Network analysis in quantitative epistemology towards open science and reflexivity

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CASA Networks Seminar
November 26th, 2021

Introduction

Knowledge production processes studied from diverse viewpoints:

- Sociology of science [Callon and Latour, 2013]
- Philosophy of science [Hacking, 1999]
- Innovation economics [Grupp et al., 1998]
- Cognitive science [De Mey, 2012]
- Scientometrics [Mingers and Leydesdorff, 2015]

→ Recent applications of network science [Fortunato et al., 2018]

→ Towards a *quantitative epistemology* [Chavalarias and Cointet, 2013]

This presentation: *Synthesis of different network analysis applied to quantitative epistemology, within the context of open science and reflexivity*

PLOS | ONE

RESEARCH ARTICLE

Classifying patents based on their semantic content

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Abstract

In this paper, we extend some usual techniques of classification resulting from a large-scale data-mining and network approach. This new technology, which in particular is designed to be suitable to big data, is used to construct an open consolidated database from raw data on

Why study patents?

$\rightarrow$ Although imperfect, patents are the most commonly used measure of innovation in economics
$\rightarrow$ Particular case of the ecology and evolution of knowledge; diffusion of knowledge

Examples:

- [Griliches, 1998]: patent as an economic indicator
- [Youn et al., 2015] interaction between technological fields; combinatorial nature of inventions
- [Bruck et al., 2016] citation network analysis to detect emerging research fronts
- [Gerken and Moehrle, 2012] [Tseng et al., 2007] semantic analysis (remains limited to specific fields and time windows)

Proposed approach
Complement existing patent office classifications using patent semantic content

Why?: more endogenous, flexible and informative (?). And comparison with *technological* classification to detect outliers.

Takeaway results

→ *An endogenous semantic classification is constructed for the full USPTO abstracts and titles, 1976-2012*

→ *Information carried in the semantic classification is complementary to the technological classification*

US006833896B2

(12) **United States Patent**
Lee

(10) **Patent No.:** **US 6,833,896 B2**
(45) **Date of Patent:** **Dec. 21, 2004**

(54) **METHOD OF FORMING AN ARRAY SUBSTRATE FOR AN IN-PLANE SWITCHING LIQUID CRYSTAL DISPLAY DEVICE HAVING AN ALIGNMENT FILM FORMED DIRECTLY ON A THIN FILM TRANSISTOR**

(75) Inventor: **Yun-Bok Lee**, Seoul (KR)

(73) Assignee: **LG.Philips LCD Co., Ltd.**, Seoul (KR)

6,407,791	B1 *	6/2002	Suzuki et al.	....	349/129
6,642,972	B2 *	11/2003	Yoo et al.	....	349/40
2001/0040648	A1 *	11/2001	Ono et al.	....	349/43
2002/0093600	A1 *	7/2002	Chol	....	349/43

FOREIGN PATENT DOCUMENTS

JP	09-005764	1/1997
JP	09-073101	3/1997
JP	09-101538	4/1997
JP	09-105908	4/1997

Technological classes: 349 (Liquid Crystal Cells, Elements and Systems), 257 (electrodes)

Prior art keywords (Google Patents): layer, method, gate, electrode, substrate

Most central keywords (our method): substrat, semiconductor, insul, gate, transistor

Descriptive statistics

Summary statistics for the USPTO database between 1976 and 2013

- 4,666,365 utility patents from 1976 to 2013
- 70,000 in 1976 to 278,000 in 2013
- 38,756,292 citation links (84% of within-class citations)
- 270,877 patents with no citations 5 years next to publication

Does this mean that innovation is 4 time larger en 2013 than in 1976...
Not necessary. Although definitely more specialized.

Database construction

Construction of a Database from US Patent and Trademark Office redbook 1976-2012 (full patent description), which provide raw data but on separate files and different formats

Data Collection Procedure

- Automatic download of raw data file
- Parsing depending on format : `dat` or `xml` (varying schema)
- Uniformisation and storing in MongoDB

$\rightarrow$ 4,666,365 patents with text data (abstract); dated by application date (current state of knowledge, differs from the granted date which implies review processes and an exogenous intervention)

Extracting relevant n-grams

Text-mining in python with `nltk` [Bird, 2006], method adapted from [Chavalarias and Cointet, 2013]. Advantage over LDA: scalability and flexibility

- Parsing and tokenizing / pos-tagging (word functions) / stemming with `nltk`
- Selection of potential *n-grams* (with $1 \leq n \leq 3$) with the rule $\bigcap\{NN \cup VBG \cup JJ\}$
- Database insertion for instantaneous use (several days $\rightarrow$ 1min)
- Estimation of *n-grams* relevance, following co-occurrences statistical distribution (*termhood* score as chi-2 score)

Estimation of n-gram relevance

- Termhood-based selection of a fixed number of keywords K_W=100, 000 (*difficulty to select terms in general*)
- Estimation on temporal moving windows $\left[t - T_w; t\right]$ (fixed to T_W=4y after sensitivity analysis)
- Filtering of network edge (parameter θ_w), with an additional exogenous control by technological class keyword concentration to filter nodes (parameter θ_c)
- Low sensibility to the length of the time window for the network structure

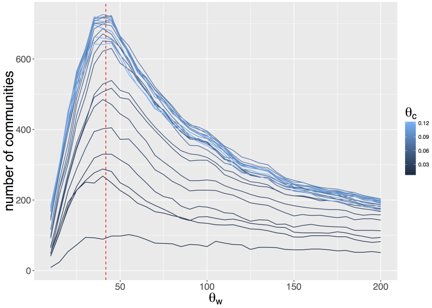
Technical aspects

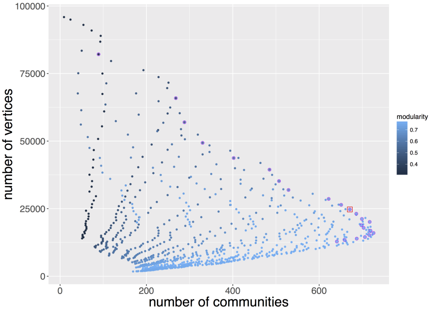
$\rightarrow$ Temporal complexity: $\mathcal{O}\left(N_P\right)$ for keyword extraction and co-occurrences (constant l_{max}^2); parallelization on a 60 cores server for a "reasonable" computation time.

