer and cybernetician Heinz von Foerster noted, "[c]ybernetics is a whole collection of concepts, supported by whole collections of people." The Josiah Macy Conferences of the 1940s and 1950s, and the establishment of the Biological Computer Laboratory at the University of Illinois at Urbana-Champaign as a pivotal center for cybernetics research, fostered the development of the "thought collective"—the scientific community of individuals exchanging thoughts and ideas—that composed cybernetics.

In an effort to shed light on the people and concepts that constituted cybernetics, this ongoing project seeks to provide basic access to a select portion of digitized cybernetics archival materials and to assess the potential of advanced machine learning methods to enhance their access and use. Between May 2017 and April 2018, specific work being undertaken includes (1) selective digitization of archival material; (2) creation and remediation of metadata about these materials; (3) preservation and basic access through established systems; and (4) initial testing and assessment of annotation, entity extraction, and network analysis tools in a prototype "thought collective" platform that exposes social research networks of communication, thought, and idea exchange. Our ultimate goal is to enable users to explore the cybernetics movement in ways that would be impossible with traditional systems, via new interfaces that use machine learning techniques to reveal previously hidden relationships between people, topics, and locations. Ultimately, we believe these approaches can enhance access not only to cybernetics materials, but any large corpus of unstructured textual documents.

II. THE CYBERNETICS THOUGHT COLLECTIVE

Between 1946 and 1953, the Josiah Macy Jr. Foundation hosted ten conferences—all but one in New York City—bringing together a diverse group of scholars representing fields from mathematics to the physical, life, social, and information sciences. Known as the Macy Conferences on "Circular Causal and Feedback Mechanisms in Biological and Social Systems," the meetings initially sought to bridge disciplinary divides by using applied science to synthesize ideas and knowledge around questions about behavior and information-feedback, for both organisms and machines. After MIT mathematician Norbert Wiener published *Cybernetics* in 1948, conference participants adopted the term "cybernetics" as the umbrella under which their interconnected and interdisciplinary web of ideas gained meaning. Cybernetics has been defined in many ways: as the science of communication and control, or "steersmanship," in organisms and machines [1]; as the study of form and pattern [2]; or, quite simply, as the study of behavior—"[cybernetics] treats, not things but ways of behaving. It does not ask 'what is this thing?' but 'what does it do?'" [3]. Cybernetics thus provided participants with a common language to articulate and discuss similar questions about behavior, or ways of behaving, across disciplines, regardless of whether the subject of study was animal, machine, or social phenomena.

Macy Conference participants included Margaret Mead and Gregory Bateson (anthropology), Warren S. McCulloch (neurophysiology), Heinz von Foerster (physics and electrical engineering), Norbert Wiener (mathematics), W. Ross Ashby (psychiatry), John von Neumann (computer science), Claude Shannon (mathematics and electrical engineering), G. Evelyn Hutchinson (ecology), and Arturo Rosenblueth (physiology), and many others. While these scholars met together at the conferences on only a few occasions, they used a variety of other means to create a *Denkkollektiv*—or a scientific "thought collective"—around cybernetics. As defined by scientist Ludwik Fleck in his influential publication *Genesis and Development of a Scientific Fact*, a thought collective is a "community of persons mutually exchanging ideas or maintaining intellectual interaction" [4]. The cybernetics thought collective subsisted during the three decades that followed the Macy Conferences.

The U.S. contingent of the cybernetics thought collective was based primarily at two interdisciplinary research centers: the Biological Computer Laboratory at the University of Illinois at Urbana-Champaign and the MIT Research Laboratory of Electronics. The thought collective survived not only in these institutional homes, but also in published writings, and in the papers, records, and private correspondence on which this project focuses.

