From research to impact collaborating with policy makers

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book

Unveiling the neurotechnology landscape: scientific advancements innovations and major trends

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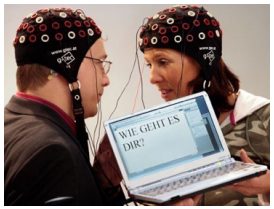
NEUROTECHNOLOGY: WHAT IS IT & WHAT DOES IT DO?



Neurotechnology consists of **devices and procedures** used to **access, monitor, investigate, assess, manipulate, and/or emulate** the structure and function of the **neural systems** of animals or human beings.

It is poised to revolutionize our understanding of the brain and to unlock innovative solutions to treat a wide range of diseases and disorders.

Viewed Image

Predicted Image

Image shown
(Viewed for one second)

Decoded output
(Shown here at 1/4 speed)

Original

Reconstruction

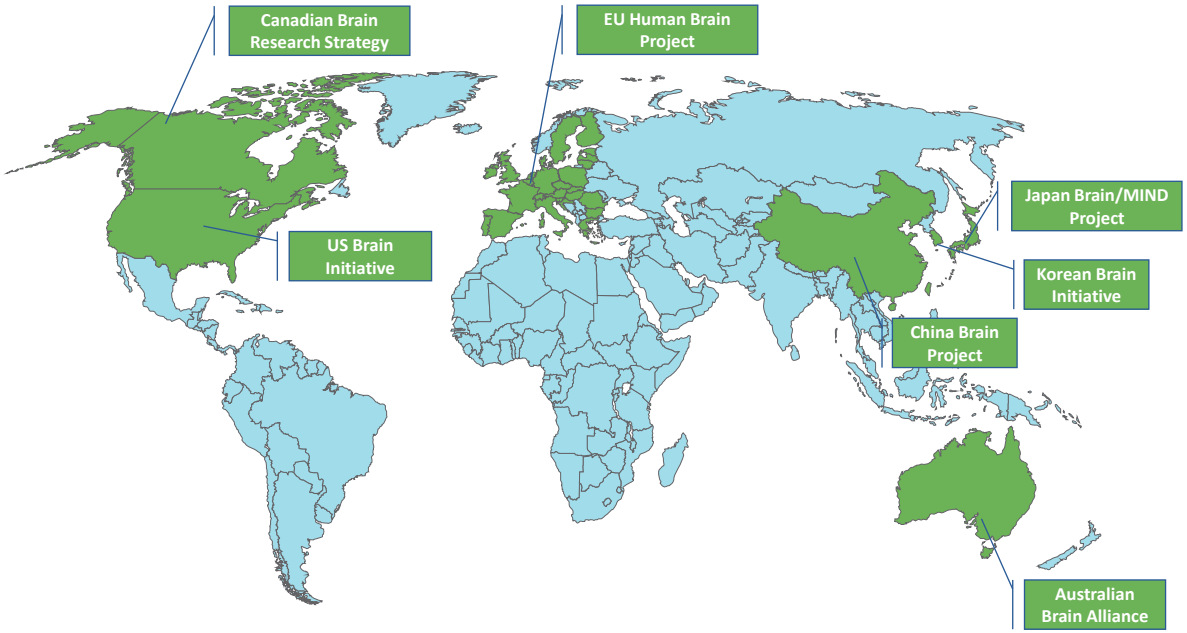
Brain-Music Decoding: Scientists decoded Pink Floyd's "Another Brick in the Wall" from brain activity using electrodes and computer models, showcasing the potential to reconstruct music from brain data.

Brain's Response to Music: The research revealed how various brain areas respond to musical elements like rhythm and harmony, highlighting the superior temporal gyrus's role in music processing.

Future Applications: This study has implications for developing communication aids for people with speech-limiting conditions and enhances understanding of the brain's perception of music and natural sounds.

Growing investments and markets

Figure 1. Government-backed and/or national-wide brain research initiatives across the world



Government investments in neurotechnology have surpassed **$6 billion since 2013**, as estimated based on available information.

GROWING INVESTMENTS & MARKETS

- Private investment in neurotech companies has also experienced remarkable growth, with annual funding increasing **22-fold from 2010 to 2020, reaching $7.3 billion** and totaling **$33.2 billion by 2020**.
- Projections point to neurotechnology's growth potential, with the neurotech devices market projected to reach **$24.2 billion by 2027**.

… AND GROWING CONCERNS

- mental integrity
- human dignity
- personal identity
- freedom of thought
- autonomy, and privacy
- potential for enhancement purposes
- accessibility
- …

AN INNOVATIVE APPROACH TO DELINEATE THE BOUNDARIES OF A COMPLEX TECHNOLOGY

- Map out the **scope and development** in neurotechnology-related neuroscience research landscape
- Identify and quantify trends within neurotechnology-related patents
- Establish a patent-classification based taxonomy for this complex multi-disciplinary technological field

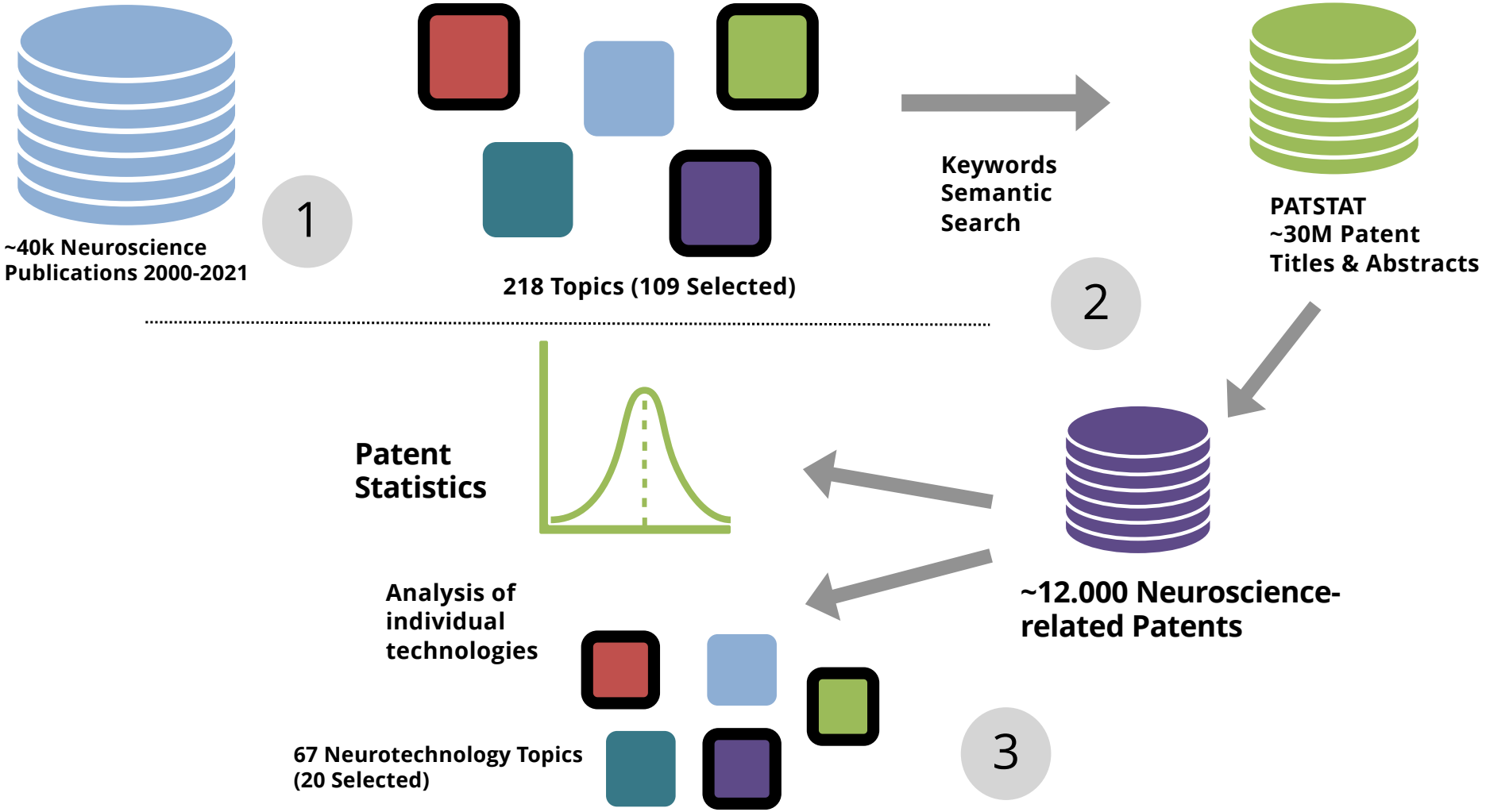
Background: Mapping Science Technology Linkages

- Why? → To understand technological evolution but also to document impact of (public) investment into research (Meyer, 2000; Looy et al., 2003), STI evaluations
- Has been proven challenging (Mansfield, 1991; McMillan et al., 2000; Narin et al., 1997). Approaches:
- Science-originating e.g. counts of patents by university staff (Henderson et al., 1994; Schmoch, 1997); author-inventor matching (Boyack and Klavans, 2008; Cassiman et al., 2007).

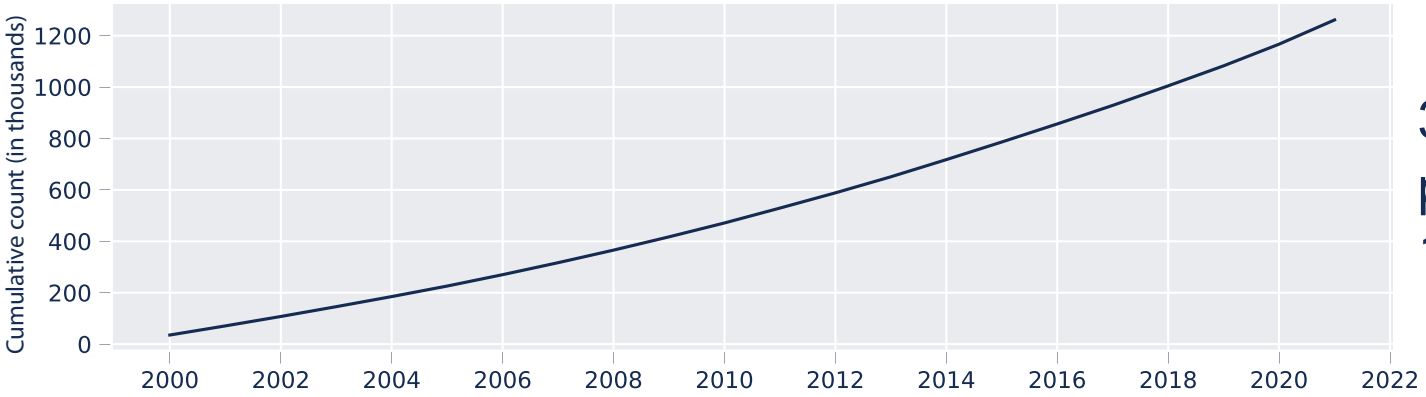
Background: Mapping Science Technology Linkages