$\rightarrow$ Memory complexity: co-occurrence matrices in $\mathcal{O}\left(K_W^2\right)$; necessitates around 600Go RAM when parallelized.

$\rightarrow$ Database management: MongoDB (nosql suited to big data).

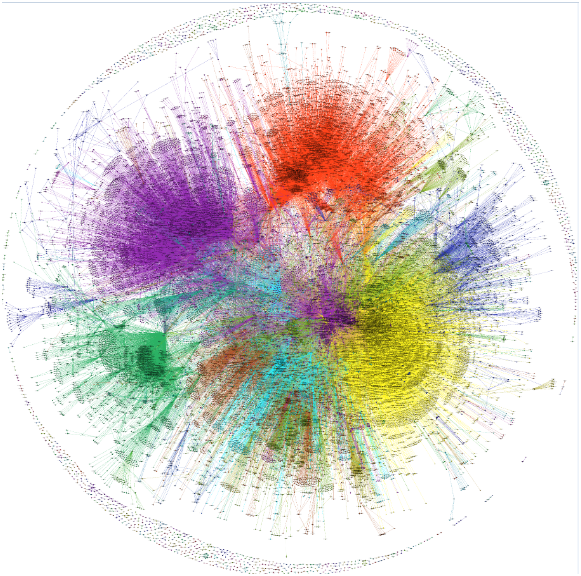
Optimizing network structure





Pareto optimization on cutoff parameters with the objectives of modularity, size and number of communities

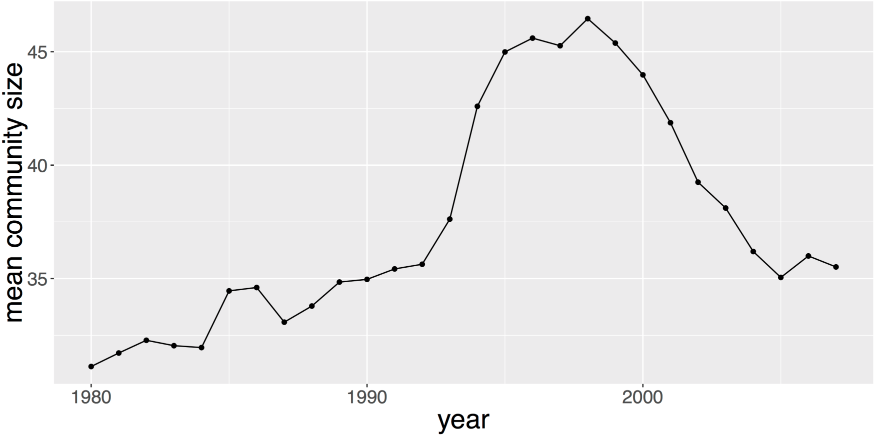
Semantic network visualization (2000-2004)



Classes Examples (2000-2004)

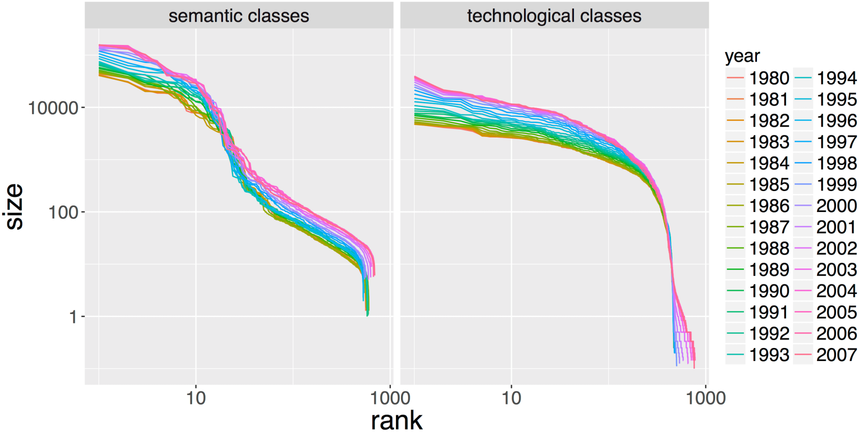
- Memory devices : `semiconductor memori devic; memori cell plural; memori cell transistor; layer ferroelectr`
- Chemical analysis : `time-of-flight mass spectromet; chromatograph column; ion trap mass`
- Particular steel : `martensit; austenit stainless steel`
- Laser : `emit laser beam; vertic caviti surfac; vcsel`
- Sewing : `circular knit machin; stitch; sew machin; embroideri`
- Lithography : `lithograph mask; project beam radiat; heat-sensit; planograph print plate`
- Tobacco : `cigarett filter; cigarett pack; tobacco; tobacco rod`

Size of classes



A peak in average class size around 1998

Hierarchical class structure



Fat-tail distribution of class size for both classification, closer to a power-law for semantic classes