In many ways cybernetics began in New York City, but as the new science evolved and spread across the United States, Europe and South America, it was adopted by new practitioners. The Macy Conference participants also established research centers dedicated to its study. As a result, the archival material of the individuals who were part of this research network is geographically dispersed. This one-year pilot project intends to begin uniting some of these materials to facilitate the study of the history of cybernetics and the thought collective it created. Led by the University of Illinois Archives in collaboration with the American Philosophical Society, British Library, and MIT Institute Archives & Special Collections, this collaborative project is digitizing select archival material that documents the cybernetics thought collective and developing a plan to make discoverable the connections and relationships between topics in this material. The project is initially uniting the papers of Heinz von Foerster (University of Illinois Archives), Warren S. McCulloch (American Philosophical Society), W. Ross Ashby (British Library), and Norbert Wiener (MIT Institute Archives & Special Collections)—four founders of cybernetics, whose mutual influences were profound and whose lives intersected in many ways. Each institution is surveying and digitizing selected resources and exploring methods and tools that not only link material in an open access/open source portal, but also enable users to discover relationships between these four "nodes." The portal will utilize a network analysis framework that highlights relationships among concepts and people, enabling users to visualize patterns that characterized the cybernetics thought collective and understand its context.

III. PROJECT RATIONALE AND METHODOLOGY

A. *Applying Computational Methods to Archives*

Recent initiatives from archival and digital humanities communities have explored ways in which computational methods can be utilized to make discoverable latent connections in archival corpora. Such emphases on computationally driven archival research require community-driven methods, technologies, and infrastructure to provide access to archival corpora and enable reuse of data. Emergent standards reflect these needs and their attendant ethical and practical considerations.[1] One of the motivations for making archival corpora computationally amenable to scholarly analysis and reuse is to reveal genealogies of idea-exchange and context [5],[2] and understand how communities of scholars (i.e., the "thought collective") generate and interrogate ideas. Extracting contextual information—namely through entities such as concepts, persons, and places—facilitates analysis of large quantities of data from a particular corpus of digital archival material, especially one composed of multiple *fonds*.[3]

Computational methods that utilize natural language processing (NLP) and named entity recognition (NER) technologies have been adopted in several archival and digital humanities projects seeking to reveal contextual information in digital archival material to facilitate either archival appraisal and/or scholarly analysis and reuse. A few recent examples of archival projects include the BitCurator NLP project [6], which seeks to apply NLP and NER to born-digital materials through the BitCurator platform; the ePADD

[1] See "Always Already Computational – Collections as Data," https://collectionsasdata.github.io/.

[2] See, for example, "Mapping the Republic of Letters, http://republicofletters.stanford.edu/ and "Epsilon: building a collaborative digital framework for c19 letters of science," https://www.darwinproject.ac.uk/Epsilon.

[3] "Fonds," Glossary of Archival and Records Terminology, Society of American Archivists, https://www2.archivists.org/glossary/terms/f/fonds.

software, which uses NLP and NER to facilitate appraisal and processing of and access to email records [7]; and the Carnegie Mellon University Archives, which is using NLP to extract metadata from its digital collections [8]. Several digital humanities projects have likewise used NLP and machine learning tools in platforms and tools to semantically parse and enhance access to archival material [9], such as ArchExtract[4] and WordSeer.[5]

B. *Project Approach*

The Cybernetics Thought Collective (CTC) team is applying NLP and NER in addition to neural network (NN) technologies to digitized material from the personal archives of von Foerster, McCulloch, and Wiener, and the scientific journals of Ashby. Exploring the use of automated annotation, entity extraction (i.e., extraction of concepts, names, etc.) and network modeling techniques that utilize advanced machine-learning algorithms to yield network and entity relationships maps, the project builds on the work of the Cognitive Computation Group within the University of Illinois Department of Computer Science. The project's advisory board includes Stephen Wolfram, CEO of Wolfram Research, who has donated technology resources to the project, including machine-learning tools.[6] Work is thus focusing on testing Wolfram Language tools to yield network relationship maps/entity relationships for the cybernetics correspondence and journals. It is hoped that tests of the two approaches will lead to the development of an open access/open source discovery platform.

