# Analyzing Research and Development Trends Using Administrative Data

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John Jankowski, Audrey Kindlon (National Center for Science and Engineering Statistics)

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September 21, 2020

# SDAD & NCSES Partnership

- Social and Decision Analytics Division (SDAD)
  - leading research group in the Biocomplexity Institute and Initiative at the University of Virginia.
  - research has a history of measuring the social condition and economic innovation from multiple perspectives – societal, economic and statistical - with the goal of understanding the bias-precision tradeoffs using new and diverse data sources
- National Center for Science and Engineering Statistics (NCSES)
  - NSF's statistical agency
  - pursuing opportunities to assess the feasibility and ability to use non-survey data flows to supplement or enhance its current efforts in collecting Science, Technology, and Innovation (STI) indicators.

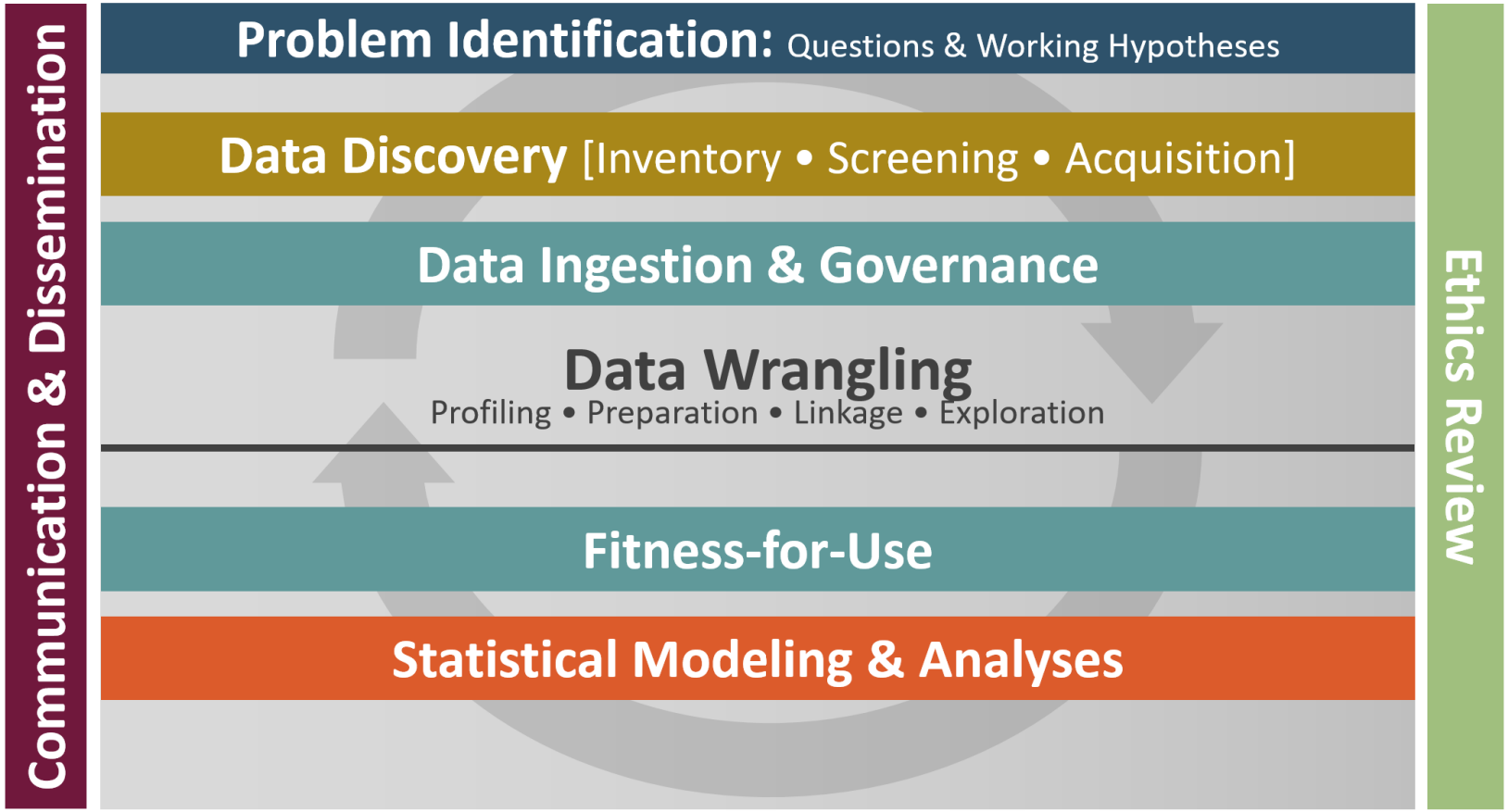
# SDAD & NCSES Partnership

We have been collaborating with NCSES since 2016 to explore the feasibility of identifying and collecting data that naturally exists and are emerging for other reasons and repurposing those data to measure innovation and related concepts.

# Project Aims

- Examine the use of administrative records to supplement or enhance data collected by NCSES.
- Use **Natural Language Processing (NLP)** and **machine learning techniques** to extract relevant Research and Development (R&D) topics from administrative records to supplement methods based on data collected in the NCSES Federal Funds Survey and Federal Support Survey.

# Approach – UVA SDAD Data Science Framework




Keller, S. A., Shipp, S. S., Schroeder, A. D., & Korkmaz, G. (2020). Doing Data Science: A Framework and Case Study. *Harvard Data Science Review*, *2*(1). https://hdsr.mitpress.mit.edu/pub/hnptx6lq/release/7

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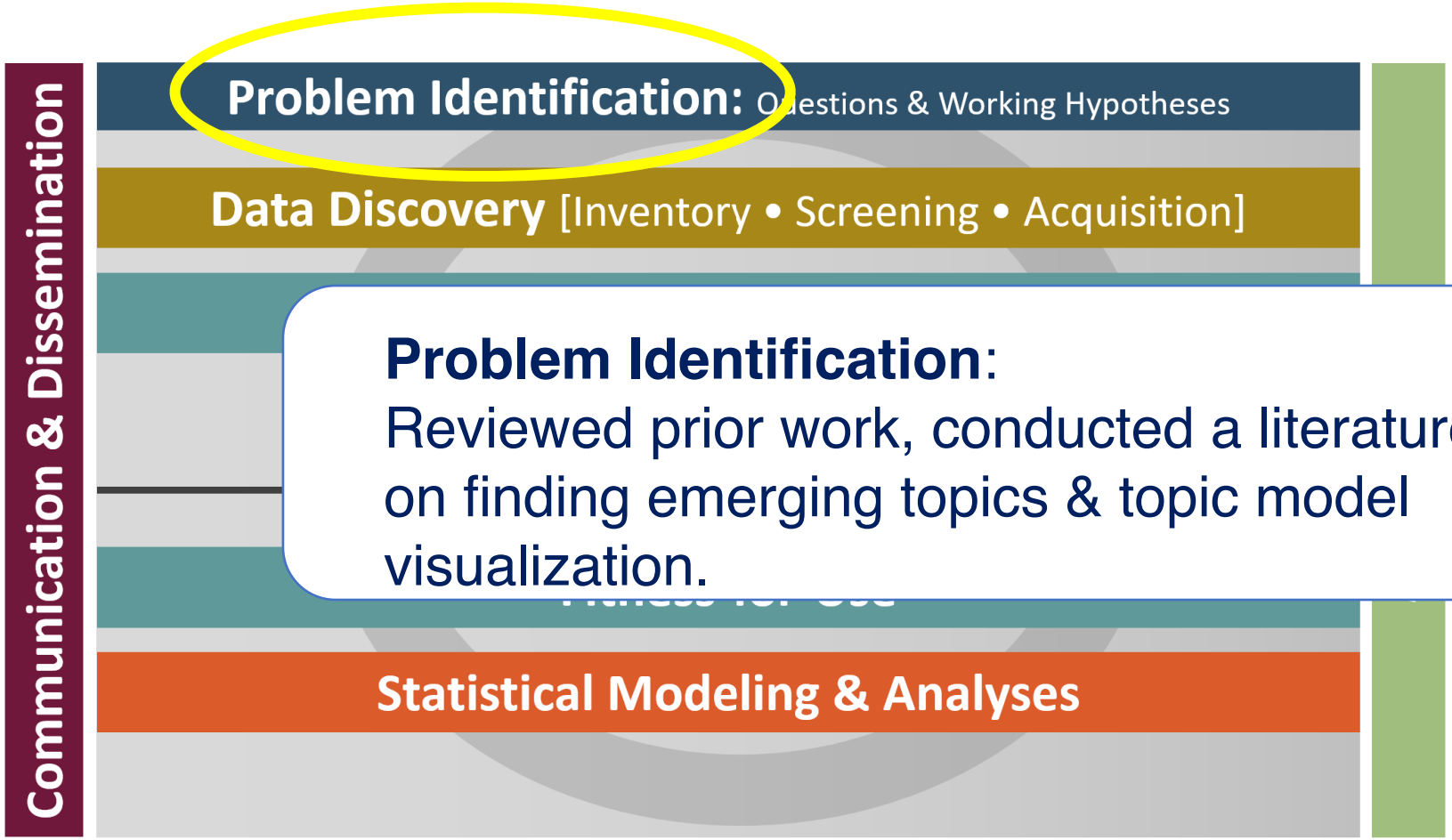


**Problem Identification**:
Reviewed prior work, conducted a literature review on finding emerging topics & topic model visualization.