UCL

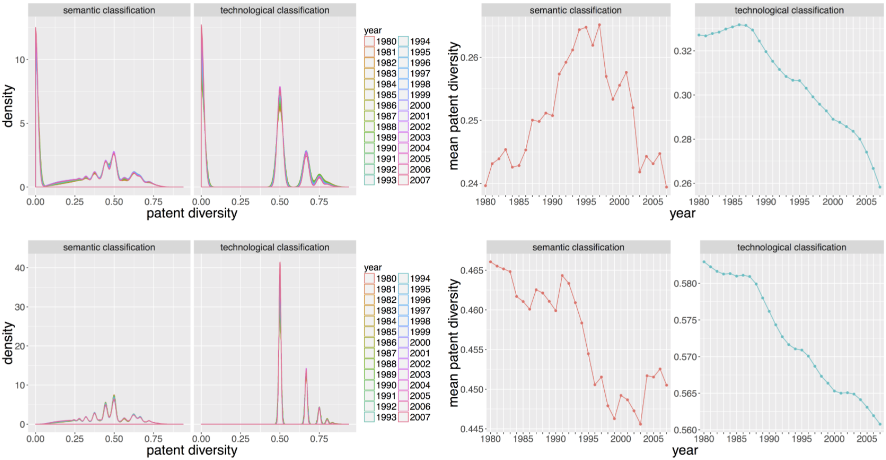
Diversity

$$D_i^z = 1 - \sum_{j1}^{N^z} p_{ij}^2, \text{ with } z \in \{tec, sem\}$$

Originality and Generality

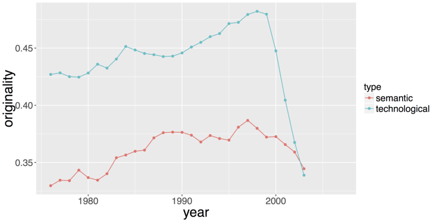
$$O_i^z = 1 - \sum_{j=1}^{N^z} \left(\frac{\sum_{i' \in I_i} p_{i'j}}{\sum_{k1}^{N^z} \sum_{i' \in I_i} p_{i'k}} \right)^2 \text{ and } G_i^z = 1 - \sum_{j=1}^{N^z} \left(\frac{\sum_{i' \in \tilde{I}_i} p_{i'j}}{\sum_{k1}^{N^z} \sum_{i' \in \tilde{I}_i} p_{i'k}} \right)^2$$

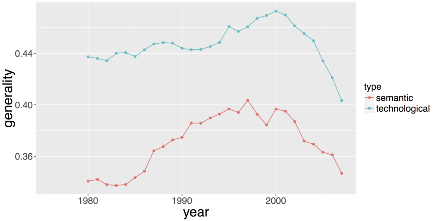
Evolution of patent diversities



General increase in average invention specialization seen both for semantic and technological; semantic regime shift in 1996

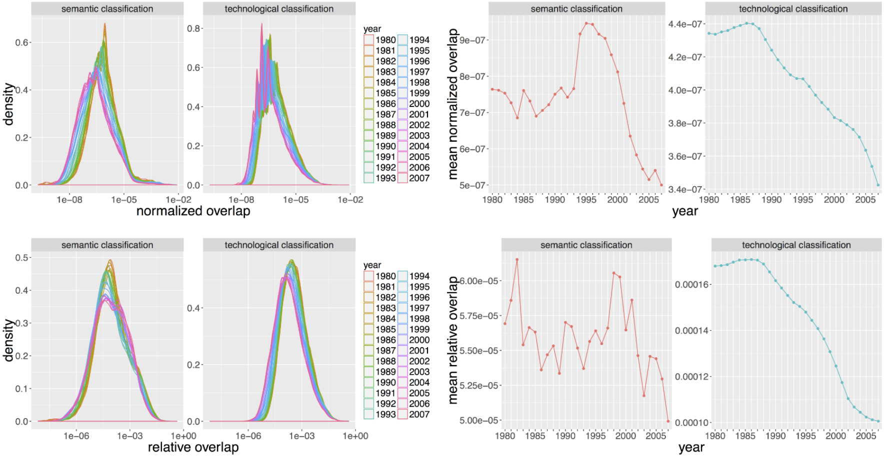
Originality and generality measures





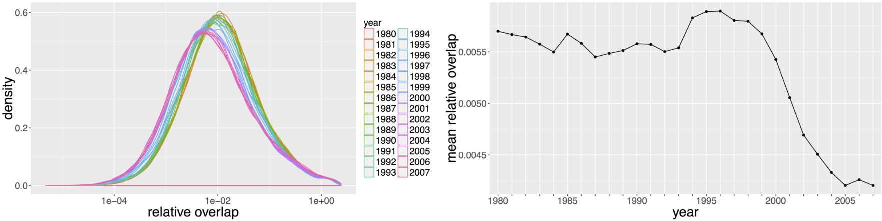
Systematically lower originality and generality (citation-based measures) for the semantic classification (consistent with the higher modularity shown thereafter).

Interaction between classes: intra-classification



Increased technological specialization; qualitative regime shift confirmed in 1996 for the semantic classification

Inter-classification overlaps



Constant then decreasing average overlap between technological and semantic classes; confirms the change in nature of inventions around 1996.

→ an impact of new information technologies (regarding knowledge production: from expert and contextualized to automatized search in references e.g.) ? Linked to structural changes in economy (increase in firm concentration since 90s) ?

Definition of modularities

Directed simple modularity [Nicosia et al., 2009]

$$Q_d^z = \frac{1}{N_P} \sum_{1 \leq i,j \leq N_P} \left[A_{ij} - \frac{k_i^{in} k_j^{out}}{N_P} \right] \delta\left(c_i, c_j\right),$$

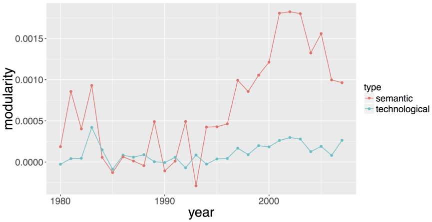
Multi-class modularity:

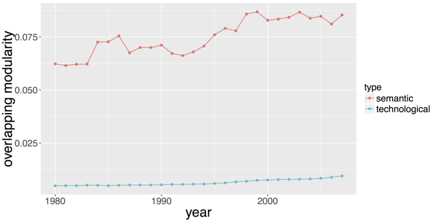
$$Q_{ov}^z = \frac{1}{N_P} \sum_{c=1}^{N^z} \sum_{1 \leq i,j \leq N_P} \left[F\left(p_{ic}, p_{jc}\right) A_{ij} - \frac{\beta_{i,c}^{out} k_i^{out} \beta_{j,c}^{in} k_j^{in}}{N_P} \right],$$

where

$$\beta_{i,c}^{out} = \frac{1}{N_P} \sum_j F\left(p_{ic}, p_{jc}\right) \text{ and } \beta_{j,c}^{in} = \frac{1}{N_P} \sum_i F\left(p_{ic}, p_{jc}\right).$$

Modularity of classifications





Semantic classification is more significant regarding the structure of the citation network, both for single-class and multi-class modularities (confirmed statistically using a simple Stochastic Block Model).

