# Tracing the Endless Scientific Frontier in Publication Text

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# Motivation

- New scientific ideas drive scientific and technological progress, economic growth, and social welfare (Bush, 1945; Price, 1963; Jones & Summers, 2020)
- Opportunities for highly novel ideas are shrinking over time
  - Slowdown of science progress and decreasing disruption (Chu & Evans, 2019; Park et al., 2023)
  - Burden of knowledge (Jones 2009; Bloom et al. 2020)
- Difficulties in identifying and evaluating the value of new scientific ideas (e.g. bias against novelty/risk) with breakthrough that can be missed (Boudreau et al., 2016; Wang et al., 2017; Veugelers et al., 2023)
- Heterogeneity in novelty and impact of new scientific ideas (Seglen, 1992)
  - General patterns of progress in science: most of the time incremental improvements in existing paradigms and occasional big shocks in paradigms (Uzzi et al., 2013)

# Background

- Current approaches to measure novelty and impact in science
  - Patterns of citations to prior art (references) (Uzzi et al., 2013; Wang et al., 2017)
  - Combinations of MeSH keywords (Azoulay et al., 2011; Boudreau et al., 2016; Carayol et al., 2016)
  - Expert assessment (Bornmann et al., 2019)
- Limitations:
  - Bibliographic data only capture prior art but not the scientific content, or, on the contrary, reflect little-to-no intellectual influence on the authors citing them (Teplitskiy et al., 2022)
  - Overlap of indicators: novelty overlaps with interdisciplinarity when looking at citations (Fontana et al., 2020)
  - No established validation method: do new combinations of citations and keywords capture novel scientific ideas?
  - Lack of external validity beyond the subjective assessments of typically small samples

# What do we do: Natural Language Processing

- We use Natural Language Processing (NLP) techniques to develop metrics of **novelty** and **impact** based on text, circumventing the use of citations
- Scientific ideas are embedded in the text of scientific articles and new scientific ideas can only be identified through shifts in language (Kuhn 1970)

"*Language shifts are the fingerprint of paradigm shifts*"
Thomas Kuhn

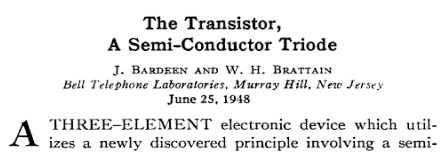
# Data

- Microsoft Academic Graph (MAG) (now OpenAlex)
  - Coverage from 1780 until 2020 (about 270M publication records)
  - Open access and broader coverage than the Web of Science or Scopus
- We develop text-based metrics for **72,245,396** journal and conference papers from 1901 to 2020 in english language
- Concatenate title, abstract, eliminate stop words, words < 2 characters, numbers, words which appear only once in all papers, lemmatization

# New word

- **new_word**
  first time appearance of a new word in a paper
- **new_word_reuse**
  number of times reused in future papers

"transistor"
(reused 152,036)

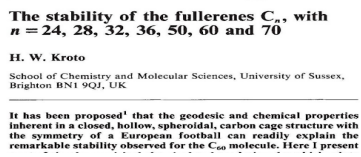


**The Transistor,**
**A Semi-Conductor Triode**

J. Bardeen and W. H. Brattain
*Bell Telephone Laboratories, Murray Hill, New Jersey*
June 25, 1948

A THREE–ELEMENT electronic device which utilizes a newly discovered principle involving a semi-

"fullerene"
(reused 32,305)



**The stability of the fullerenes $C_n$, with $n = 24, 28, 32, 36, 50, 60$ and 70**

**H. W. Kroto**

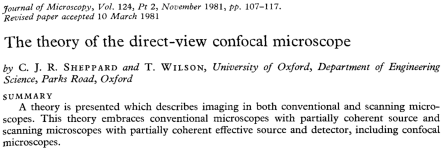
School of Chemistry and Molecular Sciences, University of Sussex, Brighton BN1 9QJ, UK

**It has been proposed[1] that the geodesic and chemical properties inherent in a closed, hollow, spheroidal, carbon cage structure with the symmetry of a European football can readily explain the remarkable stability observed for the $C_{60}$ molecule. Here I present**

# New bigram

- **new_bigram**
  first time appearance of two consecutive words in a paper
- **new_bigram_reuse**
  number of times reused in future papers

"confocal microscope"
(reused 43,401)