- NPL (non-patent-literature) references in patents (Verbeek et al., 2002; Callaert et al., 2012), and patent citation in publications
- Content based approaches: Text-mining (Bakhtin et al. 2017), topic-modelling (Ranaei et al. 2017)

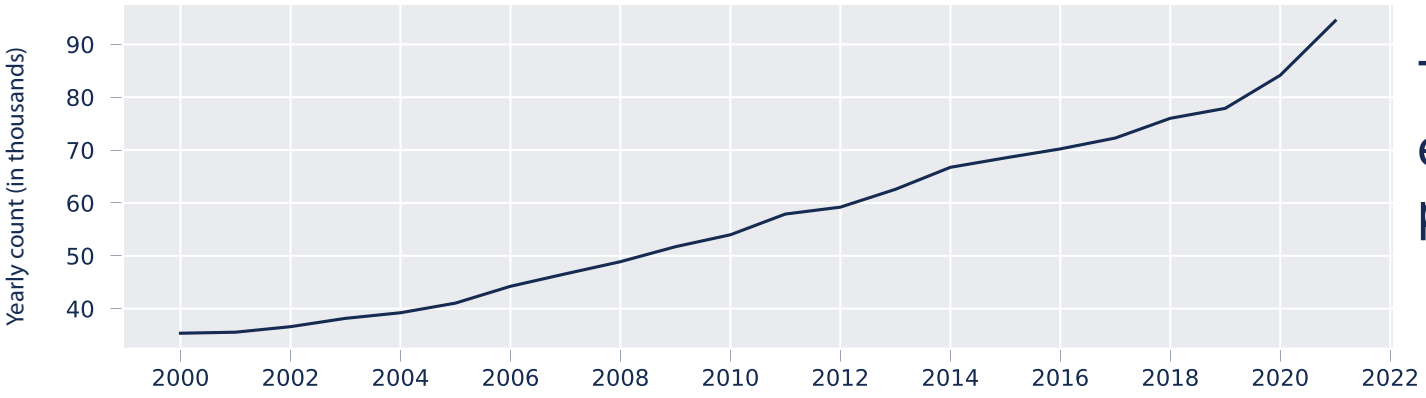
Analysis Pipeline - Overview



Neuroscience publications over time, 2000-2021



35-fold increase over the period considered, reaching 1.2 million in 2021



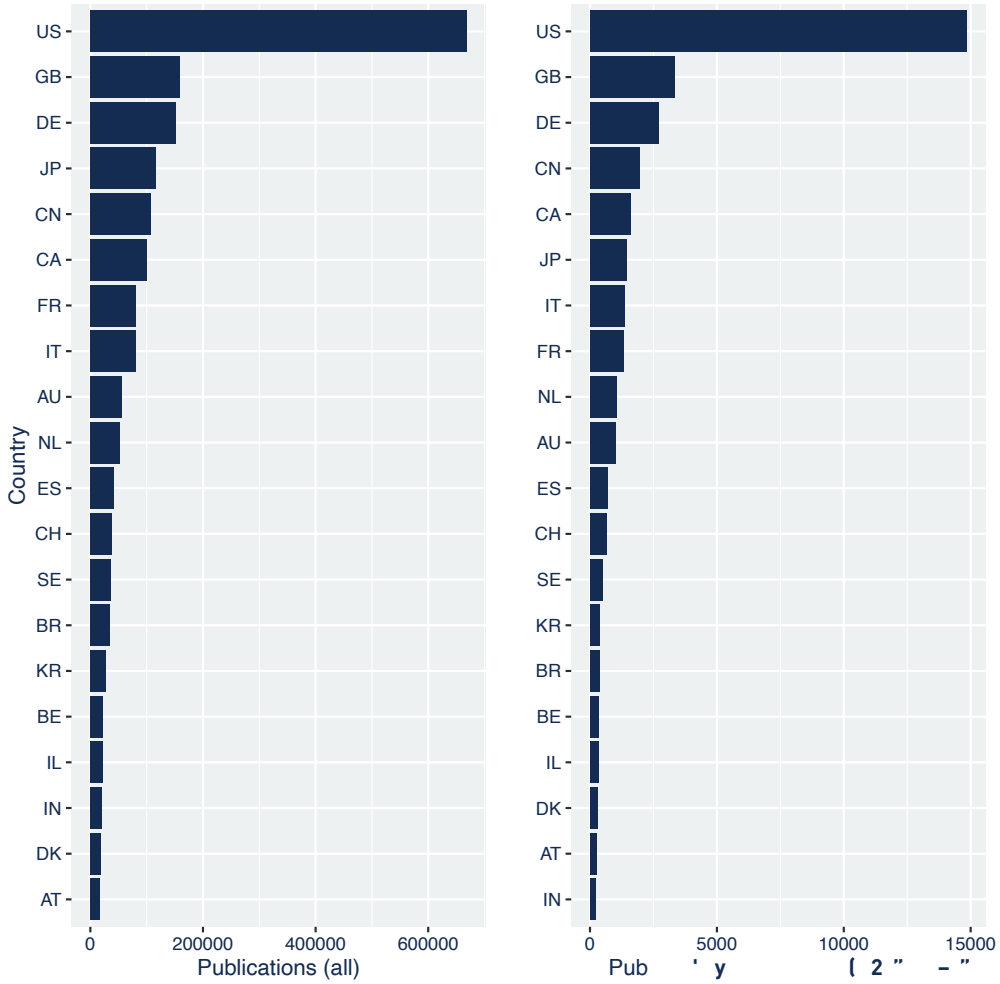
Tripled since 2000, exceeding 90,000 publications a year in 2021.

Most popular neuroscience journals and keywords

Journal	n	Keywords	n
Journal of Neuroscience	1866	**Alzheimer's Disease**	1199
Neuron	1674	**Depression**	859
Nature Neuroscience	1108	**Parkinson's Disease**	776
NeuroImage	981	**Hippocampus**	730
Brain Research	897	**Schizophrenia**	700
EMBO Journal	847	**Inflammation**	686
eLife	701	**fMRI**	666
Biological Psychiatry	668	**Microglia**	590
Neuroscience Letters	661	**Neurodegeneration**	498
Molecular Psychiatry	592	**Stress**	495
Nature Reviews Neuroscience	553	**Cognition**	494
Neuroscience	493	**Anxiety**	468
Annals of Neurology	483	**Aging**	467
Neuroscience and Biobehavioral Reviews	474	**Dopamine**	454
Neurocomputing	456	**COVID-19**	439
Movement Disorders	424	**Stroke**	423
PLOS Biology	422	**Neuroinflammation**	422
Trends in Cognitive Sciences	416	**Epilepsy**	418
European Journal of Neuroscience	398	**Multiple Sclerosis**	415
Investigative Ophthalmology and Visual Science	363	**Meta-analysis**	407

A multidisciplinary field spanning a wide range of topics from biology, clinical applications as well as psychiatric and cognitive aspects.

Neuroscience publications by country



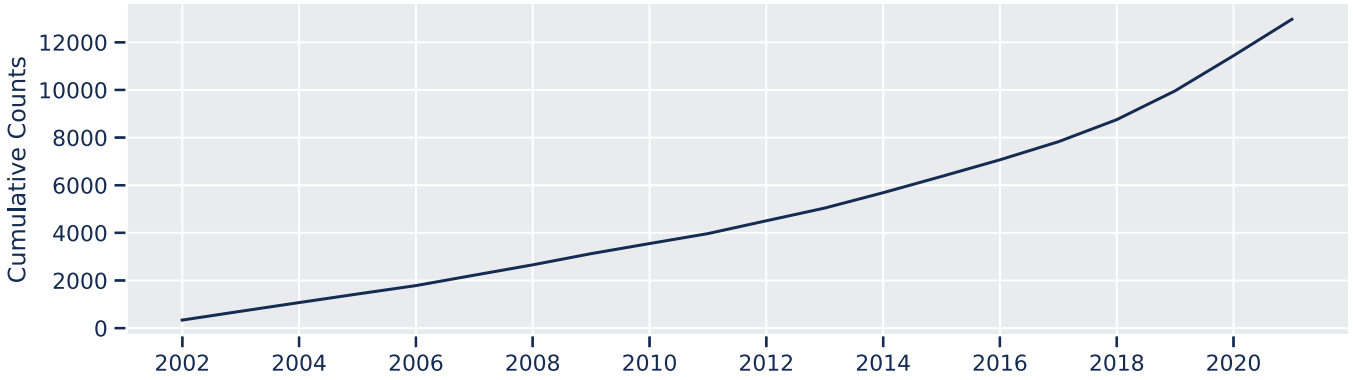
The US leads in terms of neuroscience publication output (40%), followed by the United Kingdom (9%), Germany (7%), China (5%), Canada, Japan, Italy and France (4% each) and the Netherlands and Australia (3% each)

These 10 countries together account for over 80% of neuroscience publications in 2000-21

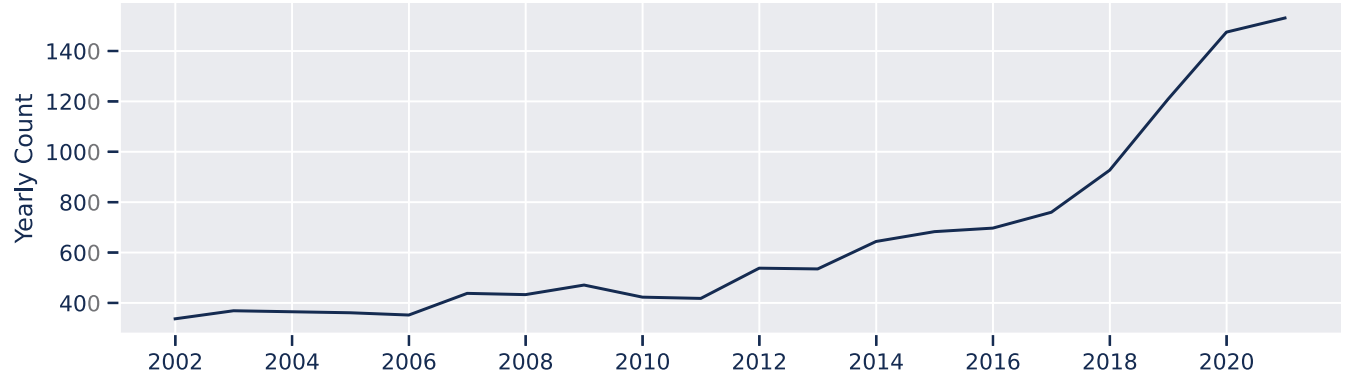
BUT

70% of countries in the world have less than 10 high-impact neuroscience publications between 2000-21