- We complete the analysis by developing a statistical model aiming at quantifying performance of both technological and semantic classification systems
- Intuitively, we look at within class citations proportion (for both technological and semantic approaches)
- Question: is the semantic classification better at predicting future within class citations?
  $\rightarrow$ short answer is yes.

Possible developments

Extensions

- Look at the correlation between patent quality indicators and centrality indices.
- Use patent-firm matching to study a *firm-level* semantic network.
- Extending the analysis to other patent offices (EPO/JPO).

Economic

- Linking semantic measures to values of firms
- Can semantic proximity helps understand M&A?
- Firms trajectories in relation to their life-cycle

Technology

- Measure of complementarity between technology?
- Possible application to detection of emerging research fronts
- An interactive exploration of semantic content?

Similar method applied to a scientific corpus

Study around the interdisciplinary geography journal Cybergeo

Scientometrics (2019) 119:617–641
https://doi.org/10.1007/s11192-019-03090-3

Check for updates

Exploration of an interdisciplinary scientific landscape

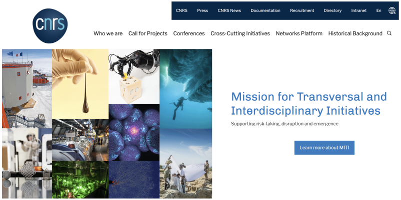
Juste Raimbault[1,2]

Received: 3 December 2017 / Published online: 25 March 2019

Interdisciplinarity

Importance of interdisciplinary approaches for knowledge itself but also to solve complex issues such as global change and sustainability

$\rightarrow$ different types of integration between disciplines in theory [Chavalarias et al., 2009] and in practice [Dupuy and Benguigui, 2015]



Quantitative Studies of Science beyond bibliometrics [Cronin and Sugimoto, 2014]:

- Maps of science [Börner et al., 2012][Leydesdorff and Rafols, 2009]
- Modeling science dynamics [Börner et al., 2011]
- Modeling social processes in science [Edmonds et al., 2011]
- Citation [Shibata et al., 2008], co-authorship, semantic networks [Gaumont et al., 2017]
- Quantitative epistemology [Chavalarias and Cointet, 2013]

Defining and measuring interdisciplinarity

- Difference between multi- and interdisciplinary, and empirical, theoretical or methodological interdisciplinarity [Huutoniemi et al., 2010]
- Specialization indices (Rao-Stirling) [Larivière and Gingras, 2010]
- Diversity indices (Leinster-Cobbold) [Mugabushaka et al., 2016]
- Network-based indices [Leydesdorff, 2007] [Rafols and Meyer, 2009]
- Semantic aspects of interdisciplinarity [Nichols, 2014] [Bouveyron et al., 2016]

Proposed approach

Difficulty to quantify interdisciplinarity (i) through multiple complementary dimensions; (ii) when data is not straightforward to gather.

For a case study journal in Geography (Cybergeo, European Journal of Geography `https://journals.openedition.org/cybergeo/`)

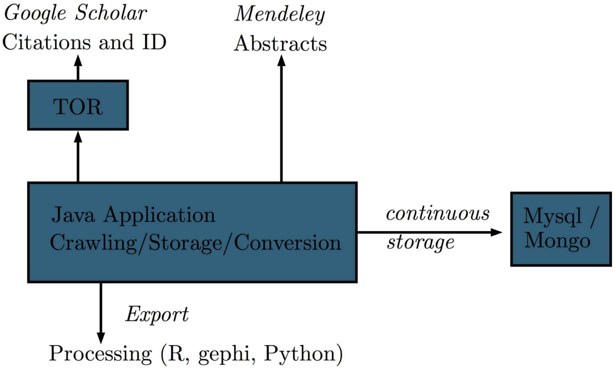
$\rightarrow$ construct a database from heterogenous sources

$\rightarrow$ quantify interdisciplinarity with citation and semantic networks

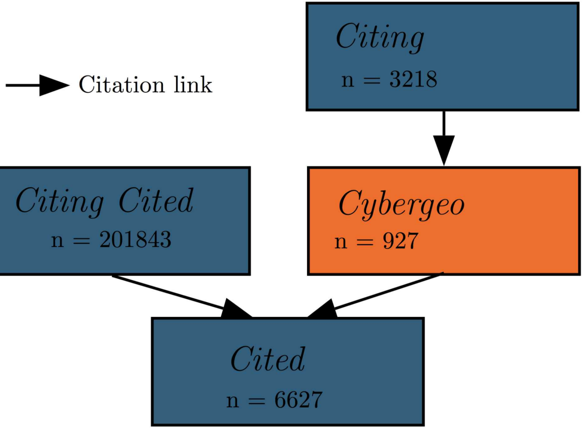
Data collection

Data collected from heterogenous sources: journal production database, google scholar for citation links, Mendeley for abstracts.

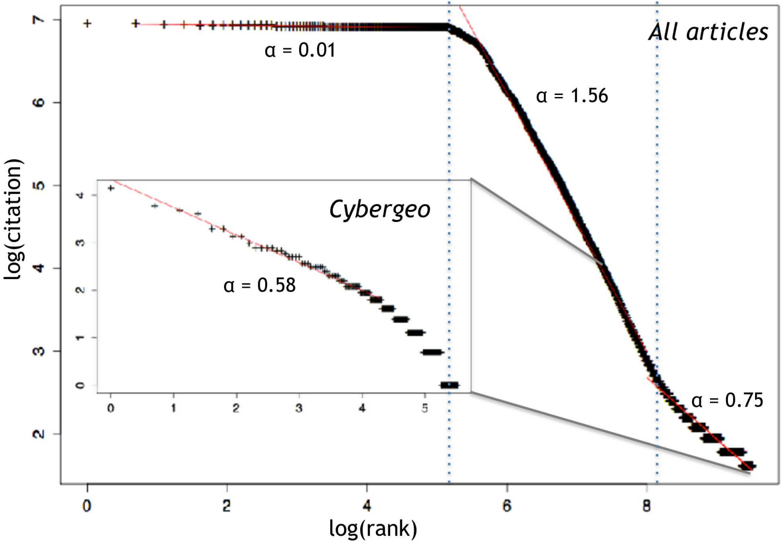
Refactored open source java library for data collection:
`https://github.com/JusteRaimbault/BiblioData`