*Journal of Microscopy*, *Vol.* 124, *Pt* 2, *November* 1981, *pp.* 107–117.
*Revised paper accepted* 10 *March* 1981

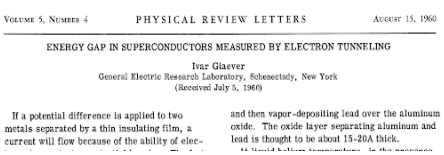
The theory of the direct-view confocal microscope

*by* C. J. R. SHEPPARD *and* T. WILSON, *University of Oxford, Department of Engineering Science, Parks Road, Oxford*

SUMMARY

A theory is presented which describes imaging in both conventional and scanning microscopes. This theory embraces conventional microscopes with partially coherent source and scanning microscopes with partially coherent effective source and detector, including confocal microscopes.

"electron tunneling"
(reused 4,759)



VOLUME 5, NUMBER 4 PHYSICAL REVIEW LETTERS AUGUST 15, 1960

ENERGY GAP IN SUPERCONDUCTORS MEASURED BY ELECTRON TUNNELING

Ivar Giaever
General Electric Research Laboratory, Schenectady, New York
(Received July 5, 1960)

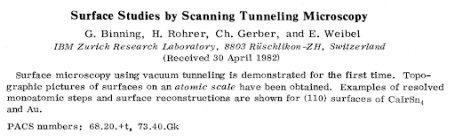
If a potential difference is applied to two metals separated by a thin insulating film, a current will flow because of the ability of elec-

and then vapor-depositing lead over the aluminum oxide. The oxide layer separating aluminum and lead is thought to be about 15-20Å thick.

# New trigram

- **new_trigram**
  first time appearance of three consecutive words in a paper
- **new_trigram_reuse**
  number of times reused in future papers

"scanning tunneling microscopy"
(reused 17,011)



**Surface Studies by Scanning Tunneling Microscopy**

G. Binning, H. Rohrer, Ch. Gerber, and E. Weibel
*IBM Zurich Research Laboratory, 8803 Rüschlikon-ZH, Switzerland*
(Received 30 April 1982)

Surface microscopy using vacuum tunneling is demonstrated for the first time. Topographic pictures of surfaces on an *atomic scale* have been obtained. Examples of resolved monoatomic steps and surface reconstructions are shown for (110) surfaces of $CaIrSn_4$ and Au.

PACS numbers: 68.20.+t, 73.40.Gk

"polymerase chain reaction"
(reused 61,626)

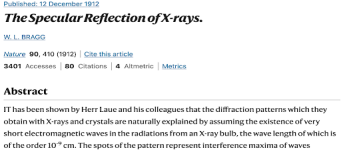
**Specific Enzymatic Amplification of DNA In Vitro: The Polymerase Chain Reaction**

K. MULLIS, F. FALOONA, S. SCHARF, R. SAIKI, G. HORN, AND H. ERLICH
*Cetus Corporation, Department of Human Genetics, Emeryville, California 94608*

# New word combinations

- **new_word_comb**
  first time of appearance of a word combination (no matter the order in the text)
- **new_word_comb_reuse**
  number of times reused in future papers

"x-ray diffraction"
(reused 528,592)



Published: 12 December 1912

***The Specular Reflection of X-rays.***

W. L. BRAGG

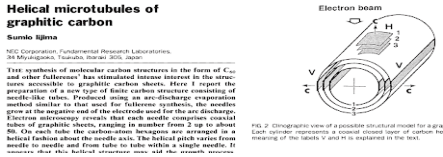
*Nature* **90**, 410 (1912) | Cite this article

**3401** Accesses | **80** Citations | **4** Altmetric | Metrics

**Abstract**

IT has been shown by Herr Laue and his colleagues that the diffraction patterns which they obtain with X-rays and crystals are naturally explained by assuming the existence of very short electromagnetic waves in the radiations from an X-ray bulb, the wave length of which is of the order $10^{-9}$ cm. The spots of the pattern represent interference maxima of waves

"carbon nanotube"
(reused 12,245)



**Helical microtubules of graphitic carbon**

**Sumio Iijima**

NEC Corporation, Fundamental Research Laboratories, 34 Miyukigaoka, Tsukuba, Ibaraki 305, Japan