Neurotechnology-related patents over time, 2000-2020

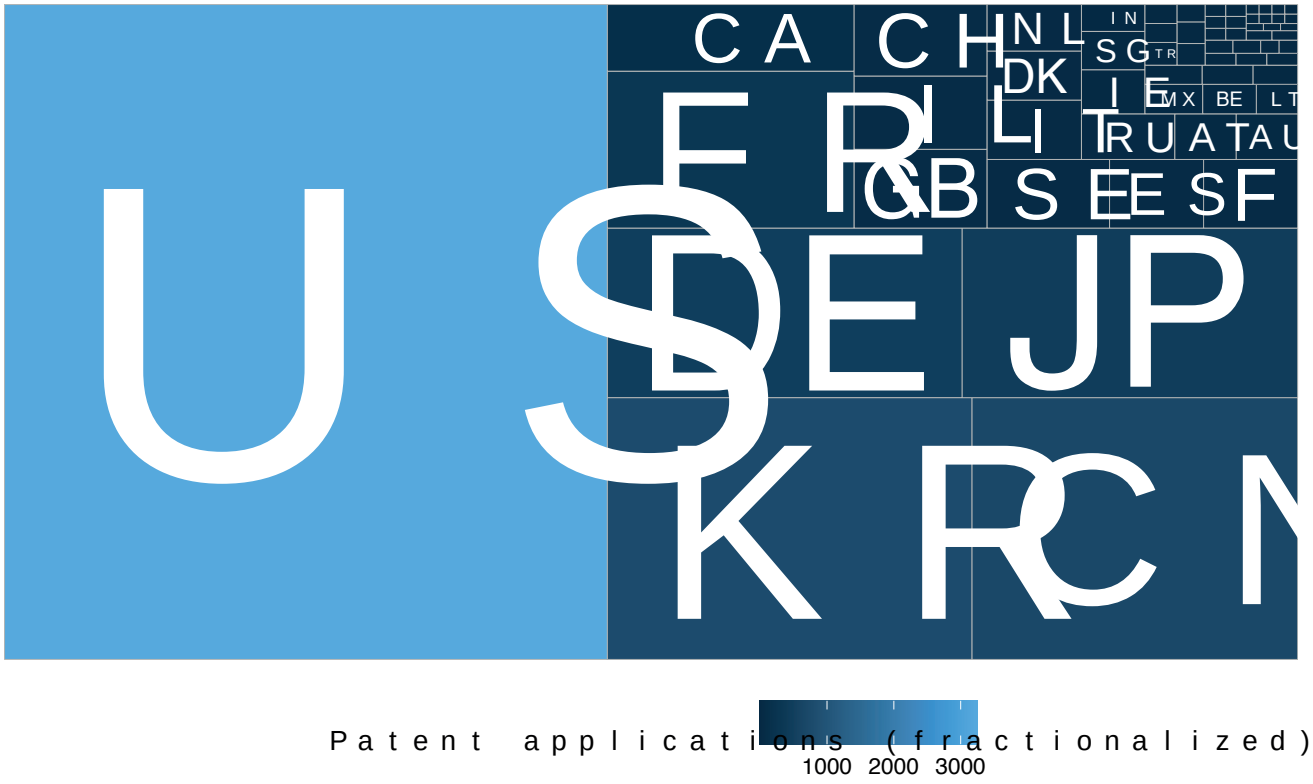


20-fold increase from less than 500 to over 12,000.



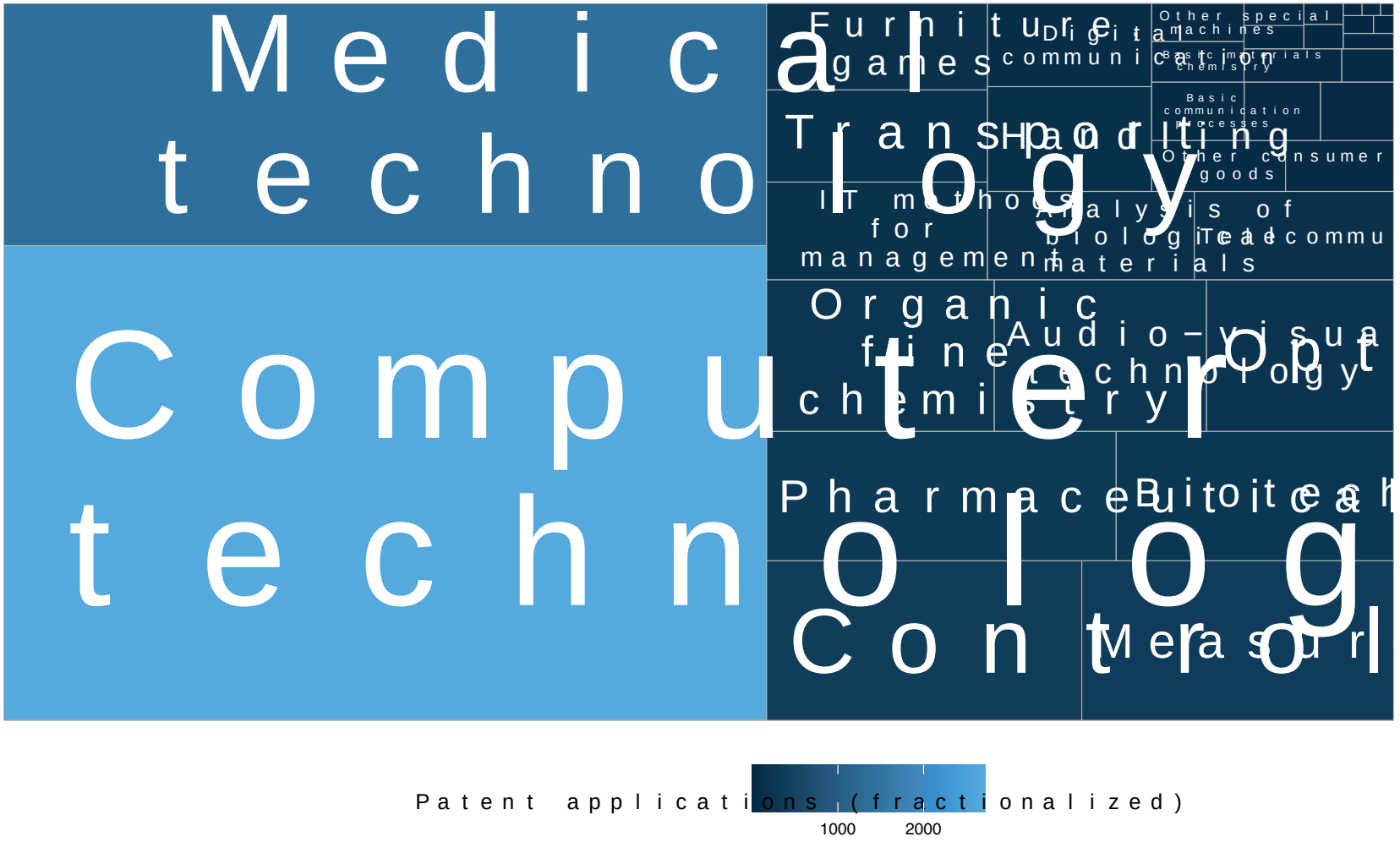
Notable doubling observed between 2015 and 2020, in terms of annual figures