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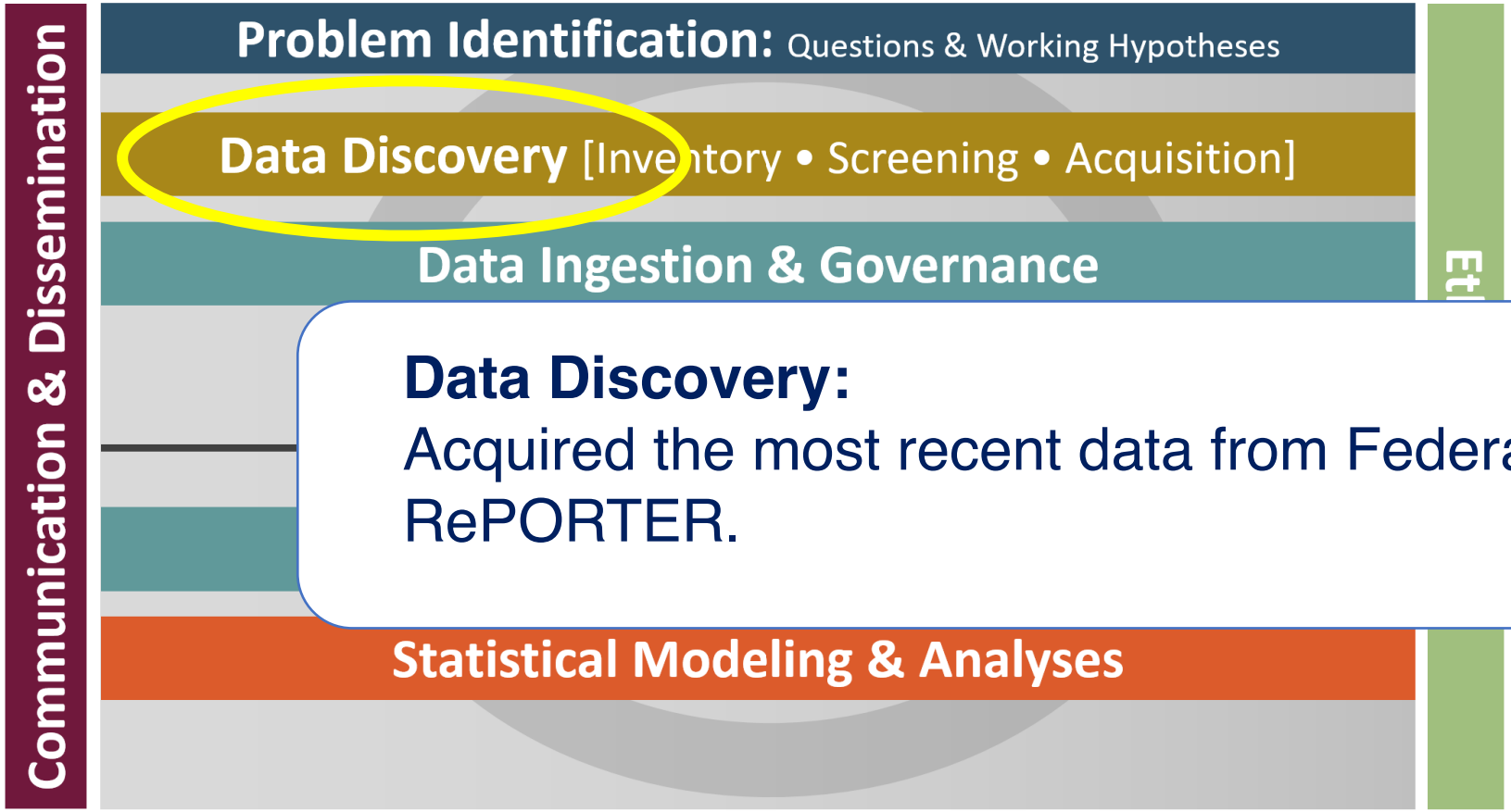


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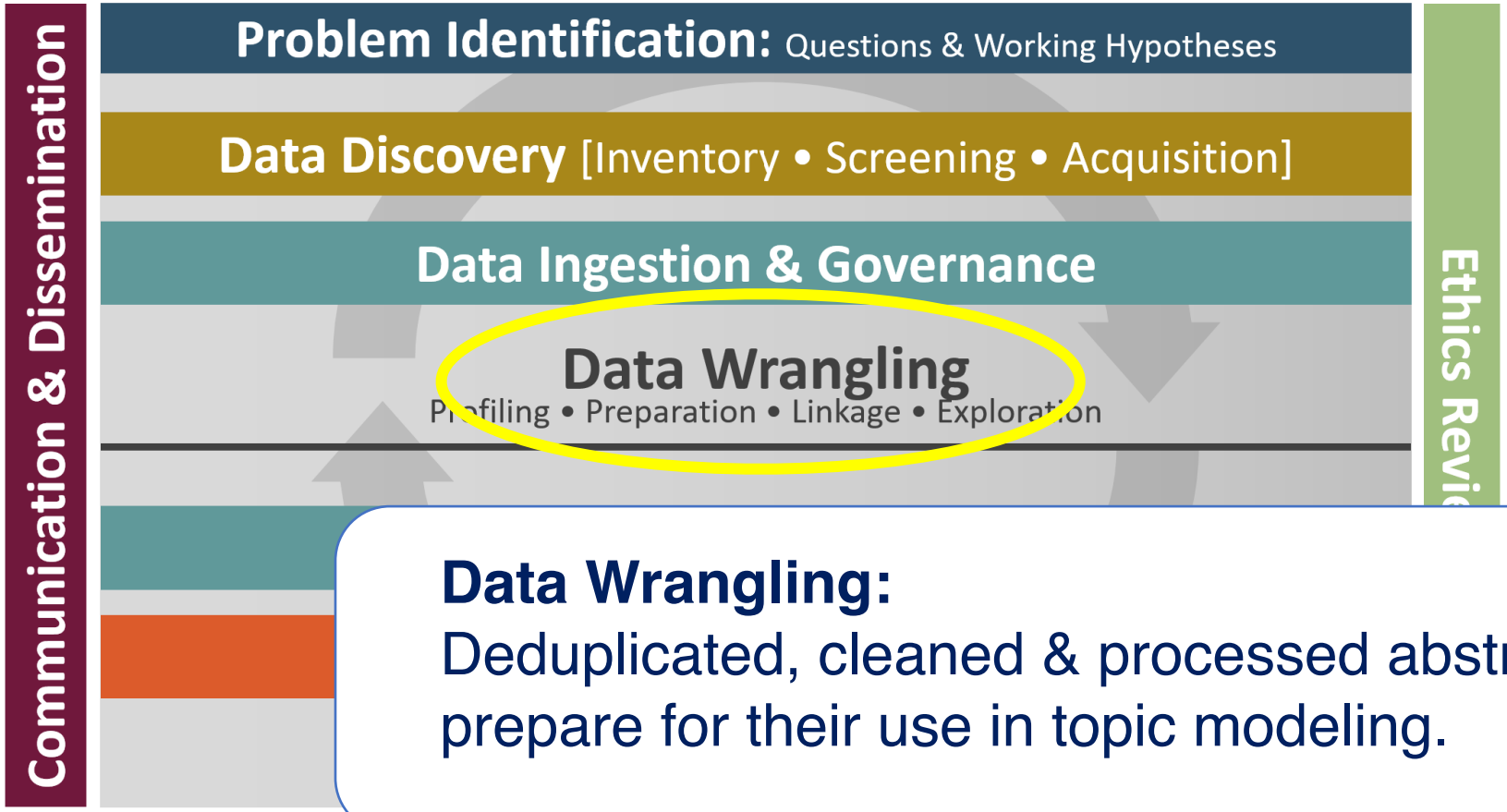


**Data Wrangling:**
Deduplicated, cleaned & processed abstracts to prepare for their use in topic modeling.

Keller, S. A., Shipp, S. S., Schroeder, A. D., & Korkmaz, G. (2020). Doing Data Science: A Framework and Case Study. *Harvard Data Science Review*, *2*(1). https://hdsr.mitpress.mit.edu/pub/hnptx6lq/release/7

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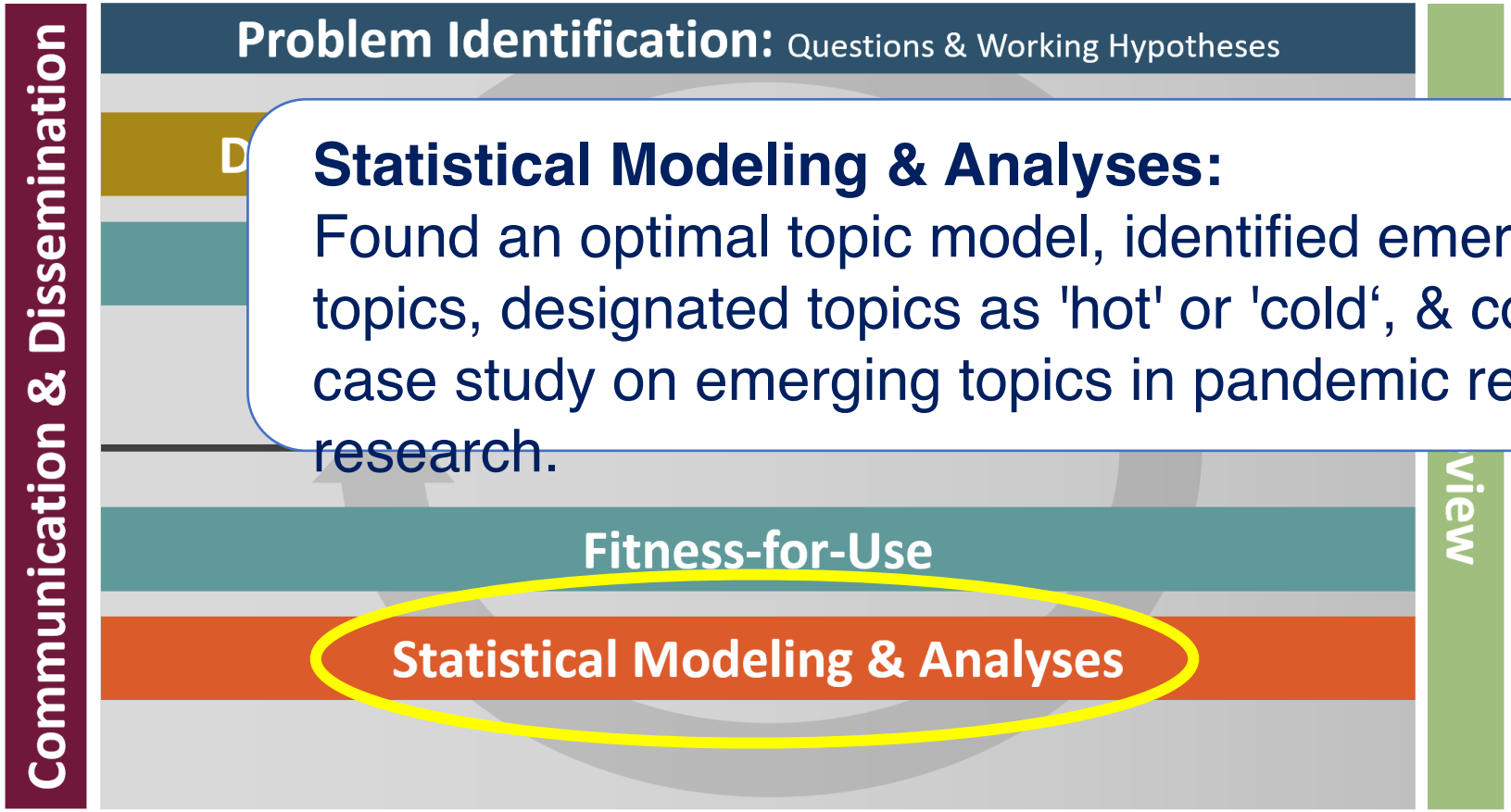


**Statistical Modeling & Analyses:**
Found an optimal topic model, identified emerging topics, designated topics as 'hot' or 'cold', & conducted a case study on emerging topics in pandemic related research.