**Tiny synthesis of molecular carbon structures in the form of $C_{60}$ and other fullerenes' has stimulated intense interest in the structures accessible to graphitic carbon sheets. Here I report the preparation of a new type of finite carbon structure consisting of needle-like tubes. Produced using an arc-discharge evaporation method similar to that used for fullerene synthesis, the needles grow at the negative end of the electrode used for the arc discharge. Electron microscopy reveals that each needle comprises coaxial tubes of graphitic sheets, ranging in number from 2 up to about 50. On each tube the carbon-atom hexagons are arranged in a helical fashion about the needle axis. The helical pitch varies from needle to needle and from tube to tube within a single needle. It appears that this helical structure may aid the growth process**

Electron beam

FIG. 2 Clinographic view of a possible structural model for a graphitic tubule. Each cylinder represents a coaxial closed layer of carbon hexagons. The meaning of the labels V and H is explained in the text.

# Descriptives: Textual Units

| | | Reuse | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **#** | **Mean** | **Std** | **Min** | **Q1** | **Q2** | **Q3** | **Skewness** |
| new_word | 7,305,080 | 75.86 | 2,943.04 | 1.00 | 1.00 | 3.00 | 7.00 | 243.49 |
| new_bigram | 32,104,336 | 26.48 | 569.07 | 1.00 | 1.00 | 2.00 | 8.00 | 359.33 |
| new_trigram | 75,573,271 | 8.00 | 141.93 | 1.00 | 1.00 | 2.00 | 4.00 | 677.10 |
| new_word_comb | 1,129,014,727 | 48.68 | 1,101.71 | 1.00 | 1.00 | 2.00 | 9.00 | 240.32 |

*Notes:* Descriptive table of the textual units identified in 72,245,396 journal and conference papers from 1901 to 2020 in english language. All textual units are reused at least once. *Q1* is the 25% percentile. *Q2* is the median (50% percentile). *Q3* is the 75% percentile. The *skewness* is the measure of the asymmetry of the probability distribution of a real-valued random variable about its mean (a positive skewness indicates that the distribution has a long right tail, while a negative skewness indicates a long left tail).

# Descriptives: Textual Units

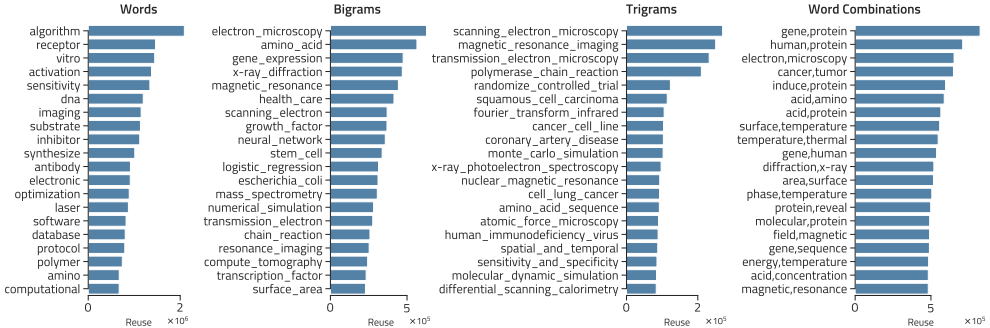



Figure: Top 20 reused words, bigrams, trigrams and word combinations.

# Paper Level Textual Metrics

- **new_word | new_word_reuse**
  n. of unique new words introduced by the focal paper
- **new_bigram | new_bigram_reuse**
  n. of new bigrams that do not contain one of the new words introduced by the paper
- **new_trigram | new_trigram_reuse**
  n. of new trigrams that do not contain one of the new words or new bigrams introduced by the paper
- **new_gram | new_gram_reuse**
  n. of new words + n. of new bigrams that do not contain one of the new words introduced by the paper + n. of new trigrams that do not contain one of the new words or new bigrams introduced by the paper
- **new_word_comb | new_word_comb_reuse**
  n. of new word combinations (word pairs) that do not contain one of the new words introduced by the paper, do not correspond to a new bigram introduced by the paper, and do not contain one of the three words contained in the new trigrams introduced by the paper