Patent applicants in neurotechnology by country

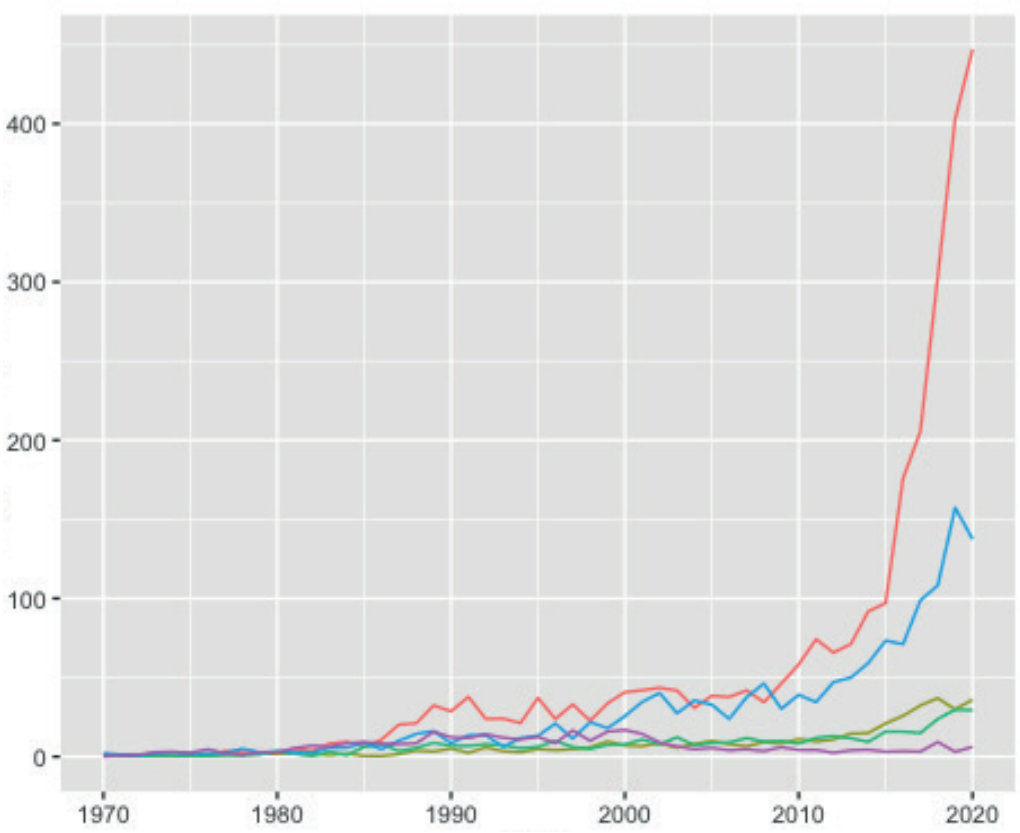


Six countries together account for 87% of IP5 neurotech patents applied

Number of Neurotechnology patents by technology field



Number of Neurotechnology patents by technology field



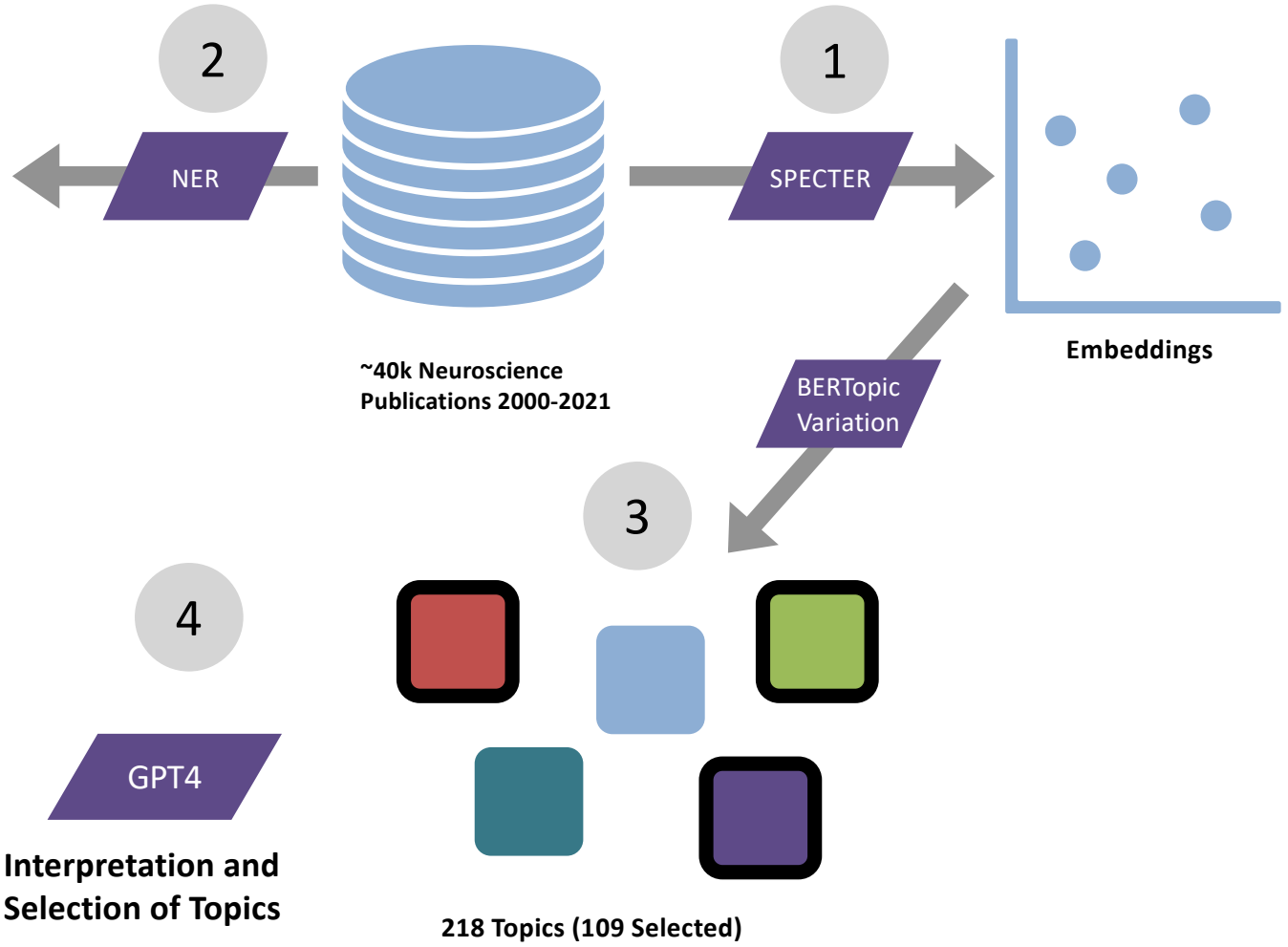
Compared to the reference year, computer technologies-related patents in neurotech increased by 355% and by 92% in medical technology.

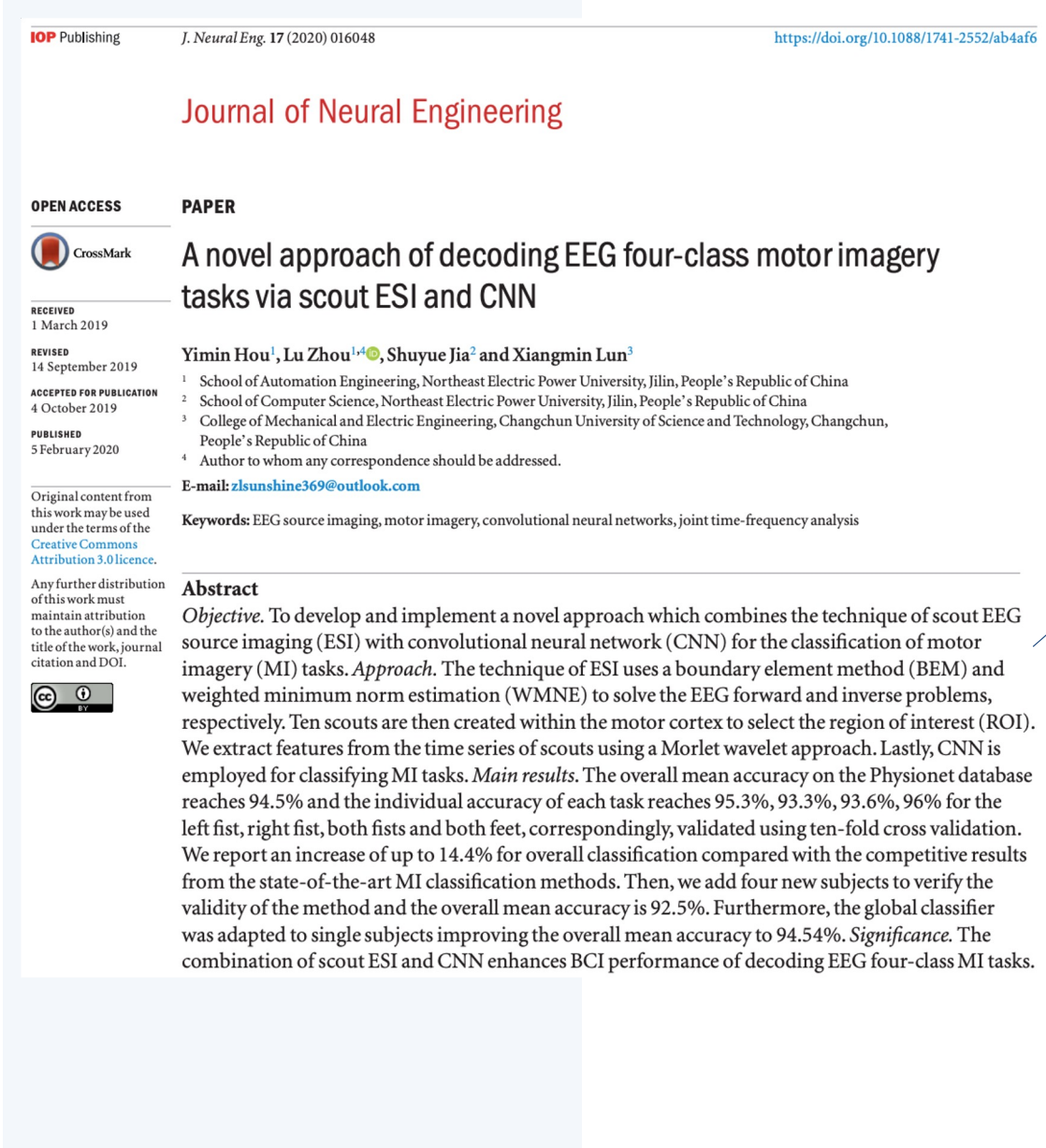
From Neuroscience Publications to Topics and Query Keywords

Neural Keyword Extraction (SciNERTopic)
DBS, STN, subthalamic nucleus, "Parkinsons disease", PD, Deep brain stimulation (DBS), deep brain stimulation (DBS), basal ganglia, GPi, STN-DBS, deep brain stimulation, subthalamic nucleus (STN), movement disorders ….

Summary: Deep brain stimulation (DBS) of the subthalamic nucleus (STN) for treating Parkinson's disease and other movement disorders.

Application: DBS is used to alleviate motor symptoms in Parkinson's disease, essential tremor, dystonia, and OCD by targeting the basal ganglia and modulating oscillatory activity.





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A novel approach of decoding EEG four-class motor imagery tasks via scout ESI and CNN

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Keywords: EEG source imaging, motor imagery, convolutional neural networks, joint time-frequency analysis

Abstract

Objective. To develop and implement a novel approach which combines the technique of scout EEG source imaging (ESI) with convolutional neural network (CNN) for the classification of motor imagery (MI) tasks. *Approach.* The technique of ESI uses a boundary element method (BEM) and weighted minimum norm estimation (WMNE) to solve the EEG forward and inverse problems, respectively. Ten scouts are then created within the motor cortex to select the region of interest (ROI). We extract features from the time series of scouts using a Morlet wavelet approach. Lastly, CNN is employed for classifying MI tasks. *Main results.* The overall mean accuracy on the Physionet database reaches 94.5% and the individual accuracy of each task reaches 95.3%, 93.3%, 93.6%, 96% for the left fist, right fist, both fists and both feet, correspondingly, validated using ten-fold cross validation. We report an increase of up to 14.4% for overall classification compared with the competitive results from the state-of-the-art MI classification methods. Then, we add four new subjects to verify the validity of the method and the overall mean accuracy is 92.5%. Furthermore, the global classifier was adapted to single subjects improving the overall mean accuracy to 94.54%. *Significance.* The combination of scout ESI and CNN enhances BCI performance of decoding EEG four-class MI tasks.

NER Example

Methods

['scout EEG source imaging (ESI)', 'convolutional neural network (CNN)', 'Approach', 'ESI', 'boundary element method (BEM)', 'weighted minimum norm estimation (WMNE)', 'Morlet wavelet approach', 'CNN', 'ten-fold cross validation', 'MI classification methods', 'global classifier', 'scout ESI', 'CNN']

Tasks

['classification of motor imagery (MI) tasks Approach', 'Approach', 'EEG forward and inverse problems', 'classifying MI', 'MI tasks', 'classification', 'BCI', 'decoding EEG four-class MI tasks']