In collaboration with the Library's digital preservation service and repository development group, the CTC team is directing the work of two computer science students to test software and explore the following for the portal's functionality:

- Use of machine learning software to automatically annotate, index, and display relationships between documents, concepts, people, location and other entities
- Capacity for archival staff to add collections and documents through web interface
    - Automatic application of named entity recognition and natural language processing algorithms on upload
    - Regeneration of named entity, topic maps, and other indices in user interface
- End user interface developed as open-source software
    - Browsable interface that provides users ways to navigate through network relationship maps or entity relationships, and other relationships
    - Ability for end users to suggest new classifications, topics, or narratives, that the natural language processing engine would use to generate new topical or entity maps
- Support for analytical and visualization tools
- Support for finding relationships between digital objects
- Responsive, adaptive, and accessible web design
- Read-only REST based API to share core metadata in JSONP format using DPLA Metadata Profile[7]

As digitization occurs over the duration of the project (May-November 2017), a small sample of material with known connections was prepared for initial testing, and additional materials will be added as they are digitized by participating institutions.

C. *Cybernetic Entities*

Before testing software, the CTC team needed to define the conceptual entities of the cybernetics corpus—what are "cybernetic concepts" and how will we recognize them? Entities such as people and locations are fairly easy to recognize, but an important goal of the project is to ultimately extract cybernetic ideas from the texts, and understand the genesis and evolution of these ideas over time. We decided to use the anthology *Cybernetics of Cybernetics: Or, the Control of Control and the Communication of Communication* (1974) compiled by Heinz von Foerster et al., as an initial source for cybernetic concepts. *Cybernetics of Cybernetics* contains discussions of fundamental ideas in cybernetics and particularly the work of Ashby, McCulloch, von Foerster, and Wiener.

The team uploaded *Cybernetics of Cybernetics* to Voyant Tools to generate the initial list based on word frequencies.[8] The text yielded a list of terms that could be ordered by broad philosophical and scientific categories (e.g., autonomy, memory, system); more specifically cybernetic categories (e.g., autopoiesis, eigenvalue, feedback); technical, sensorimotor, and concrete categories (e.g., brain, machine, nerve); and proper names (e.g., Biological Computer Laboratory, McCulloch, and Turing). The list of cybernetic concepts was also shared with the CTC Advisory Board members for review before being finalized.

D. *Supervised vs. Unsupervised Machine Learning*

Two student programmers were hired in the summer of 2017 to begin testing software on a small sample of already digitized content from the four institutions. The CTC team discussed whether to employ a supervised or an unsupervised approach to machine learning (or a combination of the two). A supervised learning approach would entail classifying a set of documents to prepare a training set for the machine-learning algorithm (either manually or with the help of tools via generated word statistics).

- Manual method: If some digitized correspondence chiefly relates to specific cybernetic concepts—e.g., "recursion" or "autopoiesis"—a sample of those documents would be tagged with these concepts, and then have the machine learning algorithm assess the rest of the texts in the corpus and classify them based on the vocabulary we've provided (based on the prepared list of

[4] https://github.com/j9recurses/archextract.
[5] http://wordseer.berkeley.edu/.
[6] http://reference.wolfram.com/language/#MachineLearning.
[7] https://dp.la/info/developers/map/.
[8] See https://voyant-tools.org/?corpus=ac8dba063f032caa44260e32c1e71ba6.

- cybernetic concepts). A few drawbacks to this approach are that it is very labor-intensive and subjective (we are projecting our own perceptions of relevance on the documents). We felt it would be important for the texts to “tell” us what they are about via assistance from the NLP and NER tools.
- Tool-assisted method: This method entails generating word statistics from the documents, revealing which words are most prominent (and occur in context together). We would then tag a sample of documents with the cybernetic concepts extracted from the texts themselves to classify the rest of the documents. A benefit of this approach is that it is less manual and labor-intensive, and we aren’t imposing (as much) of our own subjectivity on classifying the documents—we are letting the documents tell us what they are about.

An unsupervised approach to machine learning would entail working solely with neural nets. We would give a neural net the corpus and then it will generate connections that it finds. We could use the features of each text (a combination of words used, for example) and ask the algorithm to create a cluster, which has an underlying similarity to other entities in that cluster. However, this approach could be messy and the results are unknown. The CTC team leaned toward a blend of both supervised and unsupervised approaches—tagging a training set of the documents with concepts revealed from the word statistics tool, and then using a neural net to identify and classify the rest of the texts in the corpus.