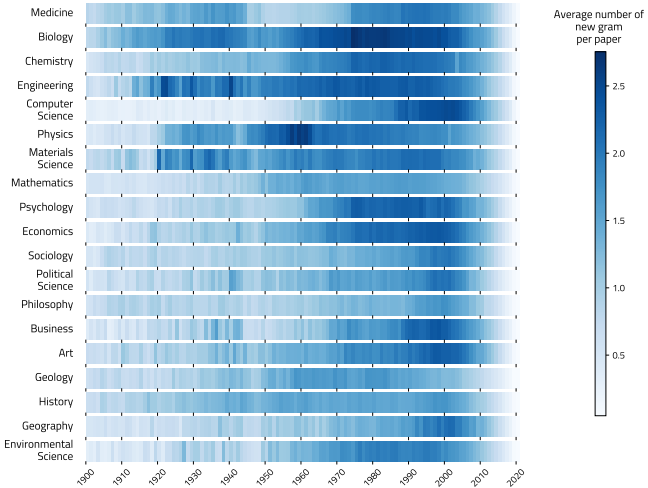
# Descriptives: Paper level

- On average, papers do not introduce new instances alone, but usually they introduce multiple instances together, expressed both as new grams or new word combinations
  - Novel papers introduce novel ideas in multiple forms

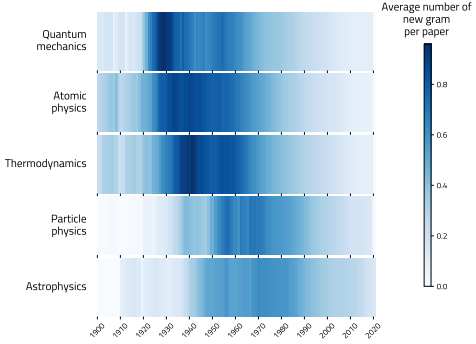
| | Share of total papers | Share of NG | Share of NC |
|---|---|---|---|
| new_gram_bin (NG) | 0.545 | 1.000 | 0.738 |
| new_word_comb_bin (NC) | 0.511 | 0.787 | 1.000 |

*Notes:* Descriptive of the binary textual metrics and their overlaps for n= 72,245,396 papers published between 1901 and 2020. Each row represents the number of papers that score positively for the binary textual metrics. Each column represents the subset of papers (share) that score positively on the particular binary metrics.

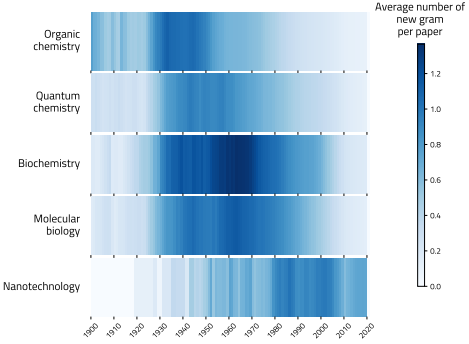
# Novelty over time by fields



# Novelty over time by subfields




(a) Subfields of Physics




(b) Subfields of Chemistry

# Benchmark

- Citation-based metrics
  - **wang**
    sum of the distance of novel combinations of cited journals (of cited papers) (Wang et al., 2017)
  - **uzzi**
    atypicality of all cited journal pairs (paper's 10-th percentile of z-score) (Uzzi et al., 2013)
  - **cd** (*disruptiveness)*
    *cd* (disruption score at 5 years level) quantifies the extent to which a paper disrupts or develops the existing literature (Funk & Owen-Smith, 2017)
- Textual Distance metrics (document embeddings of title and abstract)
  - **cosine_avg**
    1 - average cosine similarity with 5-years prior papers
  - **cosine_max**
    1 - maximum cosine similarity with 5-years prior papers

**SPECTER** document embedding (Cohan, 2020)

- transformer-based (BERT-like) language model tailored for scientific language (best performing model at the state-of-the-art)
- 768-dimensions vector representation of the title and abstract of a focal paper
- accounting for the context in which words appear (synonymity, polysemy, change in language...)