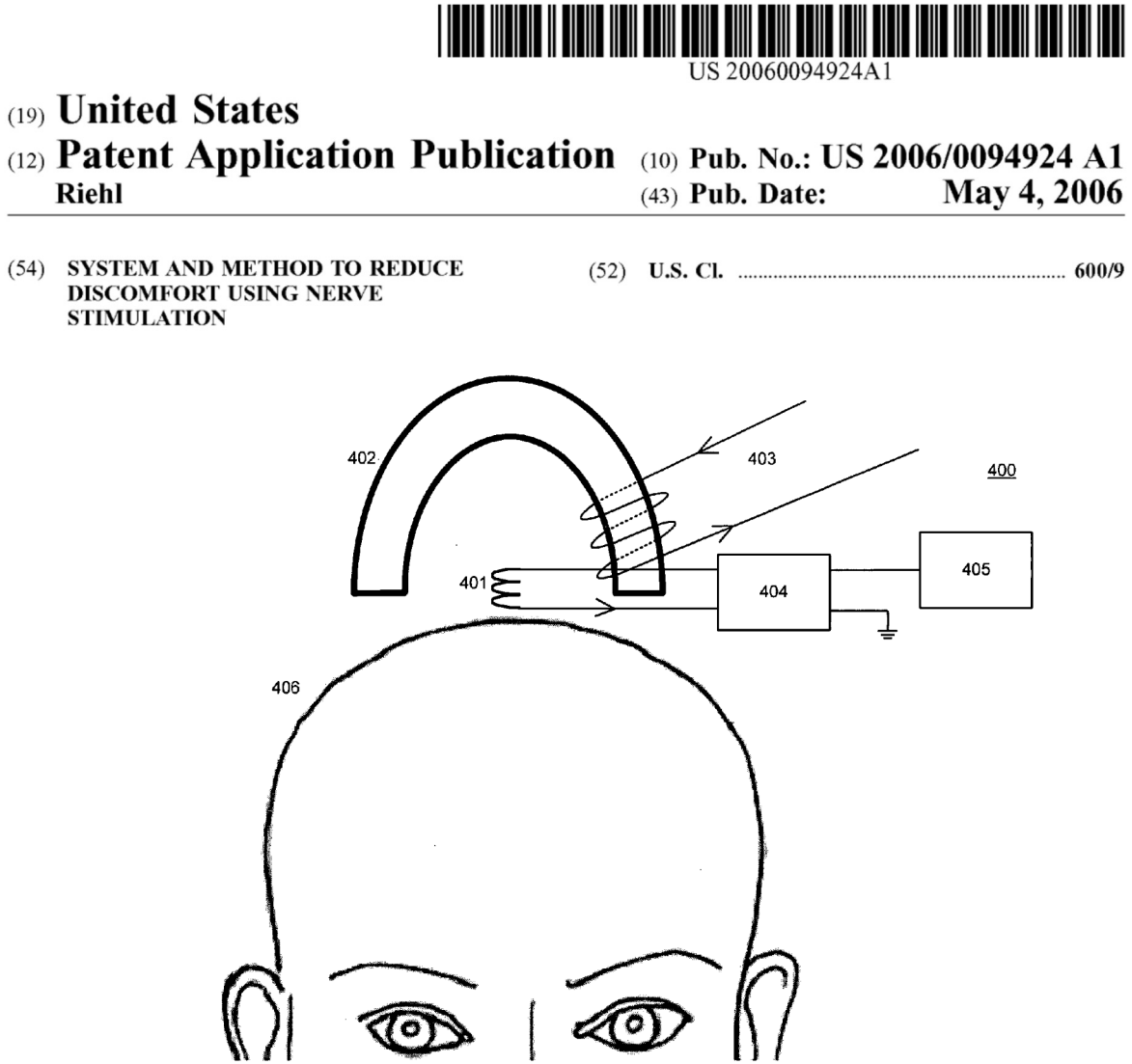
Data II: Patents

PATSTAT (Spring 2022)

Limited **to priority filings** (De Rassenfosse et al., 2013)

Only include patent families with at least one **IP5 filing**.

Augmented with further data, eg. **p2p similarity** (Hain et al., 2022), **quality indicators** (Squicciarini et al., 2013), **geocoding** (similar to De Rassenfosse et al., 2019)



US 20060094924A1

(19) **United States**

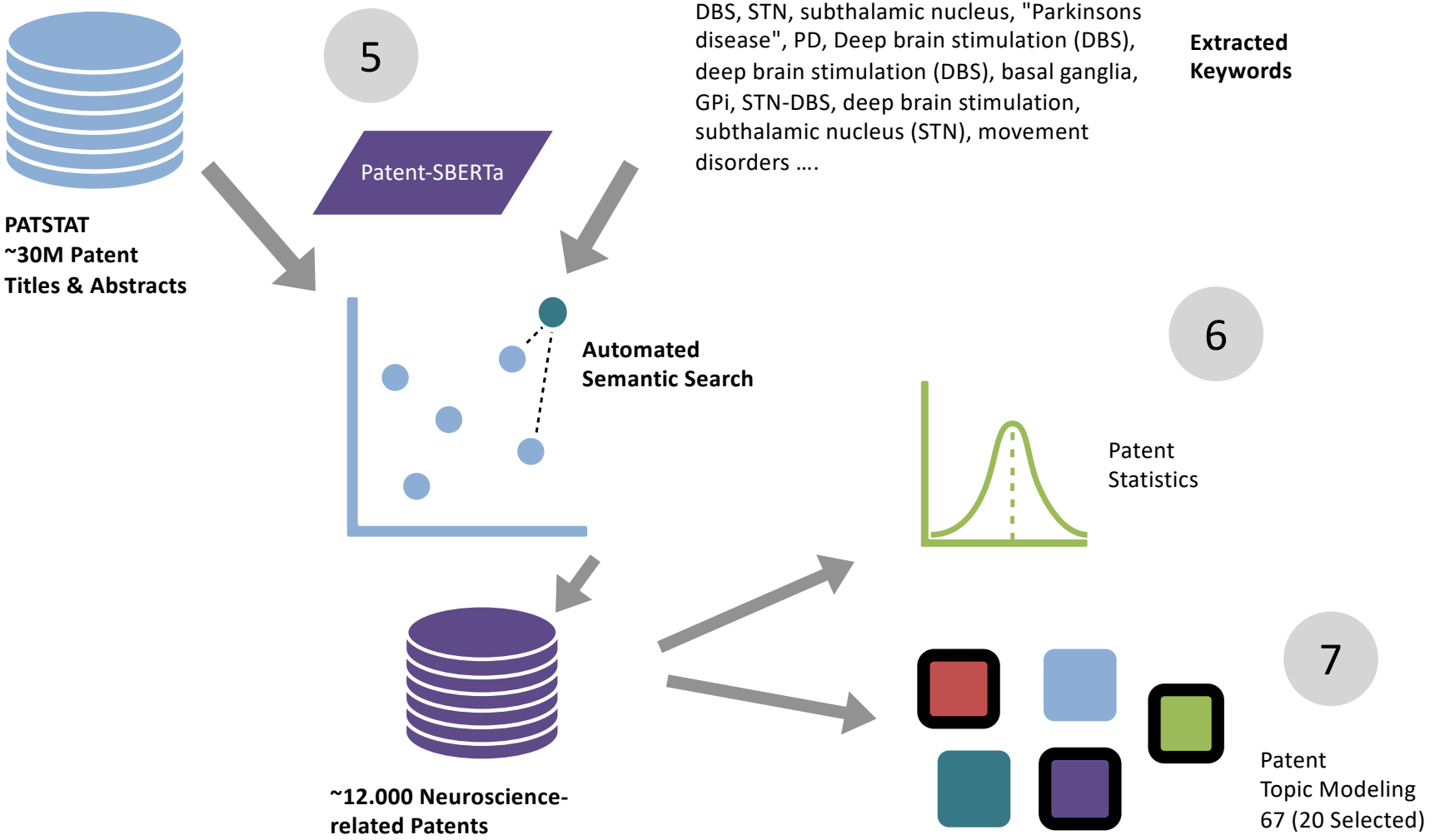
(12) **Patent Application Publication** (10) **Pub. No.: US 2006/0094924 A1**

Riehl (43) **Pub. Date: May 4, 2006**

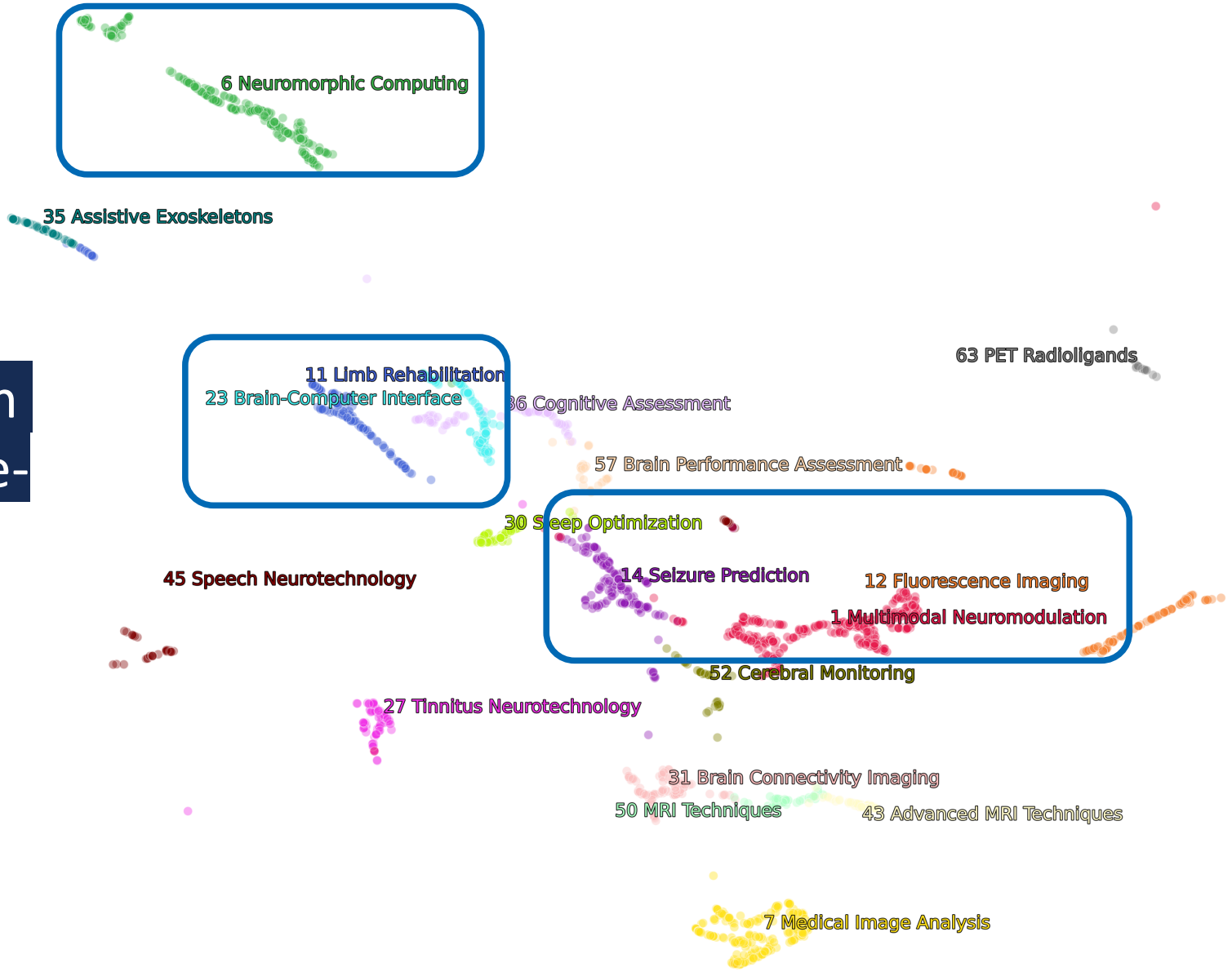
(54) **SYSTEM AND METHOD TO REDUCE DISCOMFORT USING NERVE STIMULATION**

(52) **U.S. Cl.** **600/9**

From keywords to neurotechnology patents and insights



Zooming in on patented core-technologies



Pioneering taxonomy of neurotechnologies based on IPC codes

- **67 distinct patent clusters in neurotechnology are identified, which mirror the diverse research and development landscape of the field. 20 "core technologies" related to neuromodulation, seizure prediction and BCIs**
- **Most prominent IPC within these "core-technologies"**
  - **A61B 5/00, G01R 33/00, and G01T 1/00 related to measurement technology.**
  - **G06N 3/00 concerning computer systems modeled on biological structures.**
  - **G16H 30/00, 50/00 associated with information technology.**

Uncovering Intersections in Neurotechnology via IPC Combinations

- **A61B 5/00 (Physiological Measurement)** frequently pairs with codes related to optical elements, semiconductor devices, wireless power supply circuits, and vehicle accommodations, demonstrating neurotechnology's versatility.
- **A61N 1/00 (Neurostimulation)** often intersects with **G16H 50/00 (Health Informatics)**, underscoring the crucial role of informatics and data analysis.
- **G06N 3/00 (AI Technology)** combined with codes for devices using magnetic effects, capacitors, and radiation therapy, indicating AI's integration in diverse neurotech applications.
- **G06T 7/00, G01N 21/00, and G01R 33/00 (Medical Imaging)** repeatedly pair with **A61B 5/00**, signifying heavy reliance on imaging and material analysis.