Keller, S. A., Shipp, S. S., Schroeder, A. D., & Korkmaz, G. (2020). Doing Data Science: A Framework and Case Study. *Harvard Data Science Review*, *2*(1). https://hdsr.mitpress.mit.edu/pub/hnptx6lq/release/7

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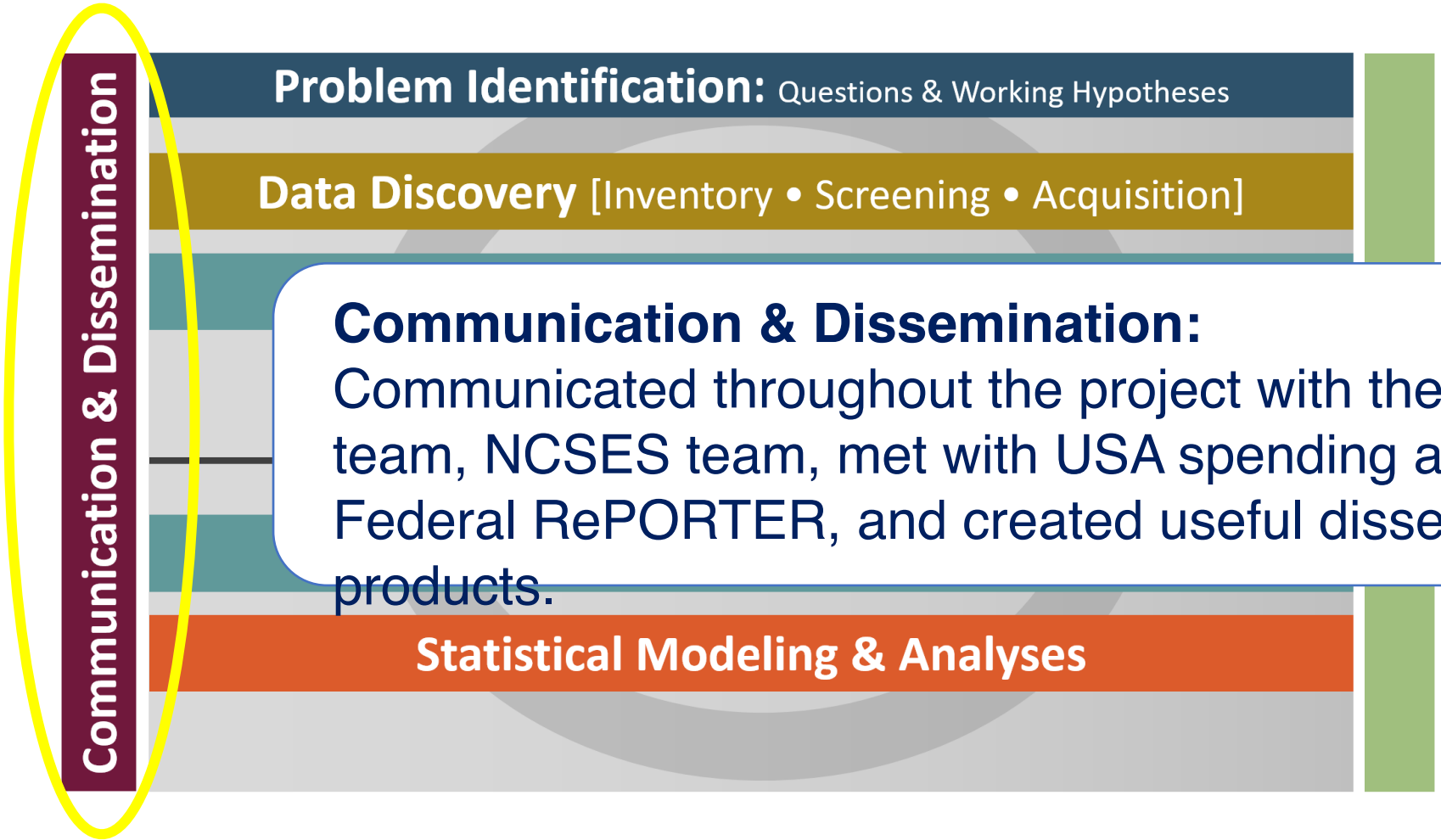


**Communication & Dissemination:**
Communicated throughout the project with the SDAD team, NCSES team, met with USA spending and Federal RePORTER, and created useful dissemination products.

Keller, S. A., Shipp, S. S., Schroeder, A. D., & Korkmaz, G. (2020). Doing Data Science: A Framework and Case Study. *Harvard Data Science Review*, *2*(1). https://hdsr.mitpress.mit.edu/pub/hnptx6lq/release/7

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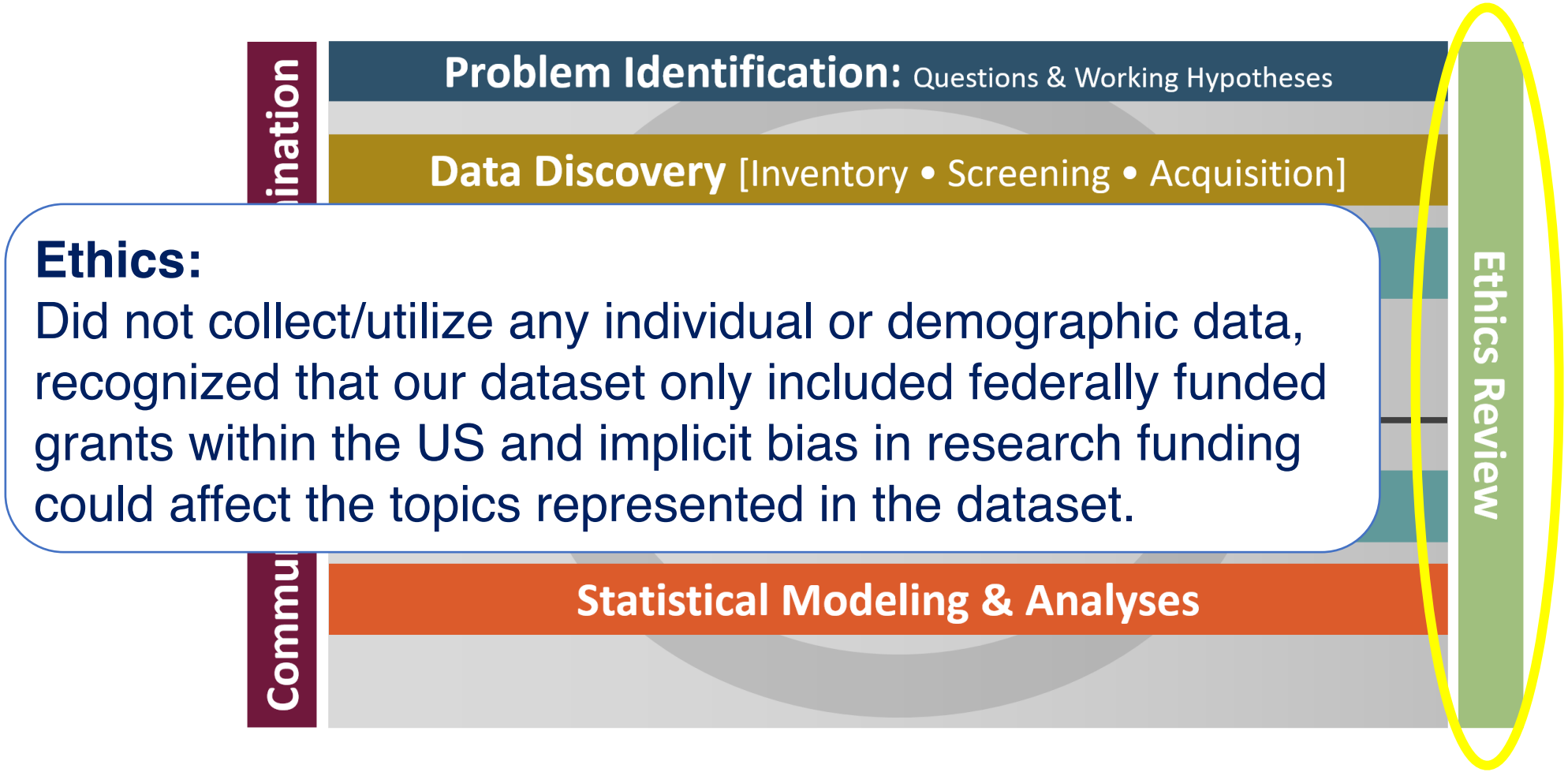


**Ethics:**
Did not collect/utilize any individual or demographic data, recognized that our dataset only included federally funded grants within the US and implicit bias in research funding could affect the topics represented in the dataset.

Keller, S. A., Shipp, S. S., Schroeder, A. D., & Korkmaz, G. (2020). Doing Data Science: A Framework and Case Study. *Harvard Data Science Review*, *2*(1). https://hdsr.mitpress.mit.edu/pub/hnptx6lq/release/7

# Data Source


- 2008-2019
- Over 1 million grants from multiple agencies, i.e., DOD, ED, EPA, HHS, NASA, NSF, USDA, VA
- Includes grant abstracts and metadata

# Topic Modeling

- Unsupervised machine learning technique for grouping text data into themes
- A topic is a list of words clustered together by the algorithm that should share semantic relationships
  - Example topics:

| | | |
|---|---|---|
| aging | management | imaging |
| age | soil | image |
| older | crop | mri |
| adult | production | resolution |
| related | agricultural | optical |
| decline | practice | mr |
| life | pest | pet |
| aged | farm | contrast |
| lifespan | economic | microscopy |
| cognitive | farmer | probe |

# Data Preparation for Emerging Topics

- We needed to:
  - fill in missing information for project start date
  - decide on a deduplication strategy for dealing with duplicate abstracts in the corpus, and
  - clean and prepare the abstracts for use in topic modeling.

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| Raw Abstract | Project Start Date | Budget Start Date | FY entered into Federal RePORTER |
|---|---|---|---|
| Waldmann co-discovered the cytokine IL-15 and ... | NaN | NaN | 2016 |
| PROJECT SUMMARY (See instructions): Protocol S... | NaN | 12/1/2015 | 2016 |
| PROJECT SUMMARY (See instructions): The objec... | NaN | 6/1/2016 | 2016 |

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- We needed to:
  - fill in missing information for project start date
  - decide on a deduplication strategy for dealing with duplicate abstracts in the corpus, and
  - **clean and prepare the abstracts for use in topic modeling**. [1]

objective ~~research~~ ~~understand~~ biophysical basis thermodynamics kinetics multivalency multivalency concerned biologically important interactions multiple receptors multiple ligands interact simultaneously focus work explore synthesis properties groups join monovalent ligands linkers synthesis multivalent ligands