# Validation

- **Nobel prize papers**
  - Papers likely introduced fundamentally new scientific ideas with a major impact on scientific progress
  - Nobel prize award specifies the novel idea that motivates the prize
- Case-control design
  - Match one-to-one Nobel prize papers with control papers (database of Nobel prize papers from Li et al. (2019))
    - Control papers: same year, journal, volume, issue
  - Ability to distinguish Nobel prize papers from control papers
    - T-test, Cohen's d
    - Precision, recall, AUC (area under the ROC-curve)

# Validation: Nobel Prizes

- Binnig and Rohrer introduce for the first time the "scanning tunnel microscopy" for which they won the Nobel prize in Physics in 1986
  - The paper "Surface Studies by Scanning Tunneling Microscopy", published in *Physical review letters* in 1982 introduce for the first time the gram "scanning tunneling miscropy" (reused 17,011 times by future papers)

**Surface Studies by Scanning Tunneling Microscopy**

G. Binning, H. Rohrer, Ch. Gerber, and E. Weibel
*IBM Zurich Research Laboratory, 8803 Rüschlikon-ZH, Switzerland*
(Received 30 April 1982)

Surface microscopy using vacuum tunneling is demonstrated for the first time. Topographic pictures of surfaces on an *atomic scale* have been obtained. Examples of resolved monoatomic steps and surface reconstructions are shown for (110) surfaces of $CaIrSn_4$ and Au.

PACS numbers: 68.20.+t, 73.40.Gk

## The Nobel Prize in Physics 1986

Photo from the Nobel Foundation archive.
Ernst Ruska
Prize share: 1/2

Photo from the Nobel Foundation archive.
Gerd Binnig
Prize share: 1/4

Photo from the Nobel Foundation archive.
Heinrich Rohrer
Prize share: 1/4

The Nobel Prize in Physics 1986 was divided, one half awarded to Ernst Ruska "for his fundamental work in electron optics, and for the design of the first electron microscope", the other half jointly to Gerd Binnig and Heinrich Rohrer "for their design of the scanning tunneling microscope"

# Validation: Nobel Prizes

89% of the Nobel papers introduce at least one new gram or new word combination that has been also found in their prize motivation summary page
(e.g. `https://www.nobelprize.org/prizes/physics/1986/summary/`)

| Prize | Prize motivation | Paper Reference | new gram (reuse) | new word comb (reuse) |
|---|---|---|---|---|
| Physics 1923 | work on the elementary charge of electricity and on the photoelectric effect | Millikan (1910) | | charge,elementary (4107) |
| Physics 1936 | Discovery of the positron | Anderson (1933) | positron (94,146) | |
| Physics 1937 | discovery of the diffraction of electrons by crystals | Davisson & Germer (1927) | electron_diffraction (46307) | |
| Medicine 1952 | discovery of streptomycin, the first antibiotic effective against tuberculosis | Schatz et al. (1944) | streptomycin (23334) | |
| Physics 1956 | researches on semiconductors and their discovery of the transistor effect | Bardeen & Brattain (1948) | transistor (152047) | |
| Physics 1959 | discovery of the antiproton | Chamberlain et al. (1955) | antiproton (5023) | |
| Medicine 1969 | discoveries concerning the replication mechanism and the genetic structure of viruses | Hershey & Chase (1952) | | nucleic,viral (8846) |
| Medicine 1971 | discoveries concerning the mechanisms of the action of hormones | Butcher & Sutherland (1962) | nucleotide_phosphodiesterase (2863) | |
| Physics 1973 | discoveries regarding tunneling phenomena in semiconductors and superconductors | Giaever (1960) | electron_tunneling (4759) | |
| Medicine 1979 | development of computer assisted tomography | Hounsfield (1973) | | sensitive,tomography (11498) |
| Chemistry 1981 | theories concerning the course of chemical reactions | Fukui et al. (1952) | | frontier,orbital (7301) |
| Medicine 1982 | discoveries concerning prostaglandins and related biologically active substances | Hamberg et al. (1974) | prostaglandin_endoperoxide (1339) | |
| Medicine 1983 | discovery of mobile genetic elements | McClintock (1950) | | chromosome,instability (8896) |
| Physics 1986 | design of the scanning tunneling microscope | Binning et al. (1982) | scanning_tunnel_microscopy (17914) | |
| Chemistry 1999 | studies of the transition states of chemical reactions using femtosecond spectroscopy | Rose et al. (1988) | | dissociation,femtosecond (907) |
| Chemistry 2001 | work on chirally catalysed hydrogenation reactions | Nozaki et al. (1968) | | chiral,synthesis (34820) |
| Physics 2005 | contribution to the quantum theory of optical coherence | Glauber (1963) | optical_coherence (50175) | |
| Medicine 2016 | discoveries of mechanisms for autophagy | Takeshige et al. (1992) | | autophagy,genetic (3396) |

*Notes:* New grams (new words or new bigram or new trigram) and new word combinations introduced for the first time by papers linked to Nobel prize winners and also found in the Nobel prize motivation summary page.