From Neuroscience Publications to Topics and Query Keywords

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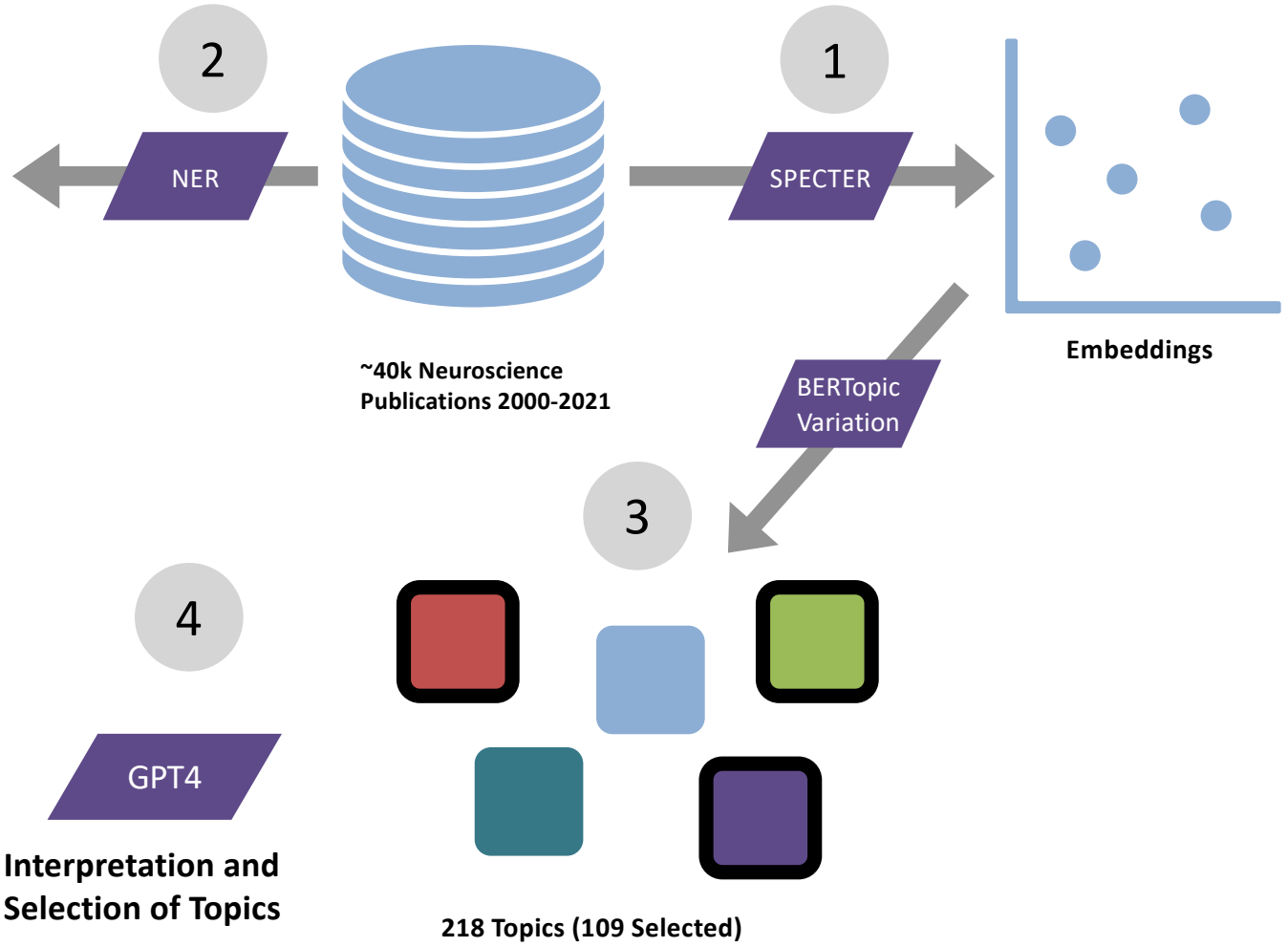
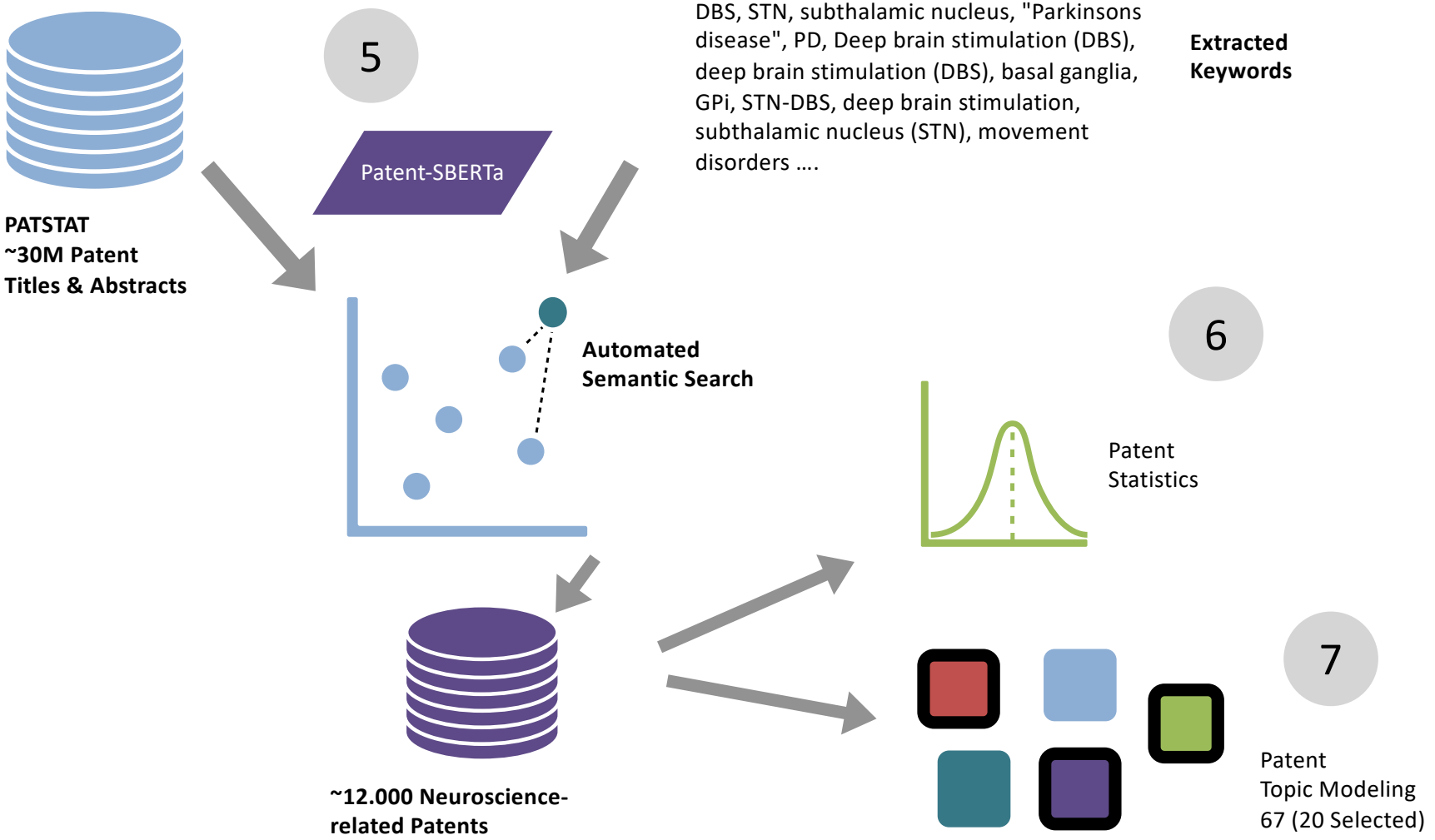
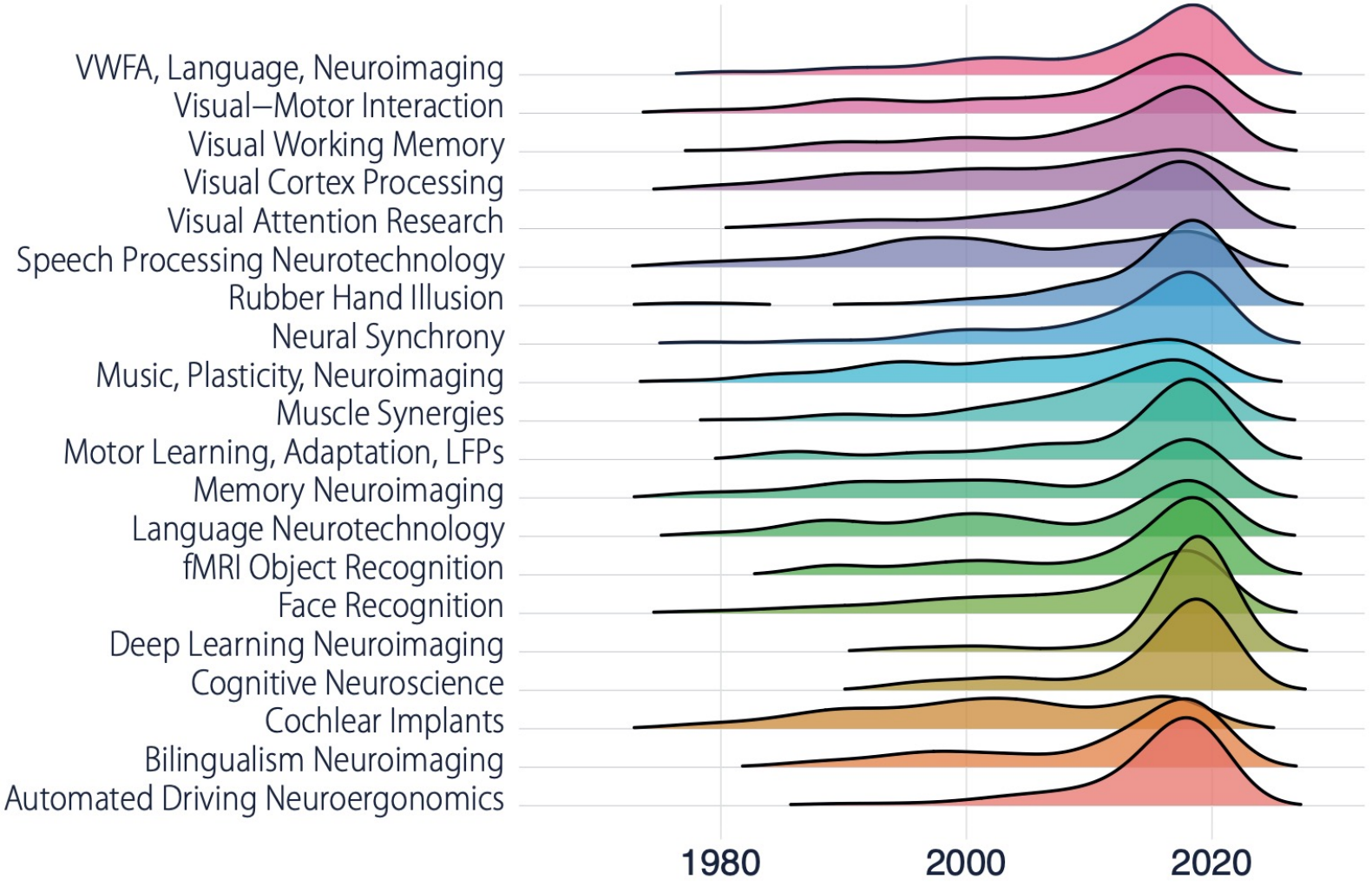