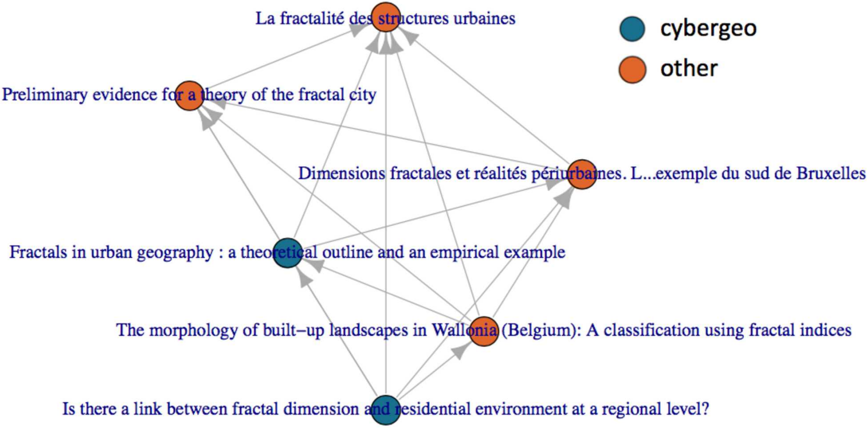
Citation network with abstract coverage: $\simeq 2.1 \cdot 10^5$ papers



Citation network properties



Example of the largest citation clique



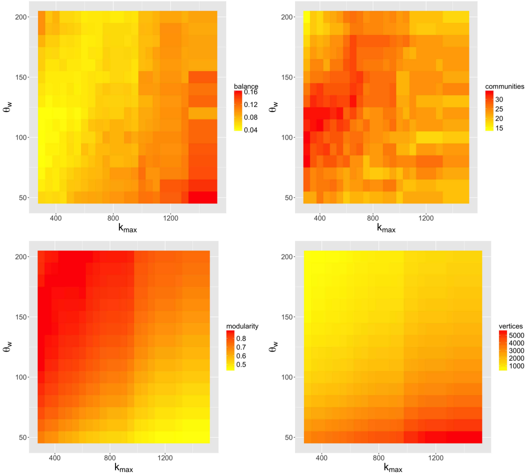
Louvain algorithm community detection to construct endogenous citation communities (modularity of 0.71)

Semantic network

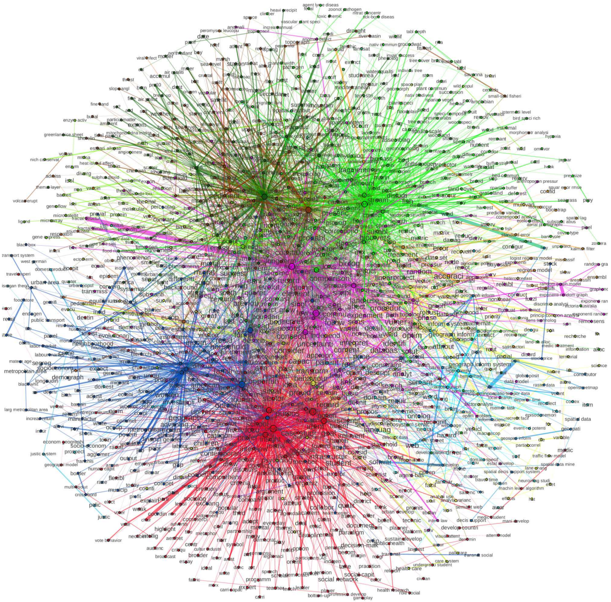
Construction of the semantic network as a co-occurence network between keywords extracted following [Bergeaud et al., 2017]:

1. Language detection using stop-words [Baldwin and Lui, 2010]
2. Part-Of-Speech tagging (`nltk` or `TreeTagger` [Schmid, 1994]); stemming
3. Construction of potential n-grams: nouns and adjectives up to size 4
4. Estimation of n-gram relevance following the deviation to the expected statistical distribution of co-occurences (chi-squared test)

Additional filtering procedure to remove relevant but common keywords: filter on edge weight and maximal degree; values chosen based on multiples objectives including modularity and network size.



Semantic network visualization

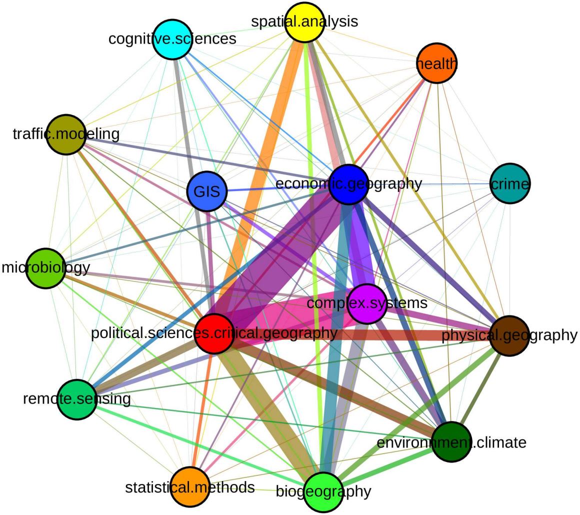


Semantic communities

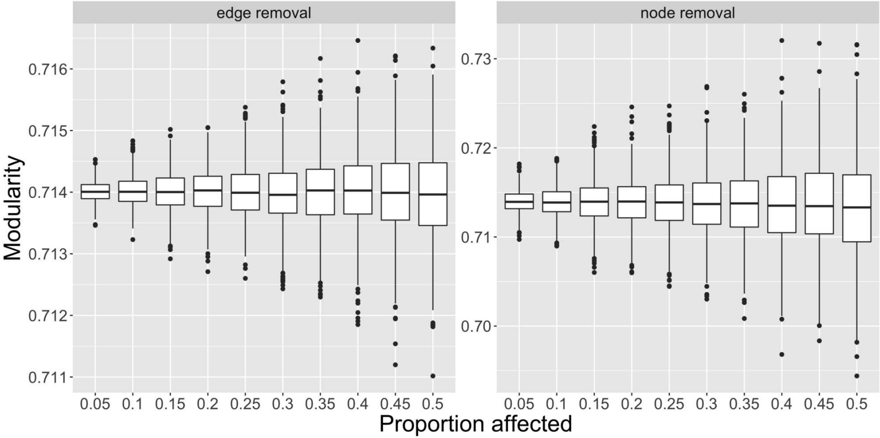
Table 1 Semantic communities reconstructed from community detection in the semantic network