# Validation: Nobel Prizes

| Prize | Prize motivation | new_gram | new_word_comb | new_gram_reuse | new_word_comb_reuse | wang | uzzi |
|---|---|---|---|---|---|---|---|
| Physics 1923 | work on the elementary charge of electricity and on the photoelectric effect | 1 | 23 | 46 | 25,680 | 0.000 | 12.233 |
| Physics 1936 | Discovery of the positron | 9 | 17 | 102,119 | 16,576 | 0.000 | 1.023 |
| Physics 1937 | discovery of the diffraction of electrons by crystals | 24 | 495 | 87,407 | 612,942 | 0.000 | 32.241 |
| Medicine 1952 | discovery of streptomycin, the first antibiotic effective against tuberculosis | 3 | 19 | 23,339 | 60,314 | 0.000 | 7.342 |
| Physics 1956 | researches on semiconductors and their discovery of the transistor effect | 2 | 1 | 152,048 | 3 | 0.000 | 8.222 |
| Physics 1959 | discovery of the antiproton | 1 | 2 | 5,023 | 17 | 0.000 | 11.342 |
| Medicine 1969 | discoveries concerning the replication mechanism and the genetic structure of viruses | 50 | 1,066 | 20,540 | 640,243 | 0.000 | -0.234 |
| Medicine 1971 | discoveries concerning the mechanisms of the action of hormones | 3 | 2 | 2,918 | 5,237 | 0.342 | -1.680 |
| Physics 1973 | discoveries regarding tunneling phenomena in semiconductors and superconductors | 1 | 2 | 4,759 | 6,086 | 0.000 | 21.234 |
| Medicine 1979 | development of computer assisted tomography | 2 | 12 | 9 | 36,560 | 0.000 | 75.557 |
| Chemistry 1981 | theories concerning the course of chemical reactions | 7 | 59 | 1,368 | 50,970 | 0.000 | -3.761 |
| Medicine 1982 | discoveries concerning prostaglandins and related biologically active substances | 10 | 73 | 2,299 | 7,100 | 1.130 | -3.184 |
| Medicine 1983 | discovery of mobile genetic elements | 11 | 94 | 486 | 24,001 | 0.000 | 35.646 |
| Physics 1986 | design of the scanning tunneling microscope | 2 | 7 | 17,927 | 1,387 | 0.000 | 6.994 |
| Chemistry 1999 | studies of the transition states of chemical reactions using femtosecond spectroscopy | 0 | 1 | 0 | 907 | 2.442 | -5.019 |
| Chemistry 2001 | work on chirally catalysed hydrogenation reactions | 10 | 307 | 577 | 205,048 | 0.000 | 32.276 |
| Physics 2005 | contribution to the quantum theory of optical coherence | 9 | 55 | 50,624 | 8,334 | 0.000 | 1.234 |
| Medicine 2016 | discoveries of mechanisms for autophagy | 8 | 133 | 144 | 7,230 | 0.000 | 1.651 |

*Notes:* Novelty metrics scores (textual and citation based) for a sample of Nobel prize papers.