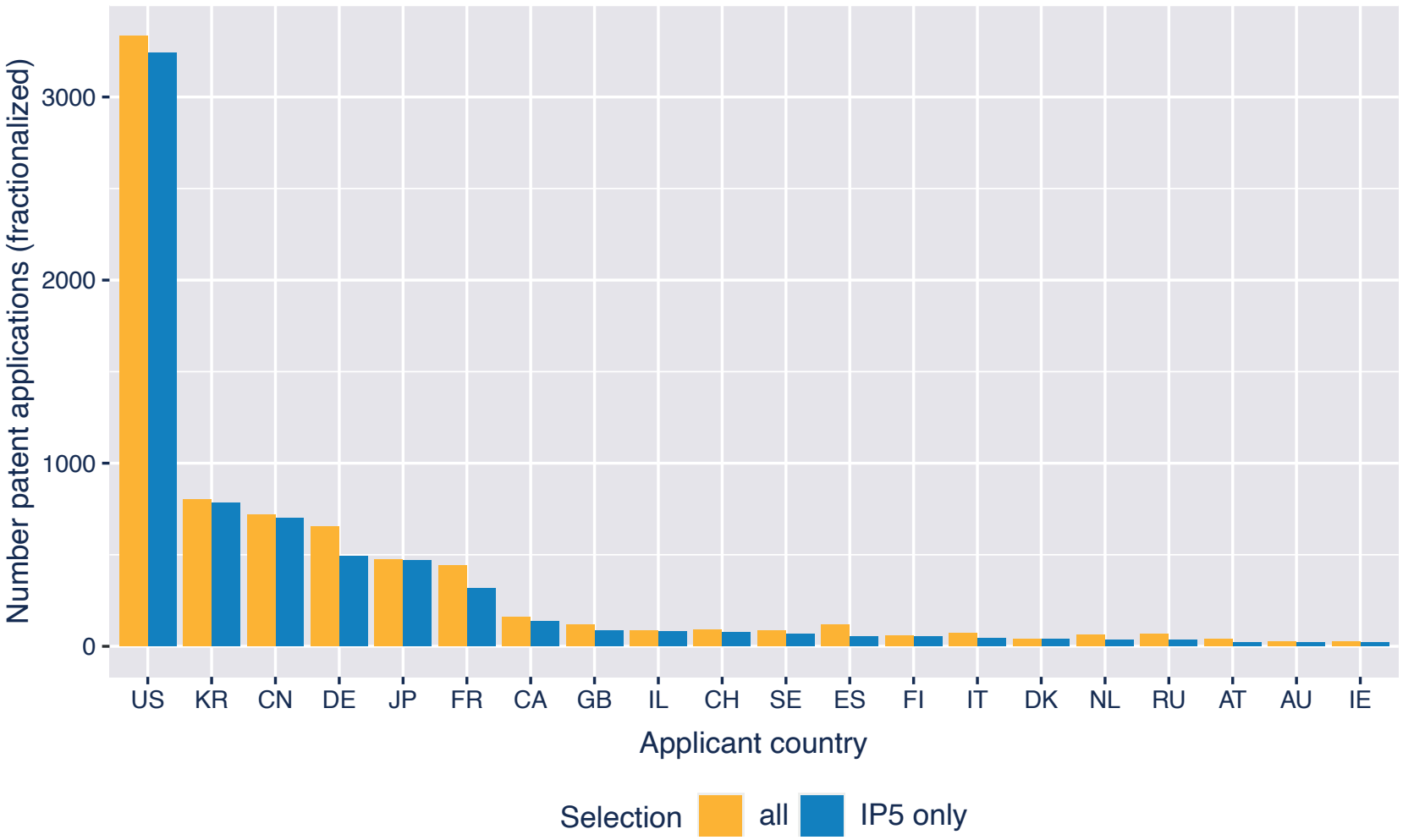
From keywords to neurotechnology patents and insights



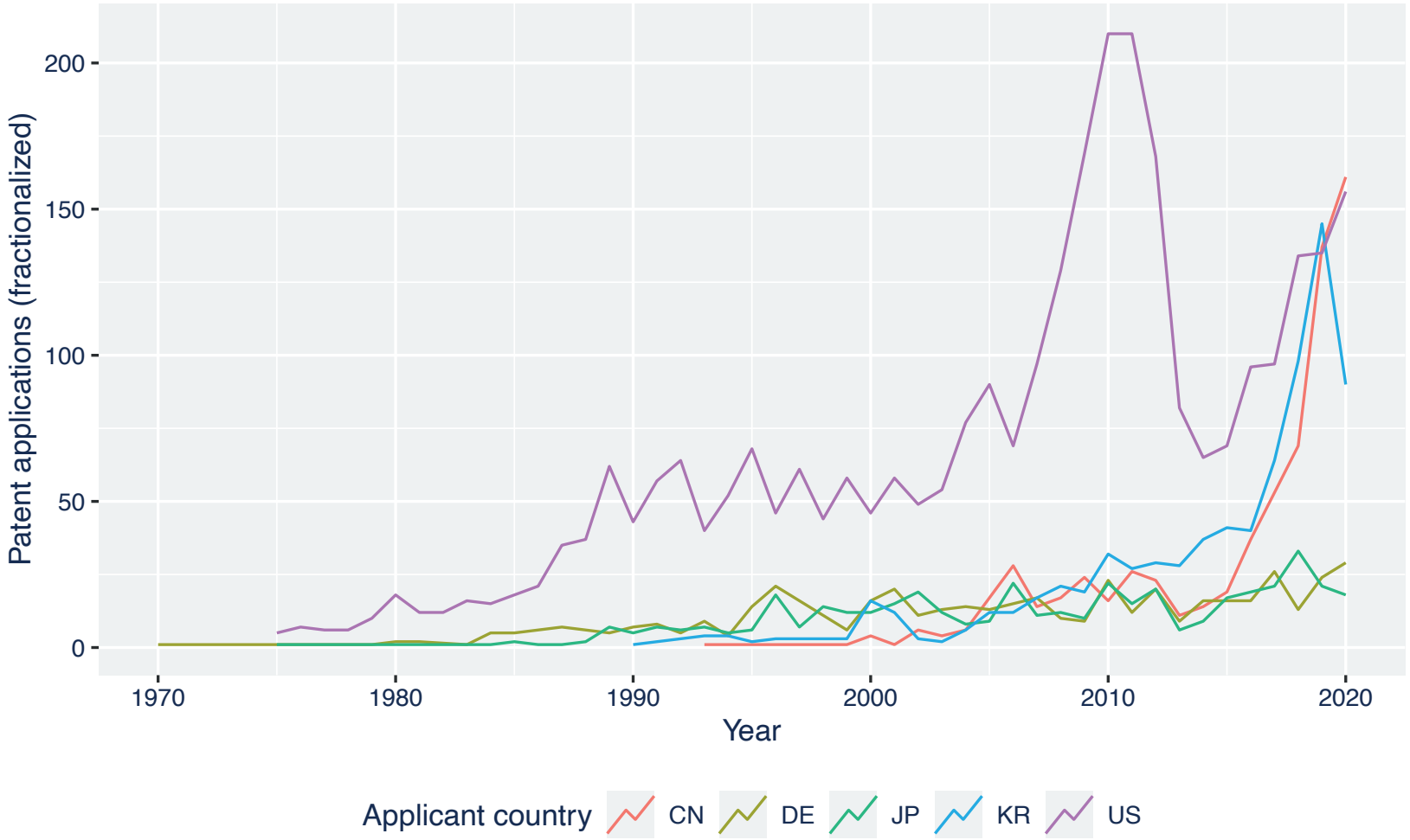
Patent applications in top technology fields (identified based on scientific publications)



Country of neurotechnology patent applicants, all vs. IP5



Patent applicants in neurotechnology by country (top-5)