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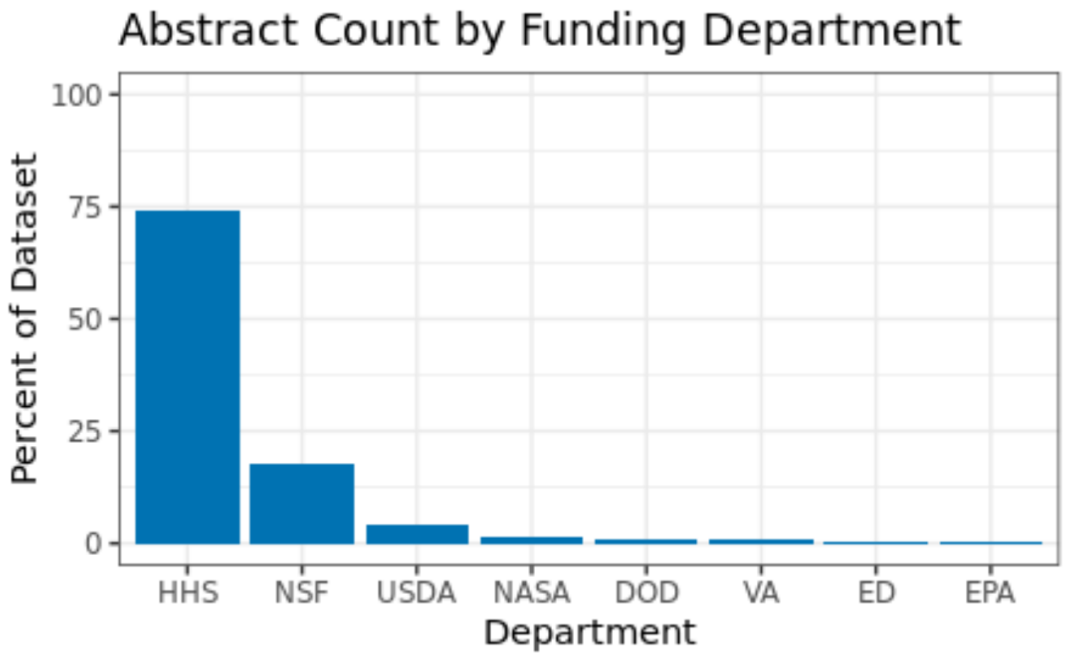
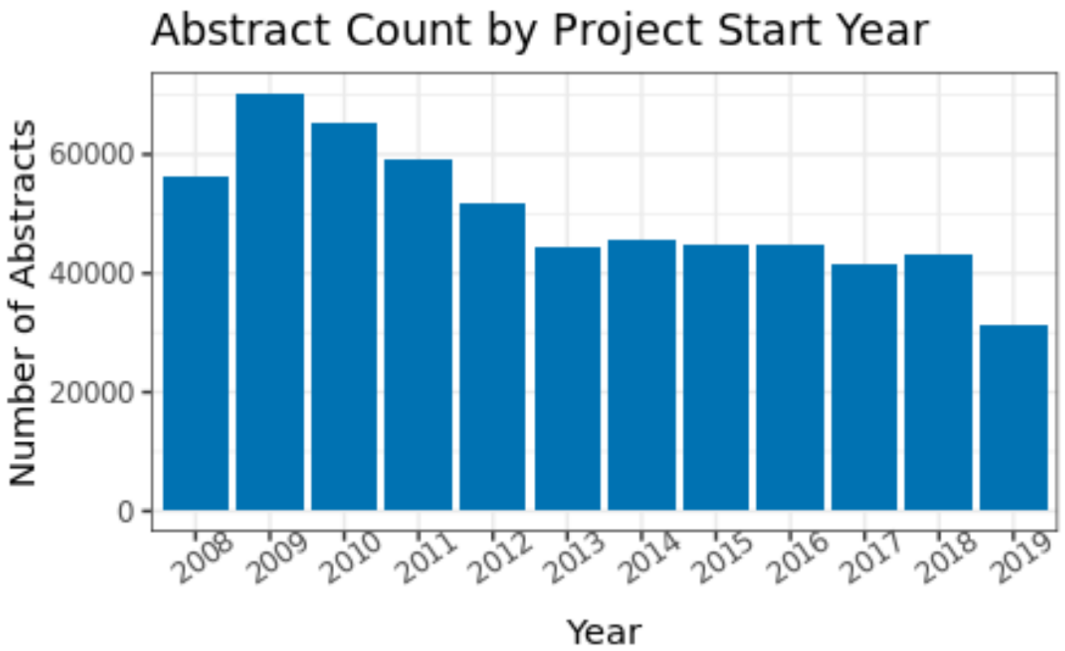
objective biophysical basis thermodynamics kinetics multivalency multivalency concerned biologically important interactions multiple receptors multiple ligands interact simultaneously focus work explore synthesis properties groups join monovalent ligands linkers synthesis multivalent ligands

| | basis | behavior | biologically | brain | … | multivalency | … |
|---|---|---|---|---|---|---|---|
| **Doc 1** | 1 | 0 | 1 | 0 | | 2 | |
| … | | | | | | | |

# Dataset after Deduplication

- 690,814 abstracts for unique projects




Data Source: Federal RePORTER, 2008-2019,
University of Virginia, Social and Decision Analytics Division computations

# Dataset after Deduplication

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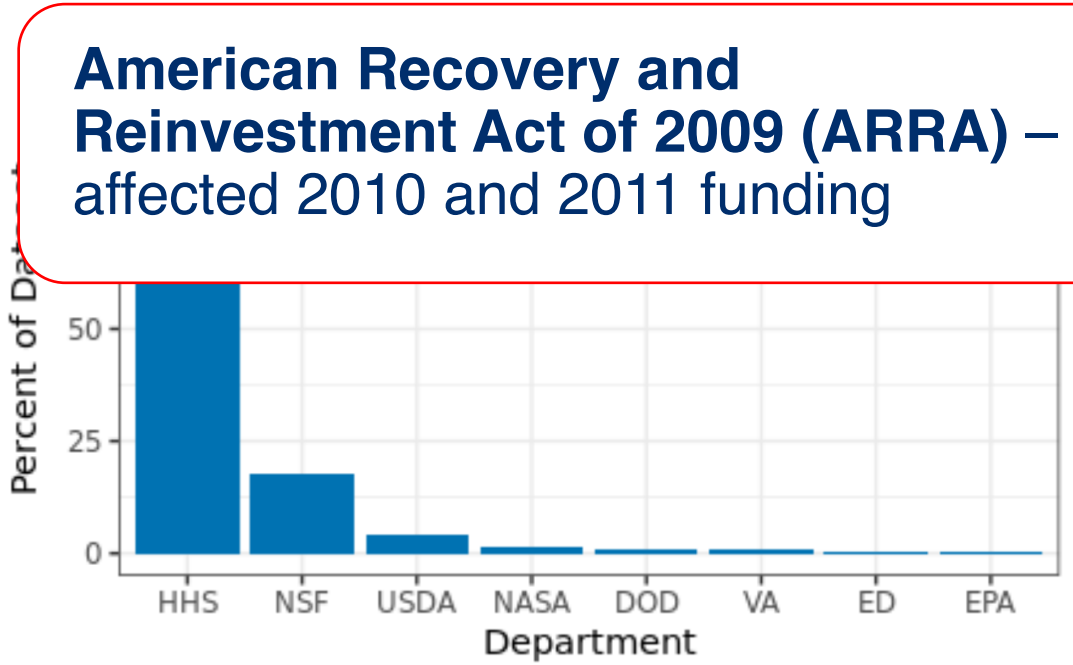
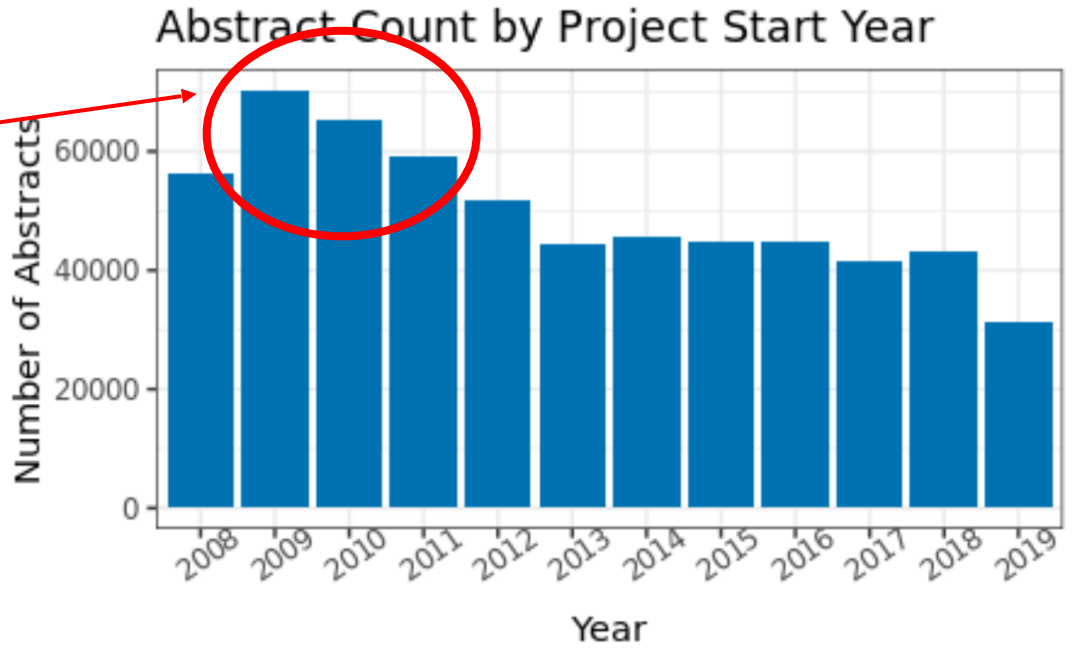
**American Recovery and Reinvestment Act of 2009 (ARRA)** – affected 2010 and 2011 funding

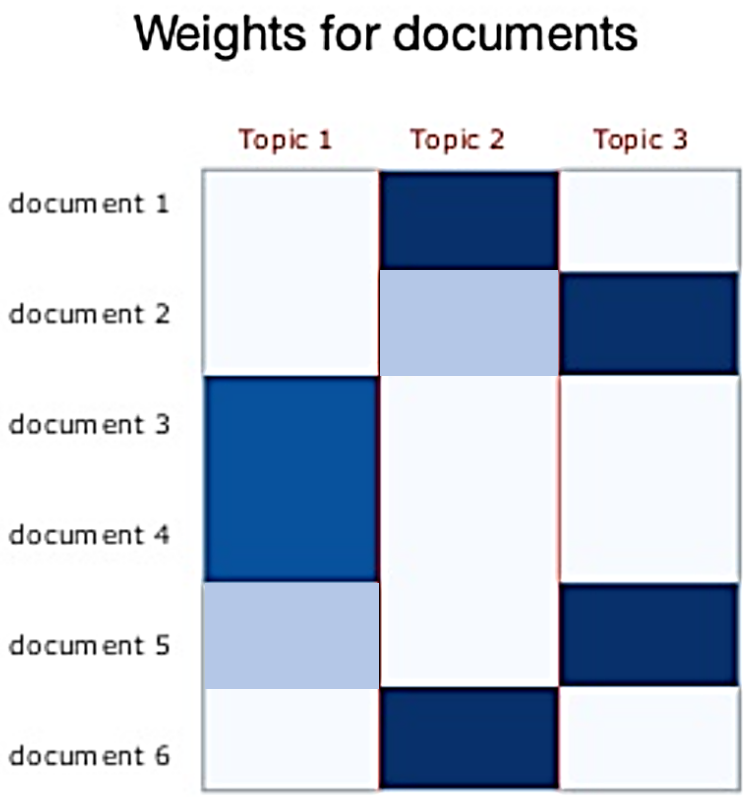


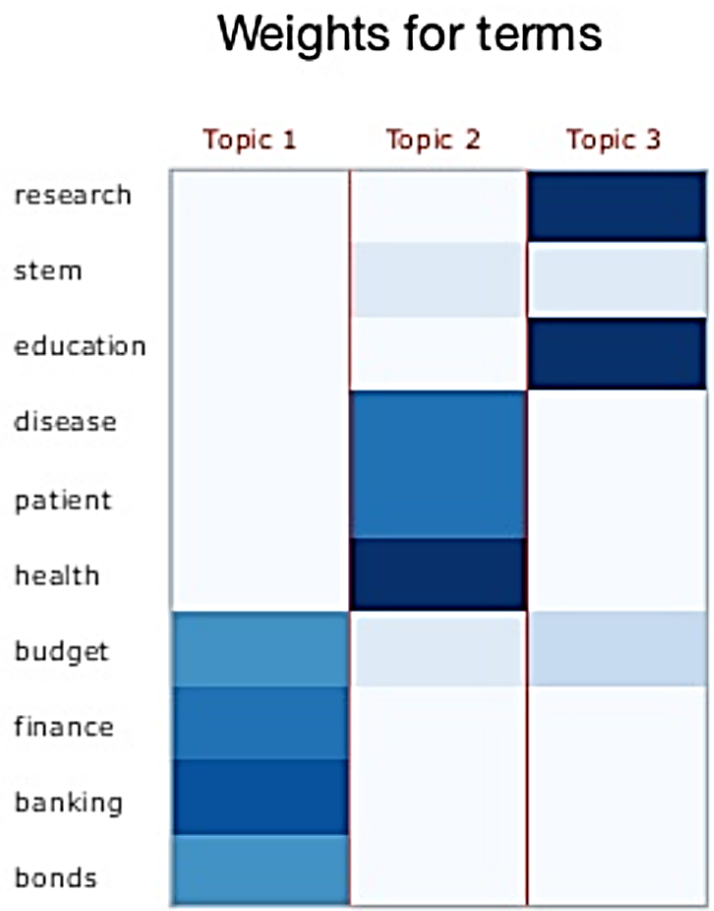




Data Source: Federal RePORTER, 2008-2019,
University of Virginia, Social and Decision Analytics Division computations