Name	Size	Keywords
Political sciences/critical geography	535	decision-mak, polit ideolog, democraci, stakehold, neoliber
Biogeography	394	plant densiti, wood, wetland, riparian veget
Economic geography	343	popul growth, transact cost, socio-econom, household incom
Environnment/climate	309	ice sheet, stratospher, air pollut, climat model
Complex systems	283	scale-fre, multifract, agent-bas model, self-organ
Physical geography	203	sedimentari, digit elev model, geolog, river delta
Spatial analysis	175	spatial analysi, princip compon analysi, heteroscedast, factor analysi
Microbiology	118	chromosom, phylogenet, borrelia
Statistical methods	88	logist regress, classifi, kalman filter, sampl size
Cognitive sciences	81	semant memori, retrospect, neuroimag
GIS	75	geograph inform scienc, softwar design, volunt geograph inform, spatial decis support
Traffic modeling	63	simul model, lane chang, traffic flow, crowd behavior
Health	52	epidem, vaccin strategi, acut respiratori syndrom, hospit
Remote sensing	48	land-cov, landsat imag, lulc
Crime	17	crimin justic system, social disorgan, crime

Interactions between communities

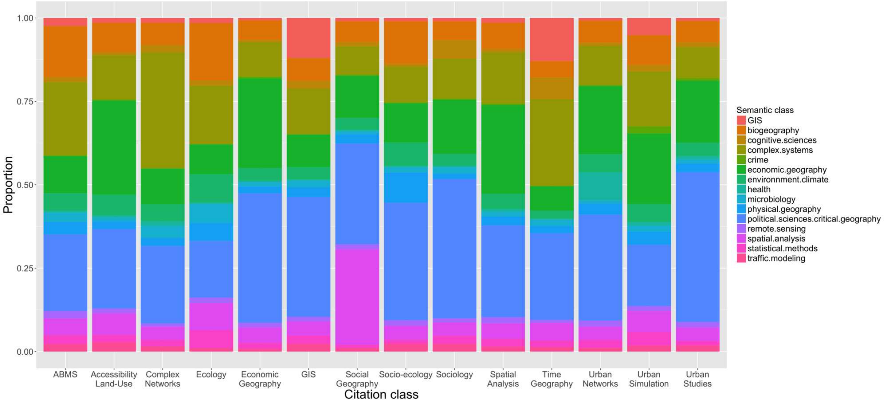


Sensitivity to corpus definition

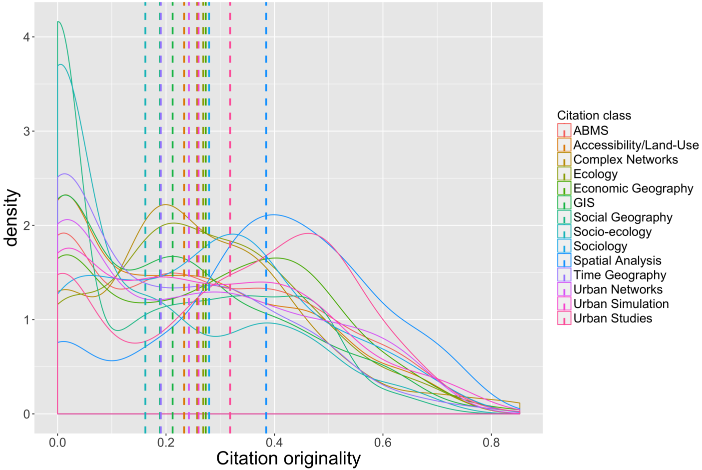


Impact of node and edge removal on the optimal modularity of the citation network

Semantic composition of citation communities

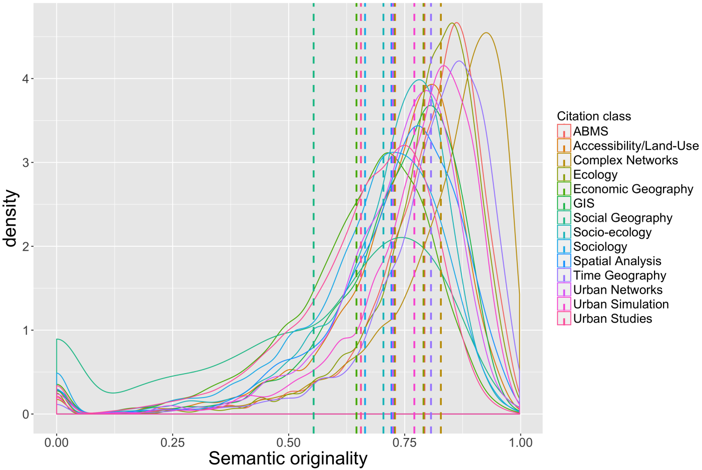


Measuring interdisciplinarity



Distribution of originalities (Herfindhal index) for how references are cited by different citation classes

Measuring interdisciplinarity



Distribution of semantic originalities

Discussion

Developments

$\rightarrow$ Journal dynamics and benchmarking, reflexivity for authors; fostering Open Science [Raimbault et al., 2019]

$\rightarrow$ Performance of the semantic classification for citation link prediction

$\rightarrow$ Correspondence of terms between disciplines

Applications

$\rightarrow$ Quantification of Domains of Knowledge [Raimbault, 2017]

$\rightarrow$ Complementary dimensions in the structure of science

$\rightarrow$ Spatial diffusion of knowledge [Raimbault, 2020b]

Multiple methods applied to the Cybergeo corpus: keywords, LDA, citation and semantic network, geographical dimension