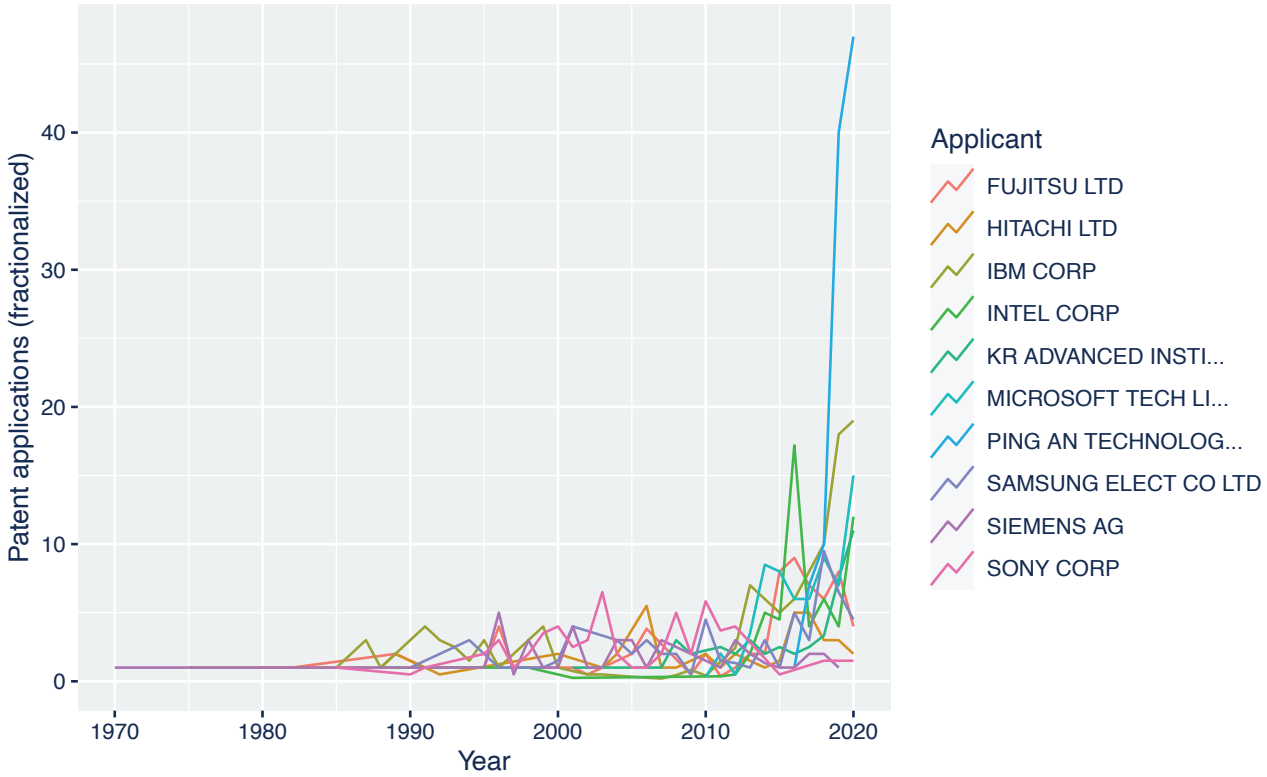


Patent quality per country

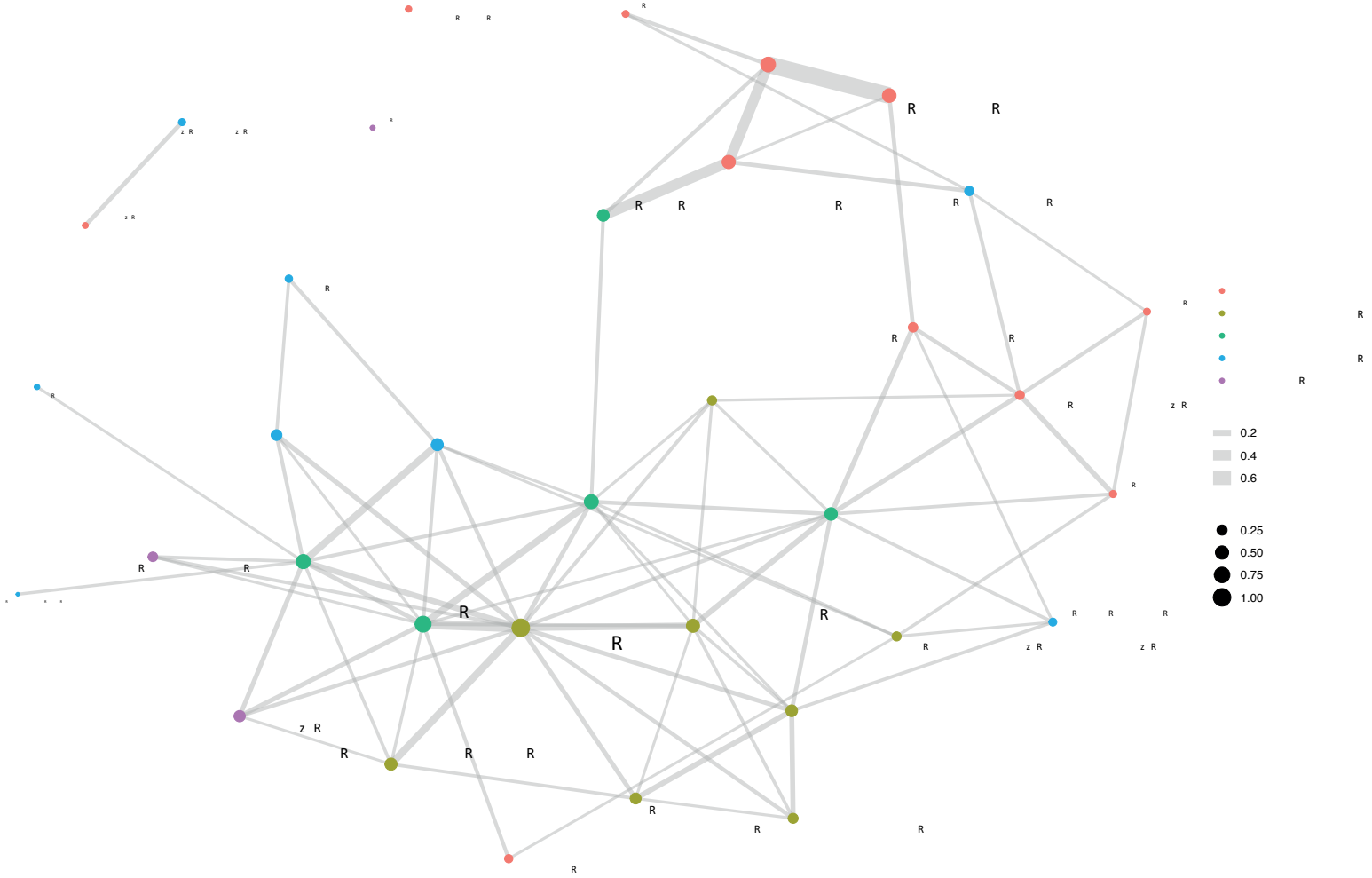
Country	Forward Citations (cohort rank)	DOCDB family size (cohort rank)
DE	0.80	0.66
US	0.72	0.77
CN	0.68	0.66
JP	0.67	0.68
KR	0.66	0.54

Top five neurotech patent applicants per top country (left) and neurotechnology patents of top applicants over time (right)

Country	Applicant name	n
US	IBM Corporation	126
US	Microsoft Technology Licensing, LLC	76
US	Intel Corporation	64
US	General Electric Company	52
US	Microsoft Corporation	51
KR	Samsung Electronics Co., Ltd.	72
KR	Korea Advanced Institute of Science & Technology	52
KR	Electronics and Telecommunications Research Institute	46
KR	LG Electronics, Inc.	26
KR	Korea University Research and Business Foundation	25
CN	Ping An Technology (Shenzhen) Co., Ltd.	105
CN	Huawei Technologies Co., Ltd.	37
CN	Zhejiang University	30
CN	Tencent Technology (Shenzhen) Co., Ltd.	25
CN	Shenzhen Institutes of Advanced Technology	23
JP	Fujitsu Ltd.	78
JP	Sony Corporation	69
JP	Hitachi, Ltd.	54
JP	Canon Inc.	39
JP	NEC Corporation	25
DE	Siemens AG	52
DE	Siemens Healthcare GmbH	32
DE	Robert Bosch GmbH	21
DE	Philips Patentverwaltung GmbH	12
DE	BASF AG	9



Technology field relationships in Neurotechnology within a technology space network



Revealed Technological Advantage (RTA) in neurotechnology by top-countries and technology field

Technology Field	China	Germany	Japan	South Korea	United States
Computer technology	1.58	0.62	1.24	0.96	1.1
Medical technology	0.72	1.18	0.69	1.3	0.92
Pharmaceuticals	0.2	2.03	0.21	0.28	1.06
Control	0.54	0.76	0.74	0.86	1.13
Measurement	1.04	1.8	0.91	0.39	0.98
Organic fine chemistry	0.13	2.06	0.06	0.22	1.08
Biotechnology	0.7	1.72	0.41	0.86	0.76
Audio-visual technology	0.71	0.47	1.78	1.05	1.03
Optics	0.62	0.9	1.16	0.99	0.94
IT methods for management	1.24	0.09	0.54	1.91	1.01
Transport	0.32	1.82	0.83	2.16	0.86
Analysis of biological materials	1.11	2.44	0.31	1.2	0.72
Telecommunications	0.29	0.64	3.34	0.64	0.93
Furniture, games	1.01	0.1	0.7	1.24	1.04
Digital communication	0.94	0.42	1.35	1.23	0.97

RTA >=1 RTA <= 0.5

Neurotechnology space – China (left) and Germany (right)

Note: Nodes = Technology Fields, Edges = Relatedness. Node color indicates RCA, node size complexity of technology field. Only technology fields with RCA >= 1 are labeled.

Source: authors' own compilation on data from European Patent Office's Worldwide Patent Statistical Database (PATSTAT) (2000-2020)

Spotlight on Core Neurotech Patents Largest clusters

Multimodal Neuromodulation

Contains 535 patents focused on deep/superficial brain stimulation for neurological and psychiatric conditions.

Technologies for treating conditions such as obsession, anxiety, depression, Parkinson's, and more.

Modalities include Deep-Brain Stimulators (DBS), Transcranial Magnetic Stimulation (TMS), and transcranial Direct Current Stimulation (tDCS).

Seizure Prediction

Encompasses 190 patents related to real-time brain wave data analysis, primarily using Electroencephalogram (EEG) or Electrocorticogram (ECoG) signals.

Detection and prediction of seizures and brain dysfunctions assist in diagnosis and treatment of neurological disorders.

Technologies classified under medical apparatus for diagnosis, antennas, and other apparatus for psychological testing or biofeedback.

Neuromorphic Computing

Includes 366 patents related to devices mimicking human neural networks for computation.

Primary inventions are resistive memory cells and artificial synapses.

Classified under neural network models, analog computers, and static storage structures.

More Core Neurotech Patents

Brain-Computer Interfaces

Consists of 146 patents enhancing the interface between the brain and external devices.

Patents classified under methods or devices for treatment or protection of eyes and ears, devices for introducing media into, or onto, the body, and electric communication techniques.

Limb Rehabilitation

Applications of neurotechnology using augmented reality, brain-computer interfaces, and virtual reality for gait and limb rehabilitation.

Tinnitus Neurotechnology & Sleep Optimization

Estimating uncomfortable loudness levels and providing relief through synchronized electrical stimulation and sound enrichment.
Creating personalized sleep classifiers for improving sleep quality.

Assistive Exoskeletons

Using electromyographic control and adjustable stiffness joints to assist human movement.

Advanced Imaging Techniques

Innovations in neuroimaging for improving spatial and temporal resolutions, reducing artifacts, tracking motion, and enabling real-time 3D imaging of biological tissues.

Provisional IPC-based Taxonomy for Neurotechnology

- **Methodology:**

  A highly filtered sample of neurotechnology patents used to develop a provisional.
  Most representative IPC codes for each cluster using cTF-IDF.

- **Key IPC Groups:**
  - A61B 5/00, G01R 33/00, and G01T 1/00 related to measurement technology.
  - G06N 3/00 concerning computer systems modeled on biological structures.
  - G16H 30/00, 50/00 associated with information technology.

Provisional IPC-based Taxonomy for Neurotechnology

- **Medical Imaging**: MRI, computerised tomographs, and various forms of spectroscopy.
- **Physiological Measurement**: Devices for monitoring blood characteristics, heart rate, pulse, body temperature, and more.
- **Neurological Technologies**: Neurostimulation, bioelectric signals measurement, EEG, and treatment devices for neurodegenerative disorders.
- **Surgical Technologies**: Surgical robots, patient positioning devices, devices for orthopedic needs.
- **Other technologies**: Audiology, Biomaterial Analysis, Bioelectric Control, Pharmaceuticals, Health Monitoring Systems, Speech Recognition, AI, Nuclear Technologies, Optical Technologies, Computer Interaction.