E. Testing and Implementation

The programmers first tested the U of I Cognitive Computation Group’s NLP Pipeline software in order to extract feature data about the data points;[9] the idea was to extract feature data that contain entities of words in common with those on the prepared list of cybernetic concepts, or in which cases those concepts from the list appear the most frequently. The NLP Pipeline is a package that bundles various software components required to run specific NLP applications and tools. We then would use machine learning to look at the category of the entry and then look at its features, and be able to predict which categories future data from the corpus material will be associated with. The results of this testing yielded a great deal of data on word frequency and counts, but much of the data would need to be cleaned and refined to eliminate prepositions and pronouns, and other words that are not obviously significant to or as cybernetic concepts or ideas.

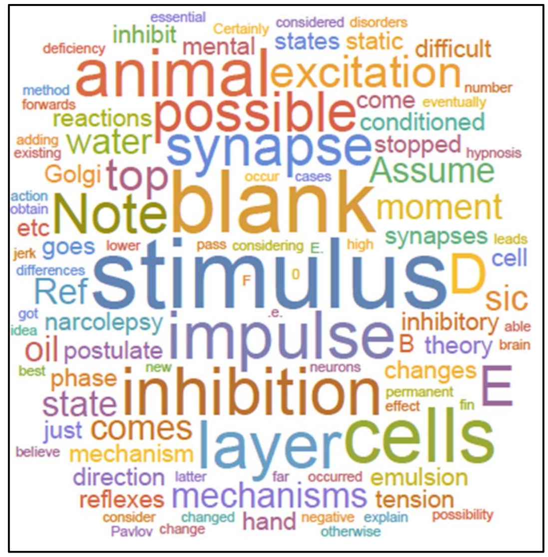

Figure 1: Word cloud of extracted conceptual terms from the W. Ross Ashby journals

In parallel, the programmers tested Wolfram Text Analysis tools,[10] including “WordCounts” and “TextWords” functions, in addition to others, to facilitate text recognition, NLP, and semantic analysis. These tools were initially tested on an eight-page excerpt of an Ashby journal. The data from the journal was processed in the following steps: 1) remove indicators (such as page numbers) and pronouns, prepositions, and other stop words; 2) extract list of words from string; 3) create a visualization of the words, through a word cloud, for example (Fig.1); 4) list most common words in text; 5) create 3-grams that show which words/concepts appear the most in proximity (Fig. 2); and 6) import 3-gram data into a “FeatureSpacePlot” to illustrate relationships between concepts (Fig. 3).

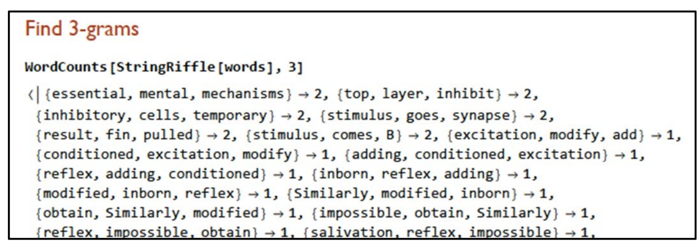

Figure 2: Example of 3-grams created of terms that occur most frequently in proximity

FeatureSpacePlot is a visualization tool that “takes collections of objects and tries to find what it considers the ‘best’ distinguishing features of them, then uses the values of these to position objects in a plot” [10]. The plot arranges the 3-grams in such a way that other 3-gram objects which have similar features are in close association. The CTC team is exploring this interface as one possible visualization of the data.

[9] https://github.com/CogComp/cogcomp-nlp/tree/master/pipeline.

[10] http://reference.wolfram.com/language/guide/TextAnalysis.html.