Article

Urban Analytics and City Science

EPB: Urban Analytics and City Science
0(0) 1–16

DOI: 10.1177/2399808319870816
journals.sagepub.com/home/epb
SAGE

Empowering open science with reflexive and spatialised indicators

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Hadrien Commenges, Denise Pumain and Christine Kosmopoulos
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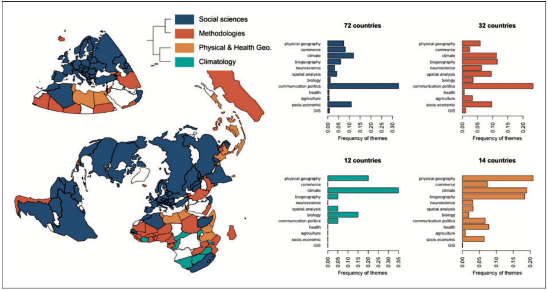
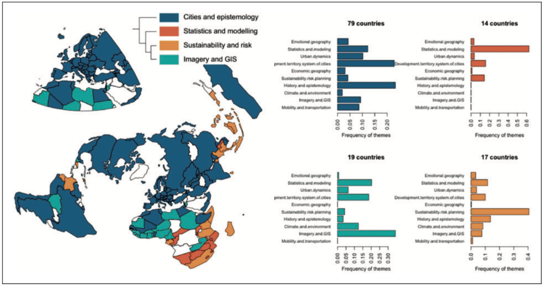
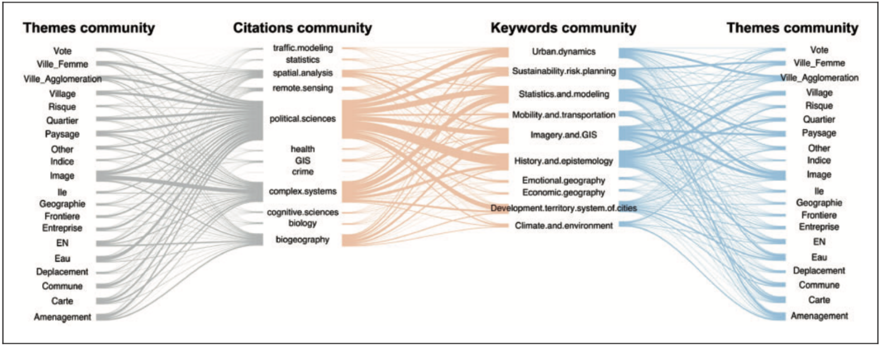
Geographical content of papers

Themes and their geographical distributions





Complementarity of methods



Interactive web application to foster reflexivity

CybergeoNetworks

analytics.huma-num.fr/geographie-cites/cybergeonetworks/

CybergeoNetworks | The Project | Overview | Citation network | Full-text Semantic network | Keyword network | Geo-semantic Networks

Cybergeo turns 20: it's time to look back for reflection and to anticipate future evolution! cybergeo.revues.org/

The editorial policy

First entirely electronic journal for social sciences in the world, peer reviewed, European, open (free of charge for authors and readers), with a focus on geography and widely open to the diversity of research agendas and methodologies in all countries. Cybergeo is a success story with now more than one million papers downloaded every year.

An app to look back

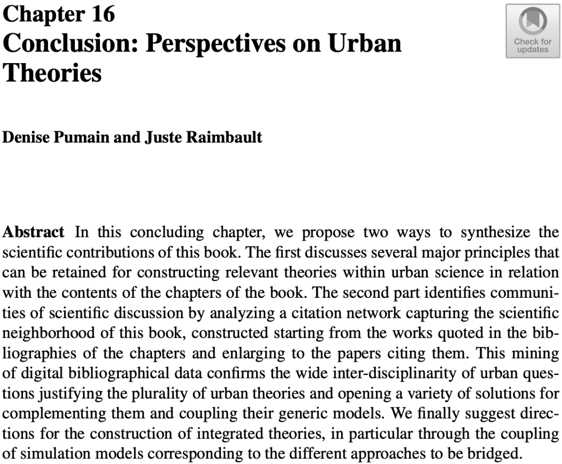
This app builds on 20 years of publication in Cybergeo. You can play with data, drawing geographical networks of authoring, studying and citing through countries, analyzing semantic networks per key words and articles' content, you can review twenty years of epistemological and thematic trends in a variety of fields of scientific interest. The networks tell who studies what, where and how. Data are regularly updated.

About the app

All data, materials and source codes are freely available on this repository: github.com/AnonymousAuthor3/cybergeo20

Multiple urban perspectives

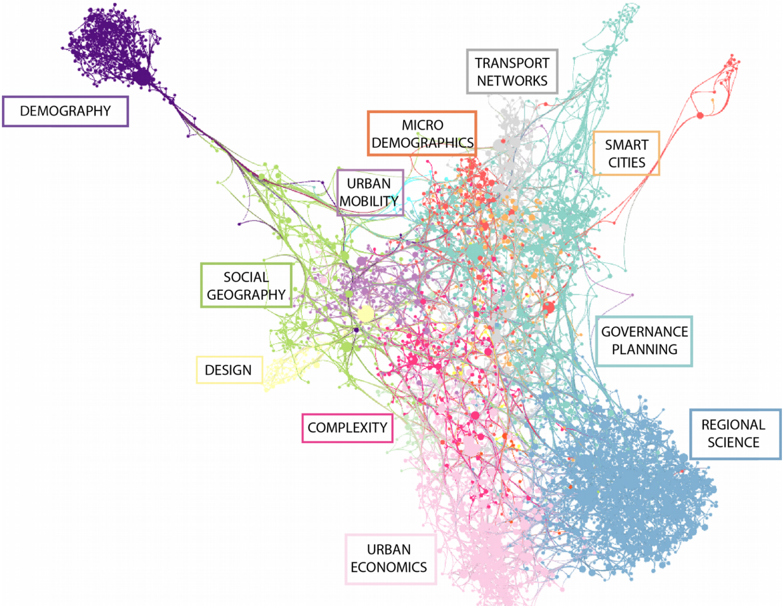
Citation network analysis of the scientific neighborhood of perspectives developed in the Geodivercity ERC book