# Topic Modeling using Non-negative Matrix Factorization (NMF)

- Linear algebra technique that can be used for clustering groups of words into topics



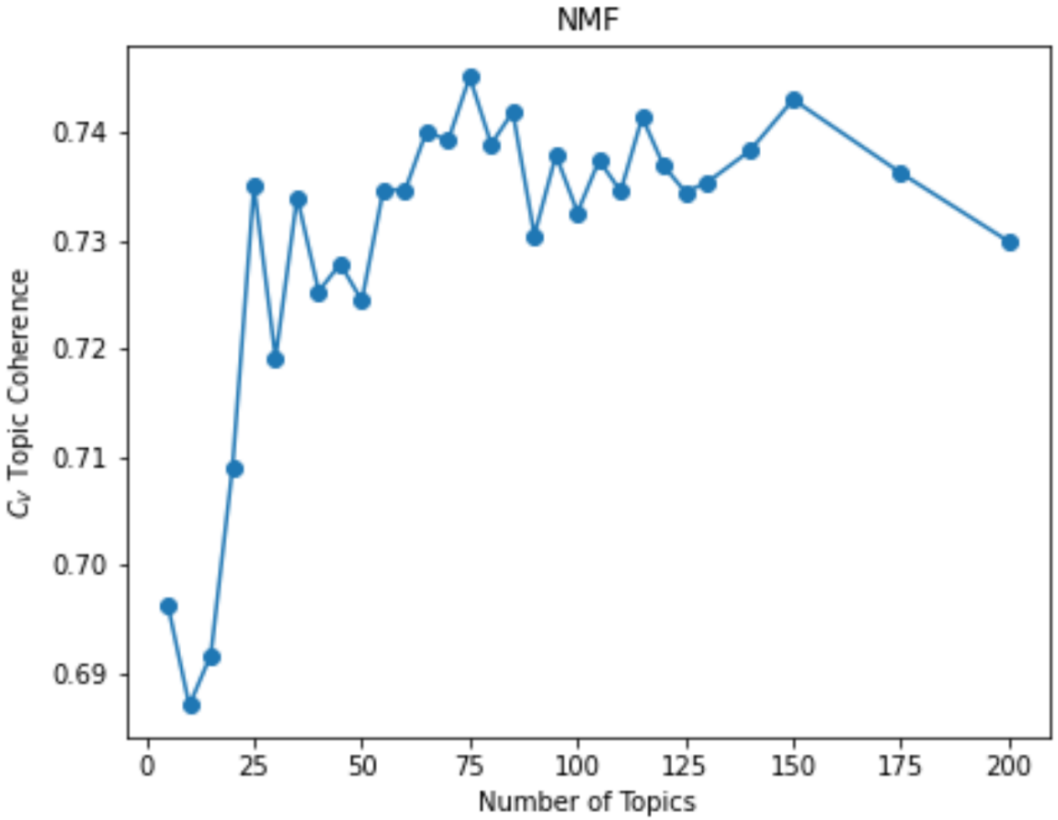

Graphic Source: [Dynamic Topic Modeling via Non-negative Matrix Factorization by Dr. Derek Greene, slide 6](#).

# Topic Modeling using Non-negative Matrix Factorization (NMF)

- We do not know the number of topics in advance, so we tested a number of topic models in order to find an optimal model.
- Measure for “goodness of fit” for topic models: $C_v$ Topic Coherence

# Tuning the Number of Topics

- Single topic model runs on the full dataset – sample results
- The best model of these is an NMF topic model with 75 topics.




Data Source: Federal RePORTER, 2008-2019,
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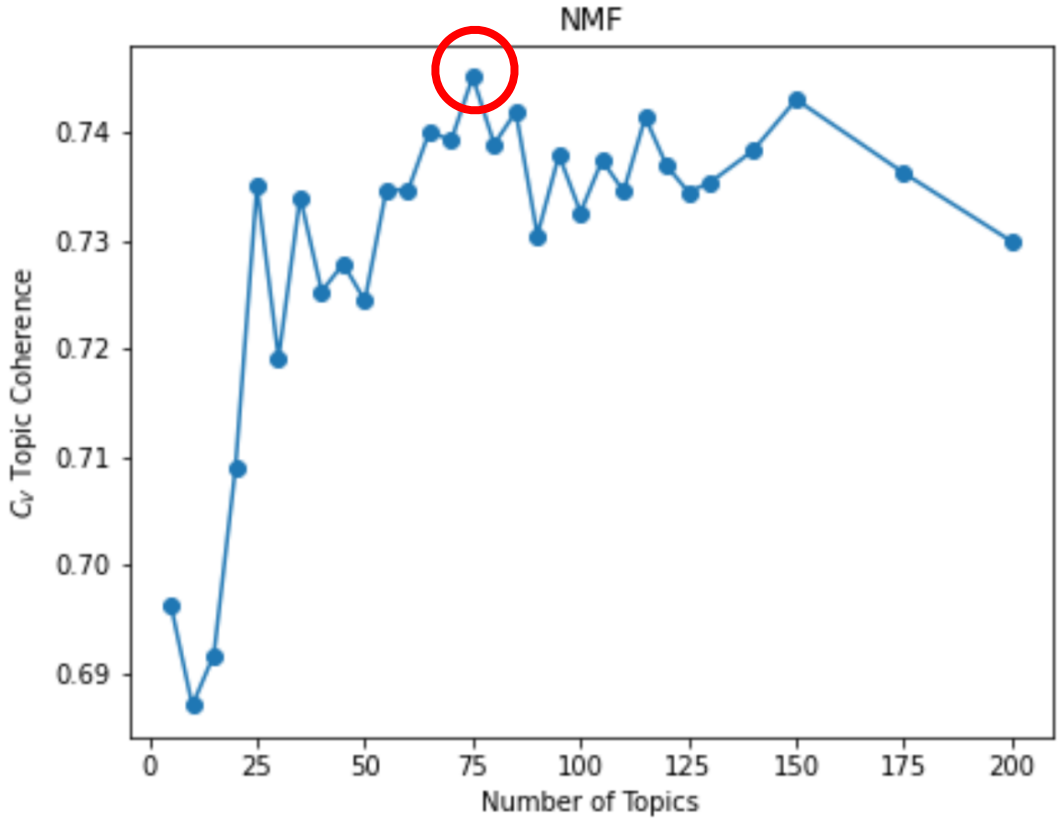
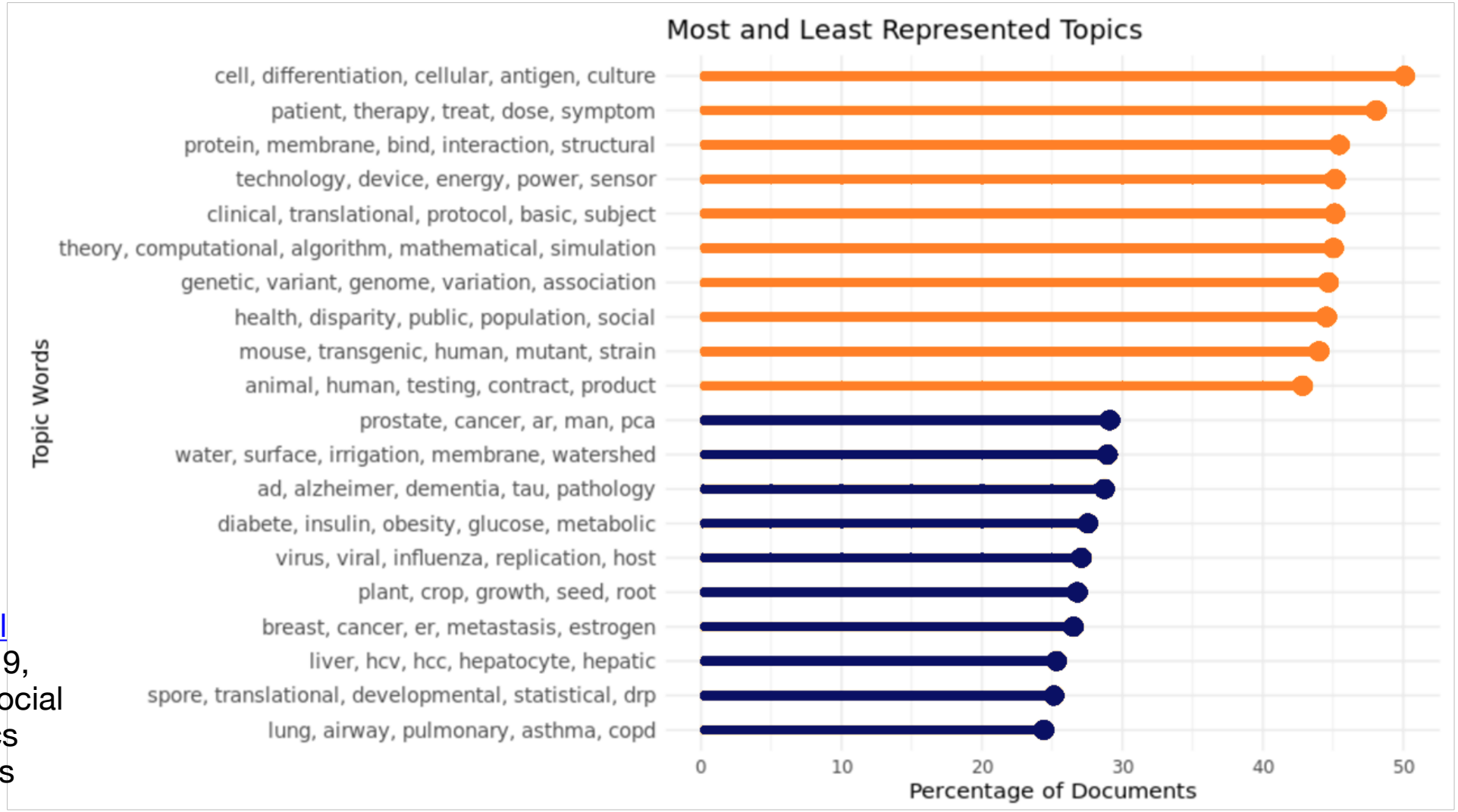