# Validation: Nobel Prizes

| | Nobel prize papers (n=501) | | | | Control papers (n=501) | | | | Cohen's d | t | Pr(\|T\| >\|t\|) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Stdev | Min | Max | Mean | Stdev | Min | Max | | | |
| new_word_binary | 0.297 | 0.458 | 0.000 | 1.000 | 0.184 | 0.388 | 0.000 | 1.000 | -0.268 | -4.247 | 0.0000*** |
| new_word | 0.260 | 0.430 | 0.000 | 2.197 | 0.154 | 0.341 | 0.000 | 1.609 | -0.273 | -4.326 | 0.0000*** |
| new_word_reuse | 1.485 | 2.736 | 0.000 | 12.343 | 0.590 | 1.545 | 0.000 | 9.128 | -0.403 | -6.375 | 0.0000*** |
| new_bigram_binary | 0.599 | 0.491 | 0.000 | 1.000 | 0.425 | 0.495 | 0.000 | 1.000 | -0.352 | -5.578 | 0.0000*** |
| new_bigram | 0.698 | 0.695 | 0.000 | 3.045 | 0.430 | 0.562 | 0.000 | 2.303 | -0.423 | -6.693 | 0.0000*** |
| new_bigram_reuse | 2.909 | 2.911 | 0.000 | 11.284 | 1.441 | 2.148 | 0.000 | 9.495 | -0.574 | -9.084 | 0.0000*** |
| new_trigram_binary | 0.727 | 0.446 | 0.000 | 1.000 | 0.623 | 0.485 | 0.000 | 1.000 | -0.223 | -3.525 | 0.0000*** |
| new_trigram | 1.012 | 0.795 | 0.000 | 3.434 | 0.701 | 0.661 | 0.000 | 2.708 | -0.425 | -6.728 | 0.0000*** |
| new_trigram_reuse | 2.866 | 2.335 | 0.000 | 9.793 | 1.740 | 1.871 | 0.000 | 8.732 | -0.532 | -8.423 | 0.0000*** |
| new_word_comb_binary (NC) | 0.804 | 0.397 | 0.000 | 1.000 | 0.663 | 0.473 | 0.000 | 1.000 | -0.324 | -5.135 | 0.0000*** |
| new_word_comb | 2.718 | 1.946 | 0.000 | 7.424 | 1.866 | 1.822 | 0.000 | 6.438 | -0.452 | -7.157 | 0.0000*** |
| new_word_comb_reuse | 6.654 | 4.055 | 0.000 | 15.230 | 4.145 | 3.800 | 0.000 | 13.849 | -0.639 | -10.107 | 0.0000*** |
| new_gram_bin (NG) | 0.828 | 0.377 | 0.000 | 1.000 | 0.721 | 0.449 | 0.000 | 1.000 | -0.260 | -4.112 | 0. 0000** |
| new_gram | 1.388 | 0.895 | 0.000 | 3.932 | 0.970 | 0.793 | 0.000 | 2.944 | -0.494 | -7.826 | 0. 0000** |
| new_gram_reuse | 4.462 | 2.878 | 0.000 | 12.485 | 2.554 | 2.358 | 0.000 | 9.512 | -0.725 | -11.478 | 0.0000** |
| cosine_max | 0.407 | 0.124 | 0.028 | 0.725 | 0.397 | 0.145 | 0.024 | 0.961 | -0.076 | -1.198 | 0.2312 |
| cosine_avg | 0.993 | 0.005 | 0.976 | 1.000 | 0.994 | 0.005 | 0.973 | 1.000 | 0.077 | 1.226 | 0.2205 |
| wang | 0.036 | 0.167 | 0.000 | 1,389 | 0.019 | 0.138 | 0.000 | 1.53 | -0.109 | -1.730 | 0.0840* |
| uzzi | 6.949 | 0.751 | 6.207 | 8,505 | 7.157 | 0.771 | 6.307 | 9,748 | 0.274 | 4.329 | 0.0000*** |
| cd | 0.097 | 0.209 | -0.522 | 0.974 | 0.042 | 0.145 | -0.5 | 0.966 | -0.307 | -4.858 | 0.0000*** |

*Notes:* n=1,002 papers of which 501 Nobel prize papers and 501 matched control papers. Each Nobel prize paper is matched to one randomly selected control paper published in the same year, journal, volume and issue. All measures except binary indicators, the metrics based on cosine similarity and cd are log transformed after adding 1 for measures with 0 values. Cohen's d is the mean difference between award and control patents divided by the pooled standard deviation. *** p<0.01, ** p<0.05, * p<0.10