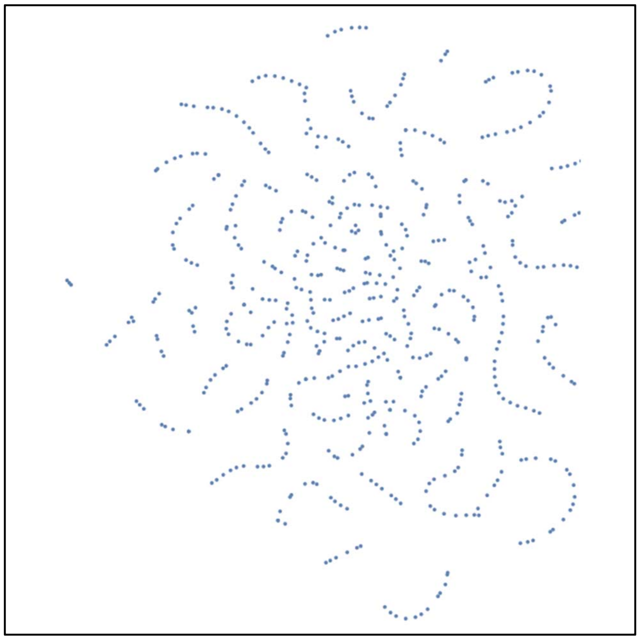

Figure 3: FeatureSpacePlot generated from Ashby text. This interactive visualization is one possible means by which we can show relationships between cybernetic concepts—each data point represents a 3-gram of a cybernetic concept. The plot arranges data points together which are the most similar

Once we've extracted and processed data from the corpus, the next step will be to utilize machine learning and convolutional neural networks to build relationship graphs, in a project-specific schema, following the draft Records in Context conceptual model, to the extent practical [11]. By testing these methods, we hope to discover ways in which the software can be used to automate metadata creation, lay bare previously hidden relationships, and generate highly interactive user interfaces that allow users to suggest and develop new topical or entity maps.

F. *Future Work*

We hope to develop a prototype toward the end of the project, but do not intend this to be a publicly accessible site until a later phase of the project. Given the outcomes of the assessment process for the prototype portal, we will also explore steps that might be taken to integrate the thought collective prototype site as an extension of the University of Illinois Library's Digital Library [12].[11] As proposed, this would comprise three main components: digitized and OCRed content in PDF format; searchable interface developed as open-source software; and browsable interface that provides users ways to navigate through network and entity relationships (such as connections over geographic space, topics, people, or organizations). The ultimate goal of this testing is to develop interfaces and a portal that allow researchers to identify additional connections in the cybernetics thought collective (the "research network"), and testing the software from the Cognitive Computation Group and Wolfram will allow us to begin developing tools that can provide these features for other collections of unstructured text. Future work will also include assessing research on unsupervised learning methods that generate cybernetic ontologies from unstructured or semi-structured texts [13].

IV. Conclusion

This paper describes the preliminary progress of the Cybernetics Thought Collective project. The portal, which will utilize a network analysis framework that highlights relationships among concepts and people, will enable users to visualize patterns that characterized the cybernetics thought collective. We envision this as a long-term project, eventually digitizing the personal archives of Ashby, McCulloch, von Foerster, and Wiener in entirety (as appropriate) and incorporating texts from other institutions holding cybernetic material. We hope to expand the portal into a comprehensive resource that reveals a highly nuanced picture of the cybernetics thought collective, an "inter-discipline" that influenced the development of scientific disciplines such as artificial intelligence, computing, and anthropology. In addition, later phases of the project would more fully develop the software we plan to test during this pilot phase.

Cybernetics, with its inter/transdisciplinary appeal, continues to beckon scholars from many fields. Documenting the evolution of cybernetics ideas, collaborations, and networks of communication is of interest to a wide array of humanists and social scientists, including historians of science and technology, sociologists, literary critics, as well as anthropologists, biologists, and philosophers for whom the study of cybernetics is central to their research agendas.

Despite the uniqueness and significance of the personal archives of Ashby, McCulloch, von Foerster, and Wiener, they have been largely inaccessible to scholars who are unable to travel to the United State or Europe for research. Digitizing and making accessible these geographically dispersed archives in a centralized portal will enable scholars to access the archives of cybernetics in one space as well as reconstruct and explore different aspects of that network. Recreating the cybernetics thought collective through the material substrates of its scholarly activities—i.e., archival material—and enabling users to explore connections between correspondents, ideas, and places latent in the materials, will enhance the research value of these personal archives and records. This pilot project is helping us begin revealing and enhancing access to the larger context of the cybernetics phenomenon and the actors at its center.

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[11] https://digital.library.illinois.edu/.

paper also appear on the project website: https://archives.library.illinois.edu/thought-collective/.

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