Data Source: Federal RePORTER, 2008-2019,
University of Virginia, Social and Decision Analytics Division computations

# Optimal Topic Model Results

## Measuring the percentage of documents in which each topic occurs

- Full dataset
- NMF - 75 topics

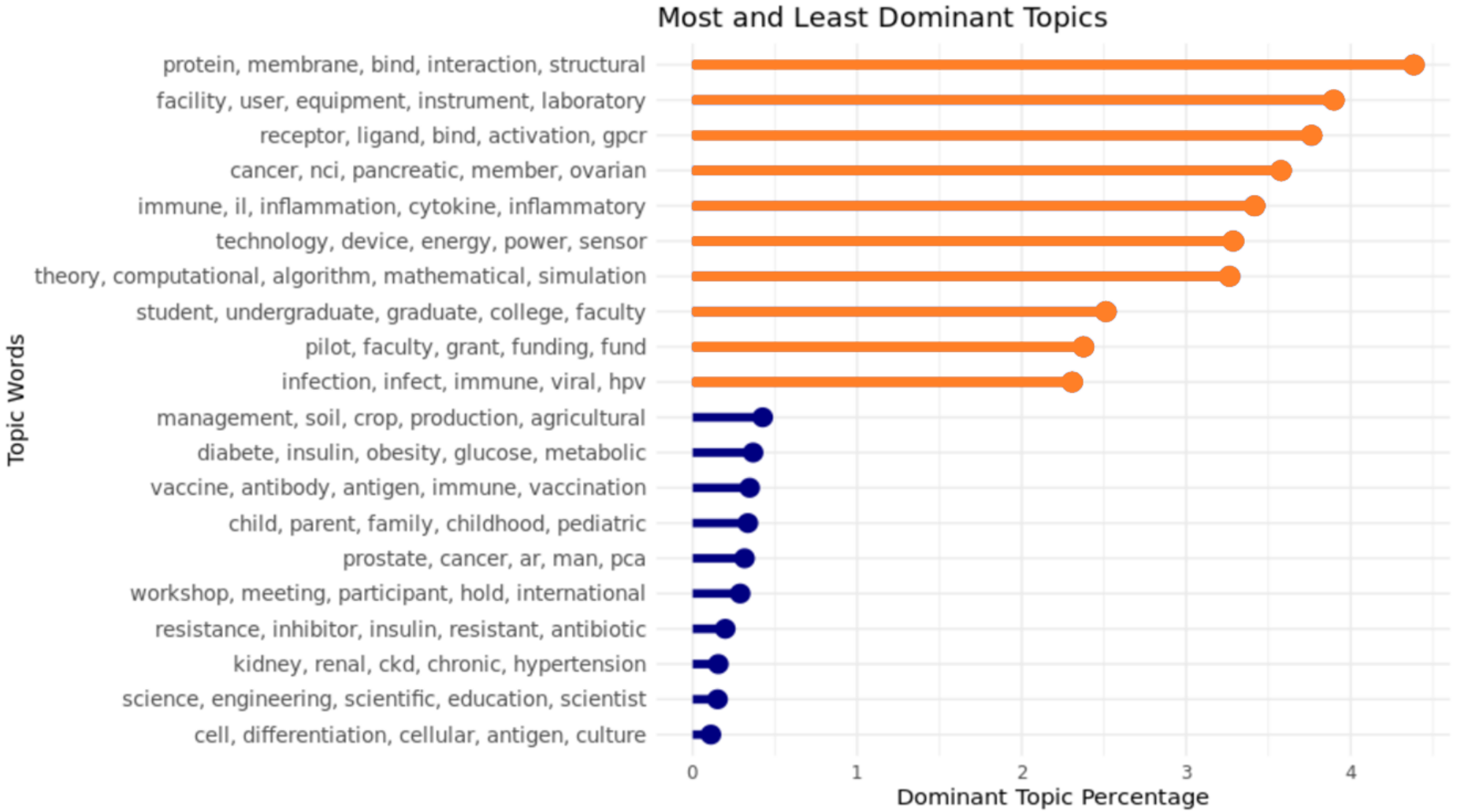



Data Source: Federal RePORTER, 2008-2019, University of Virginia, Social and Decision Analytics Division computations

# Optimal Topic Model Results

Measuring the percentage of times each topic was “dominant,” i.e., the topic with the highest weight for a document.

- Full dataset
- NMF - 75 topics



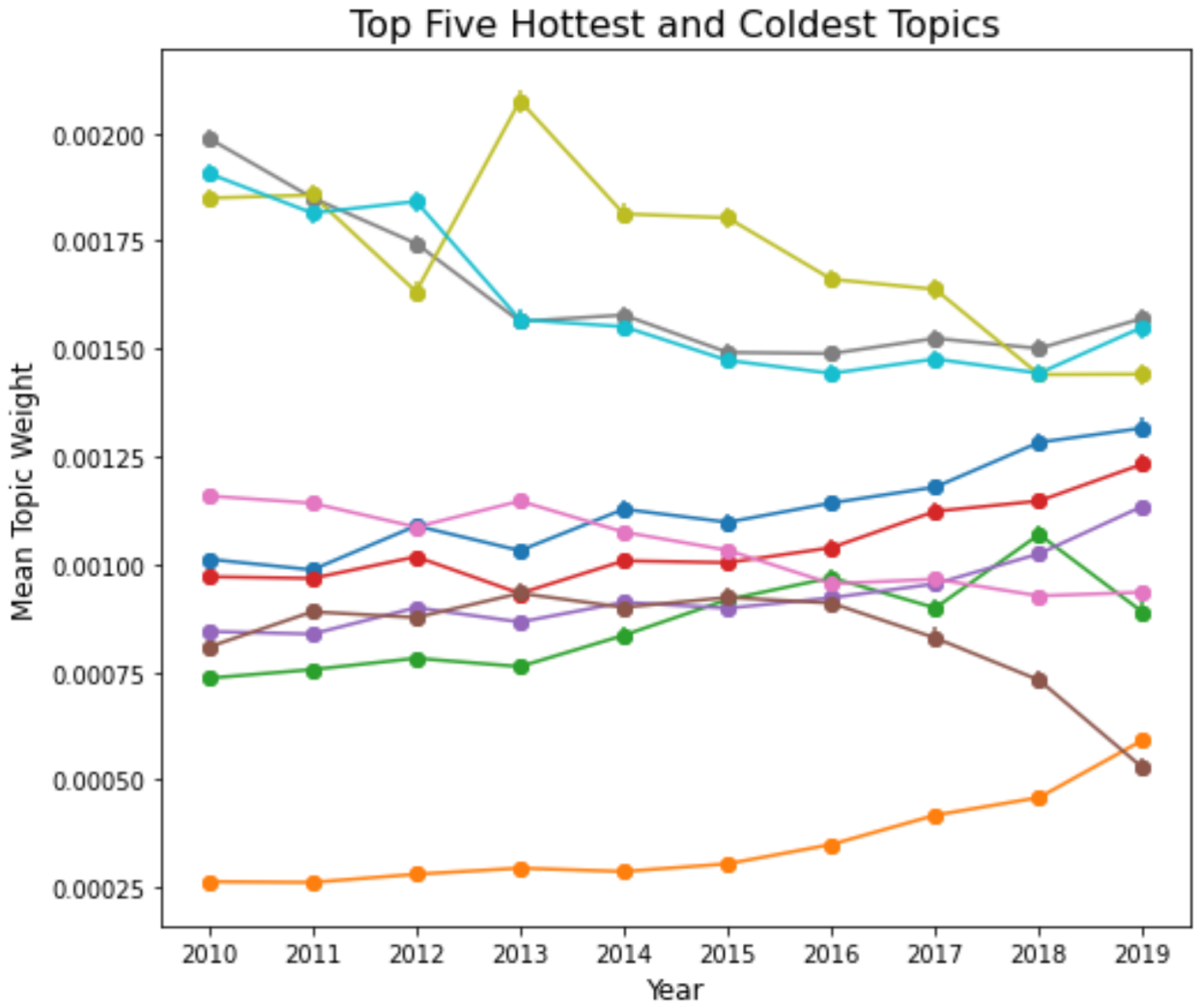

Data Source: Federal RePORTER, 2008-2019, University of Virginia, Social and Decision Analytics Division computations

# Emerging Topics Method

- Using our optimal topic model, an NMF model with 75 topics, we analyze its results to discover and characterize 'hot' and 'cold' topics.
- We follow the approach of [2] using our optimal NMF topic model. We also use the work in [3] as a reference.
- To categorize a topic as “hot” or “cold”, we
    1. Find the average weight of each topic in each year between 2010-2019.
    2. Model the relationship between the average weights and years for each topic using linear regression.
    3. Topics that have regression lines with positive slopes are considered ‘hot' and those that have regression lines with negative slopes are considered ‘cold'.

# Emerging Topics Results

## Full dataset, NMF - 75 topics




Top Five Hottest Topics

- care, provider, practice, medical, cost
- ad, alzheimer, dementia, tau, pathology
- stem, hsc, hematopoietic, progenitor, college
- brain, neural, mri, region, fmri
- patient, therapy, treat, dose, symptom

Top Five Coldest Topics

- water, surface, irrigation, membrane, watershed
- animal, human, testing, contract, product
- protein, membrane, bind, interaction, structural
- facility, user, equipment, instrument, laboratory
- receptor, ligand, bind, activation, gpcr

Note: “cold” topics can still be popular, but just trending downward in prevalence

Data Source: Federal RePORTER, 2008-2019, University of Virginia, Social and Decision Analytics Division computations

# Pandemics Case Study Approach

- We explore emerging topics around the research areas of pandemics and coronavirus.
  1. We use information retrieval techniques to create two smaller corpora: one that focuses on pandemics, and one that focuses on coronavirus.