# Validation: Nobel Prizes

- Likelihood of Nobel prizes: **Novelty**

| | (0) | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) new_word | | 0.456** | | | | | | | | | | | | | | |
| | | (0.226) | | | | | | | | | | | | | | |
| (2) new_bigram | | | 0.775*** | | | | | | | | | | | | | |
| | | | (0.164) | | | | | | | | | | | | | |
| (3) new_trigram | | | | 0.698*** | | | | | | | | | | | | |
| | | | | (0.161) | | | | | | | | | | | | |
| (4) new_word_comb | | | | | 0.450*** | | | | | | | | | 0.287*** | | 0.287*** |
| | | | | | (0.082) | | | | | | | | | (0.091) | | (0.091) |
| (4) new_word_comb_reuse | | | | | | 0.278*** | | | | | | | | | 0.193*** | |
| | | | | | | (0.032) | | | | | | | | | (0.035) | |
| (5) new_gram | | | | | | | 0.940*** | | | | | | | 0.689*** | | 0.694*** |
| | | | | | | | (0.165) | | | | | | | (0.180) | | (0.179) |
| (5) new_gram_reuse | | | | | | | | 0.346*** | | | | | | | 0.244*** | |
| | | | | | | | | (0.039) | | | | | | | (0.042) | |
| (6) cosine_max | | | | | | | | | -0.107 | | | | | | | |
| | | | | | | | | | (0.702) | | | | | | | |
| (7) cosine_avg | | | | | | | | | | -29.730* | | | | | | |
| | | | | | | | | | | (16.617) | | | | | | |
| (8) wang | | | | | | | | | | | 0.317 | | | | | 0.940 |
| | | | | | | | | | | | (0.532) | | | | | (0.843) |
| (9) uzzi | | | | | | | | | | | | -0.325*** | | | | -0.279*** |
| | | | | | | | | | | | | (0.071) | | | | (0.075) |
| (10) cd | | | | | | | | | | | | | 2.517*** | | | 2.329*** |
| | | | | | | | | | | | | | (0.579) | | | (0.616) |
| Pseudo R-squared | 0.093 | 0.095 | 0.112 | 0.109 | 0.120 | 0.165 | 0.124 | 0.167 | 0.093 | 0.094 | 0.094 | 0.098 | 0.116 | 0.132 | 0.193 | 0.138 |
| Precision (%) | 64.41 | 64.26 | 65.82 | 64.31 | 65.94 | 70.06 | 65.22 | 69.98 | 64.60 | 64.66 | 64.41 | 64.60 | 67.27 | 67.26 | 71.49 | 67.70 |
| Recall (%) | 69.96 | 69.12 | 70.38 | 68.91 | 69.96 | 73.74 | 69.33 | 72.48 | 70.17 | 69.96 | 69.96 | 72.06 | 70.80 | 71.22 | 73.74 | 73.11 |
| AUC | 0.6966 | 0.6982 | 0.7176 | 0.7110 | 0.7234 | 0.7647 | 0.7295 | 0.7651 | 0.6968 | 0.6979 | 0.6967 | 0.6996 | 0.7234 | 0.7369 | 0.7844 | 0.7401 |
| Marginal Effect (%) | | 2.72 | 10.74 | 11.26 | 18.27 | 22.56 | 17.24 | 19.10 | -0.60 | -1.84 | 1.12 | -5.13 | 9.83 | | | |

*Notes:* Logit regression, robust standard errors between brackets. All measures, except metrics based on cosine similarity and *cd* are log transformed after adding 1 for measures with 0 values. All models include publication year and field of study fixed effects, and additionally control for whether the paper has an abstract available, text length, and the number of unique papers and journals cited by the focal paper. AUC is area under the ROC curve. Marginal effects are calculated as the % increase in the likelihood of being a Nobel prize paper associated with an increase in the metric with one standard deviation. *** p<0.01, ** p<0.05, * p<0.10

# Findings

- Text based measures seem to better identify novel ideas compared to citation based indicators
- Impact and diffusion of novelty with text-based measures can be studied through their reuse rather than only citations
- Pool of different textual-based measures at paper level
- Interpretable novelty and impact indicators

# Conclusions

- Limitations
  - we cannot use the full text due to the open access data restrictions
  - we do not have a true set of novel papers, which is why any validation exercise remains imperfect
- Robustness check
  - *Review papers* vs control papers
  - Analysis of only the title of publications (similar results)
- Future work
  - How new scientific ideas diffuse in patents?
  - How does the context (surrounding words) in which new scientific ideas appear and diffuse change?
  - *Novelty* vs *Interdisciplinarity*

# Conclusions

We will provide open access to
all text metrics for all papers in MAG published until 2020 (n=72,529,264).

We hope our data will open up opportunities for future research.

Thank you for your attention and for your questions

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# CRISPR example??

What did we find? Too much recent Nobel prize (2020)

- Jinek, M., Chylinski, K., Fonfara, I., Hauer, M., Doudna, J. A., & Charpentier, E. (2012). A programmable dual-RNA–guided DNA endonuclease in adaptive bacterial immunity. *Science*, 337(6096), 816-821.
  - 13 new grams and 156 new word combinations introduced by the paper -> 3 new gram and 18 new word combinations found in the Nobel prize motivation
    - rna-programmable_genome_editing,
    - cas9,tracrrna
    - crisp,tracrrna
    - ...