### Smaller Corpora Sizes

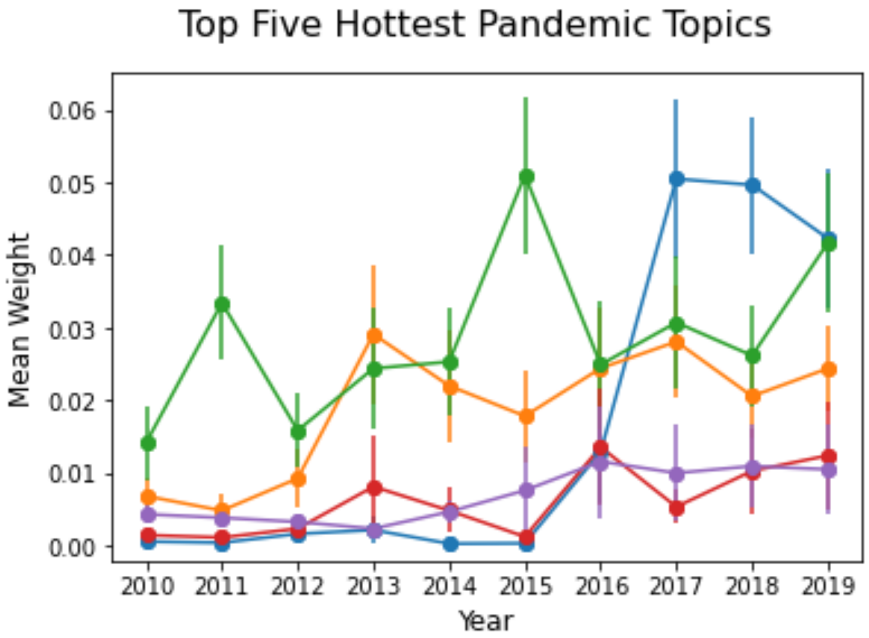
| Corpus | Number of Projects |
|---|---|
| Pandemics | 1137 |
| Coronavirus | 1012 |

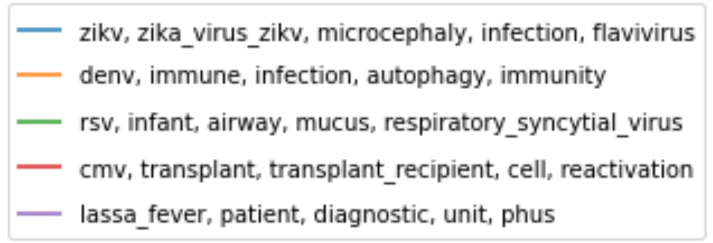
Data Source: Federal RePORTER, 2008-2019,
University of Virginia, Social and Decision Analytics Division computations

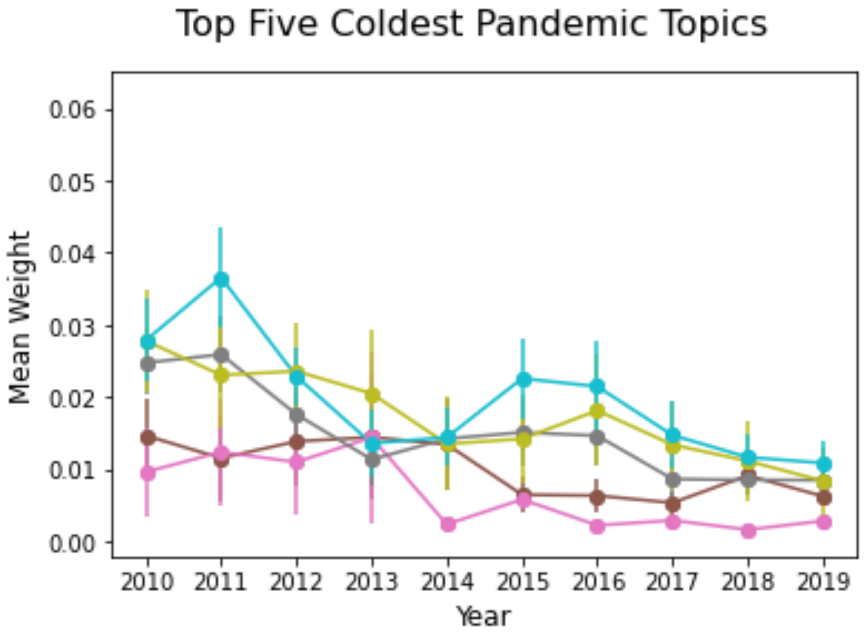
  2. We use an NMF topic model of 30 topics on each smaller corpus and conduct the emerging topics analysis.

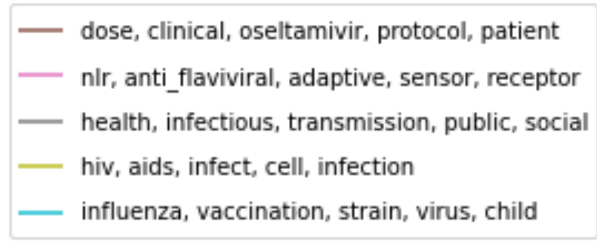
# Case Study Results – "Pandemic" Corpus

## Hottest and Coldest Topics



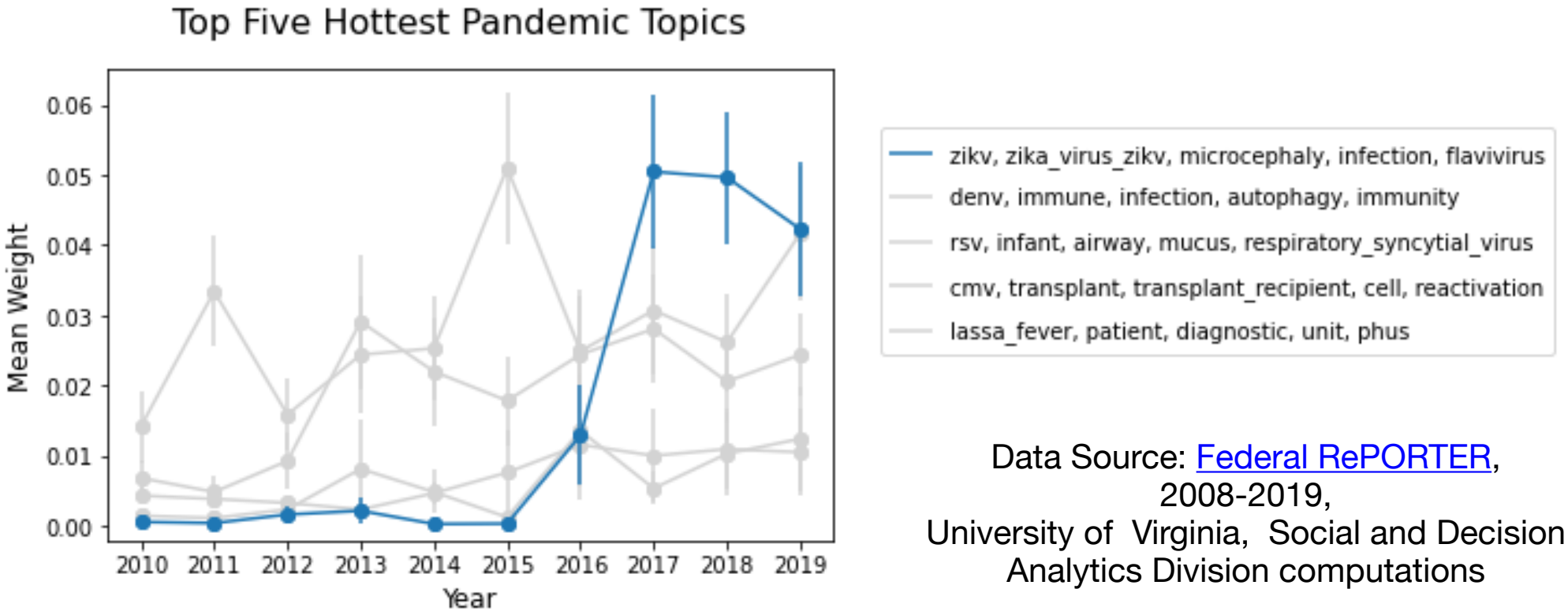




Data Source: Federal RePORTER, 2008-2019, University of Virginia, Social and Decision Analytics Division computations

# Case Study Results – “Pandemic” Corpus

## NMF - 30 topics

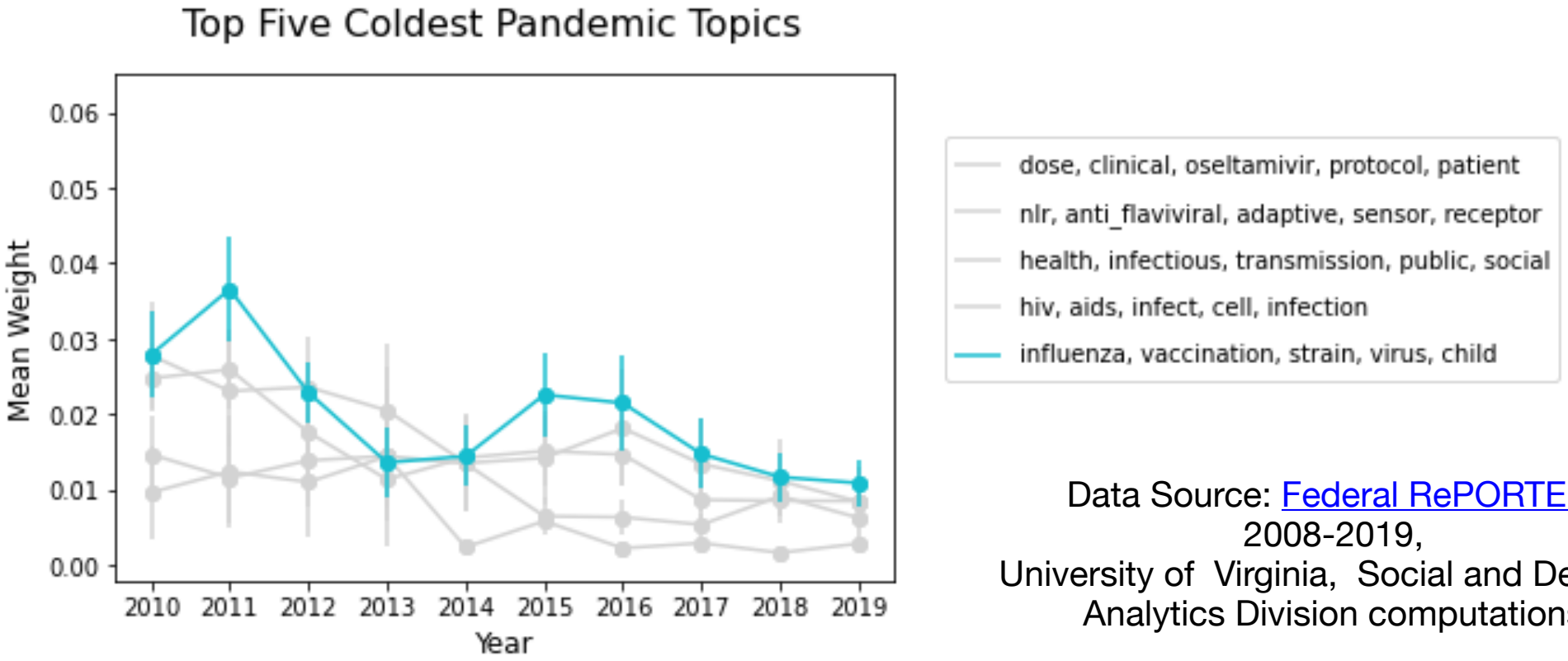



Data Source: Federal RePORTER, 2008-2019, University of Virginia, Social and Decision Analytics Division computations

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| n | 105 | 87 | 90 | 55 | 76 | 74 | 59 | 68 | 84 | 77 |

# Case Study Results – “Pandemic” Corpus

## NMF - 30 topics




Data Source: Federal RePORTER, 2008-2019, University of Virginia, Social and Decision Analytics Division computations

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
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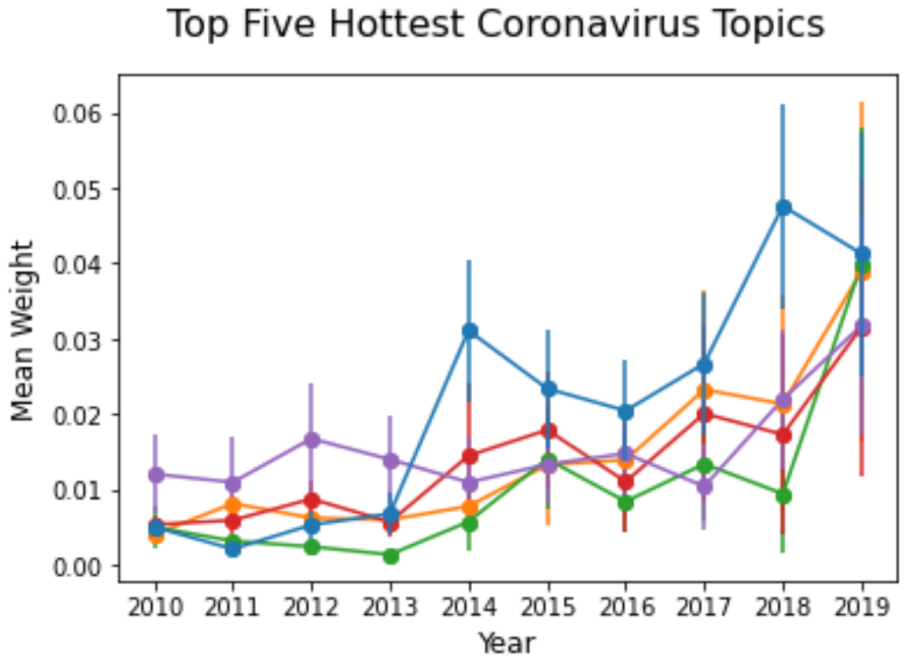
# Case Study Results – "Coronavirus" Corpus

NMF-3 Topics



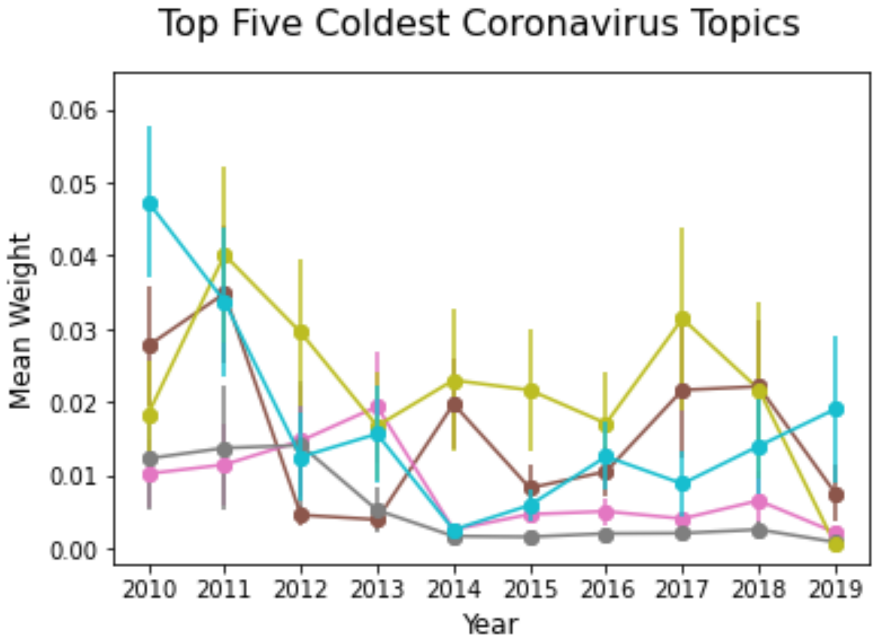

mers_cov, mers, dpp4, vaccine, rbd

influenza, phage_display_library, surface_plasmon_resonance, task, vaccinate

cmv, ensure, leader, cell, expertise

m_tuberculosis, patient, tb, infection, therapy

ebv, cell, patient, nhl, lymphoma




fusion, protein, receptor, entry, spike

cns, cn, mhv, cell, demyelination

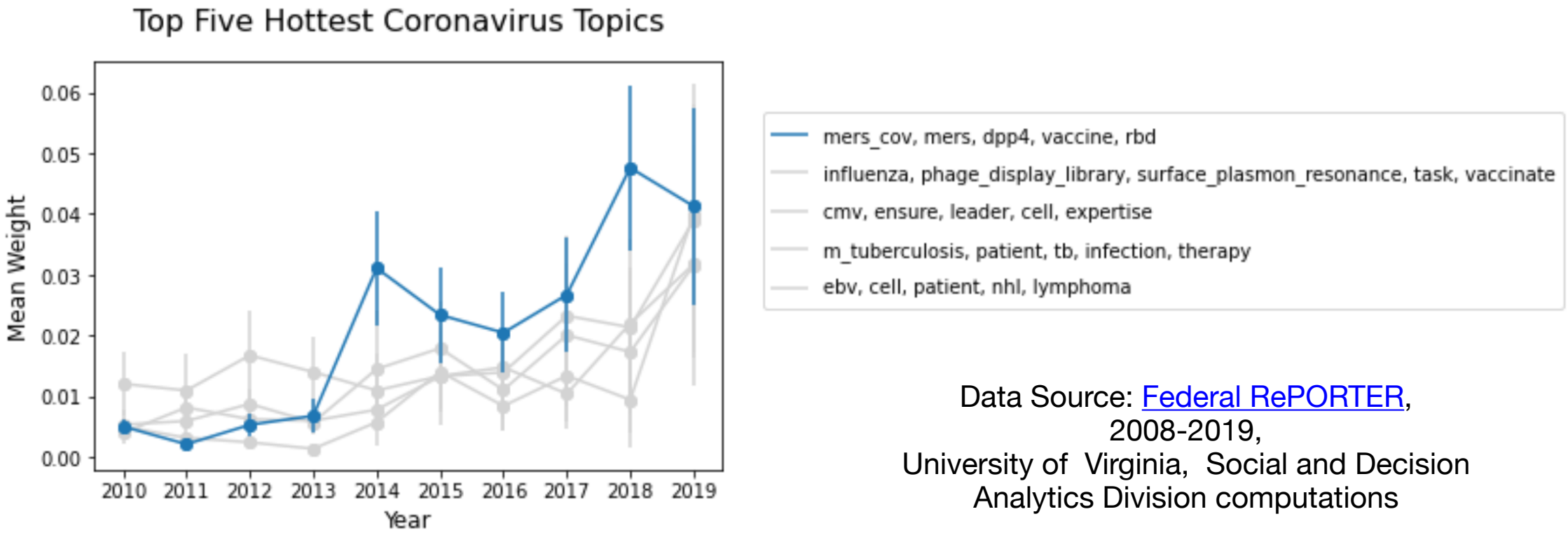
hrv, asthma, virus, airway, assay

hsv, woman, shedding, genital, reactivation

siv, cd4, infect, aids, macaque

Data Source: Federal RePORTER, 2008-2019, University of Virginia, Social and Decision Analytics Division computations

# Case Study Results – “Coronavirus” Corpus

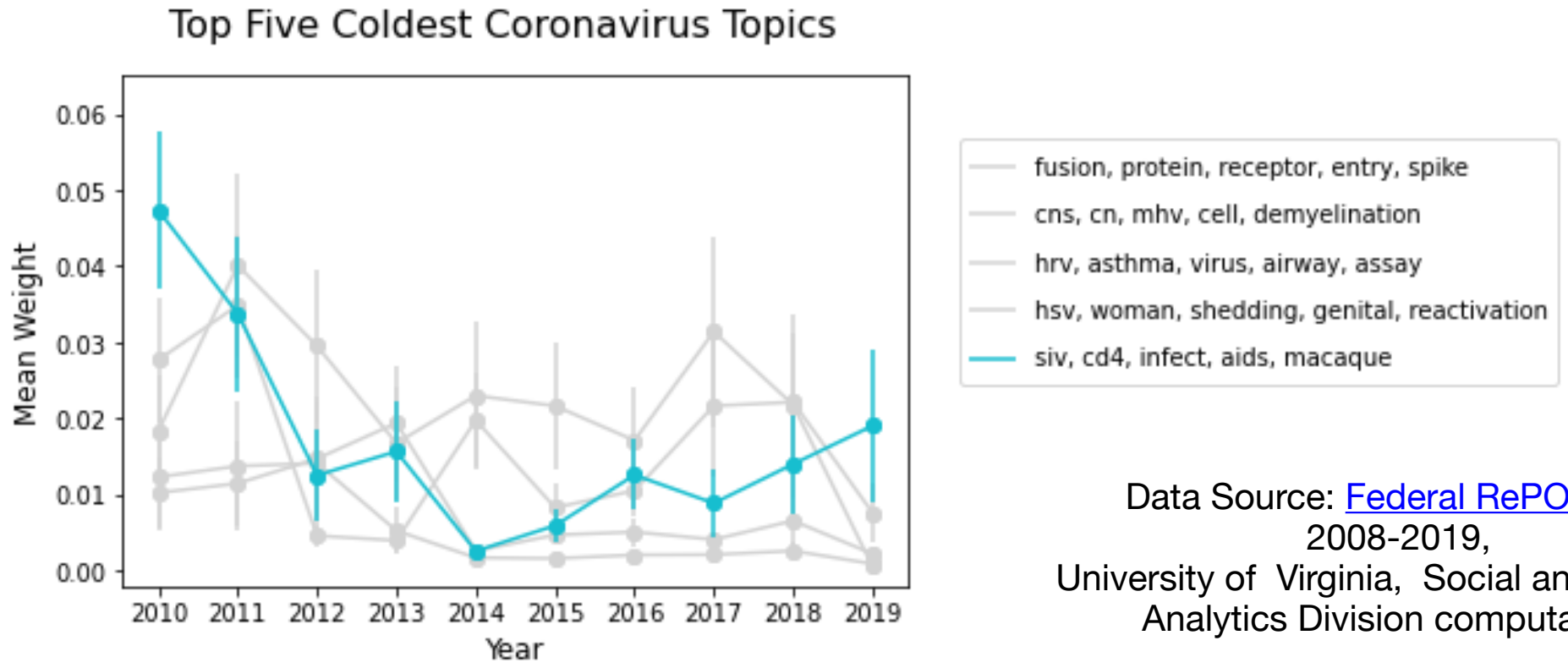



Data Source: Federal RePORTER, 2008-2019, University of Virginia, Social and Decision Analytics Division computations

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| n | 89 | 74 | 71 | 69 | 62 | 80 | 89 | 51 | 45 | 30 |

# Case Study Results – “Coronavirus” Corpus

NMF-30 Topics




Data Source: Federal RePORTER, 2008-2019, University of Virginia, Social and Decision Analytics Division computations

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|---|---|---|---|---|---|---|---|---|---|---|
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# Takeaways

- We discovered that emerging topics methods can give the user valuable information about the popularity of topics over time and current research trends.
- We implemented topic modeling for specific areas of interest:
  - We combined a search engine strategy and topic model
  - This can quickly give users a “deeper dive” into a specific area
  - Allows for finer grained topics
- Our dashboard provides results and documentation for the project: http://rnd.policy-analytics.net/ (temporary link)

# Next Steps

- Assess whether the slopes of each topic trend line are significantly different from 0.
- Quantify uncertainty around topic model results.
- Investigate hierarchical models and how we may integrate them into our research.
- Begin researching methods for statistically aggregating results from multiple topic model runs.

# Acknowledge our Data Science for the Public Good Students

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# References

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Other references are on the dashboard