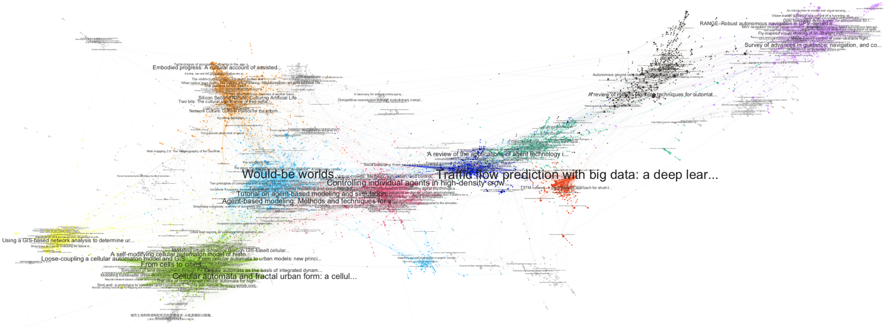

Chapter 16
Conclusion: Perspectives on Urban Theories

Denise Pumain and Juste Raimbault

Abstract In this concluding chapter, we propose two ways to synthesize the scientific contributions of this book. The first discusses several major principles that can be retained for constructing relevant theories within urban science in relation with the contents of the chapters of the book. The second part identifies communities of scientific discussion by analyzing a citation network capturing the scientific neighborhood of this book, constructed starting from the works quoted in the bibliographies of the chapters and enlarging to the papers citing them. This mining of digital bibliographical data confirms the wide inter-disciplinarity of urban questions justifying the plurality of urban theories and opening a variety of solutions for complementing them and coupling their generic models. We finally suggest directions for the construction of integrated theories, in particular through the coupling of simulation models corresponding to the different approaches to be bridged.

Citation network





Citation network of ALife studies of urban systems

Transfer of concepts: Urban morphogenesis, bio-inspired design, urban ecology, autopoiesis [Batty and Marshall, 2009]

Raimbault, J. (2020). Cities as they could be: Artificial life and urban systems. arXiv preprint arXiv:2002.12926.

Knowledge Frameworks

Knowledge Framework : *A systemic framework containing an epistemological component dealing with the nature of knowledge or knowledge production.*

$\rightarrow$ Knowledge management: [Durantin et al., 2016] coupling engineering with design paradigms; [Carlile, 2004] knowledge at the boundaries of disciplines.

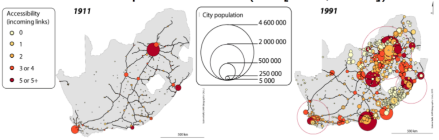
$\rightarrow$ Meta-modeling frameworks: [Cottineau et al., 2015] multi-modeling; [Golden et al., 2012] unified formal description of Complex Systems.

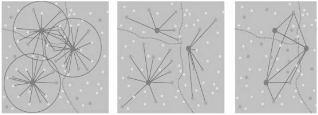
$\rightarrow$ Applied frameworks: [Moulin-Frier et al., 2017] typology of approaches in Artificial Intelligence.

Iterative Construction of Knowledge across Domains

Databases
(ex. [Swerts, 2017])

Empirical studies (ex. [Baffi, 2016])

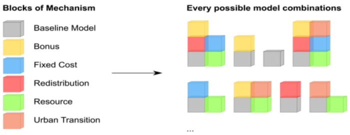




Models (ex. [Pumain, 2008])

OpenMOLE

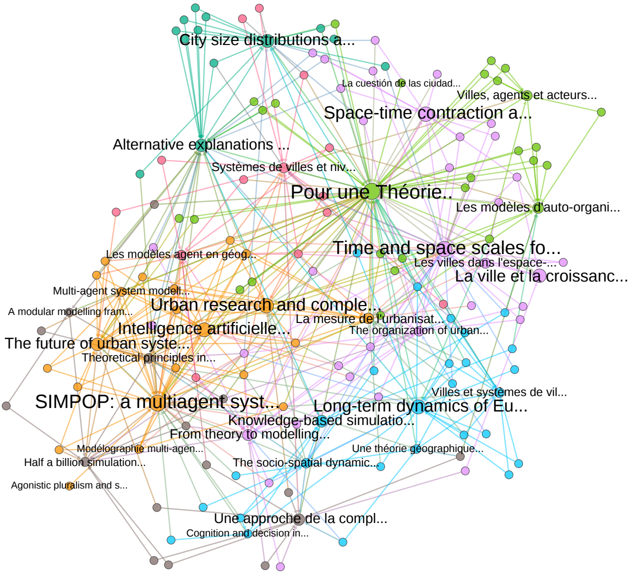
Tools (ex. [Reuillon et al., 2013])



Methods (ex. [Cottineau et al., 2015])

Theory
[Pumain, 1997]
[Pumain, 2010]

Citation Network Analysis



Core citation network of Evolutive Urban Theory

$|V|=155$

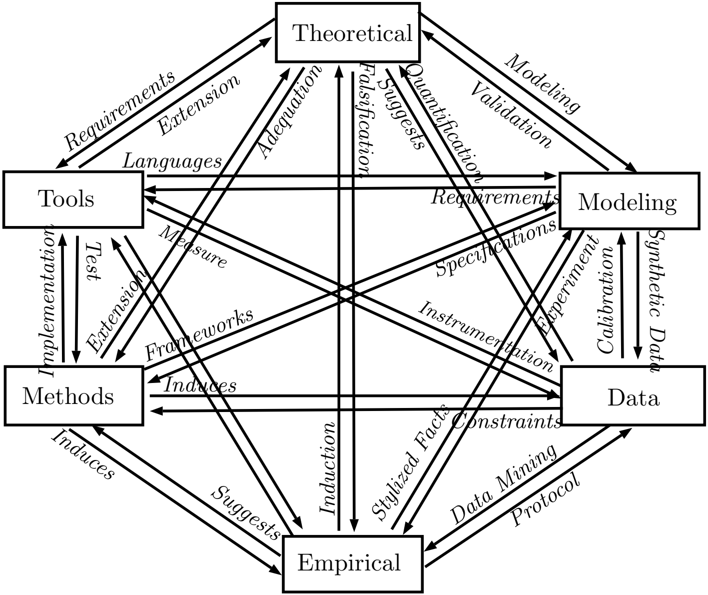
$|E|=449$

7 communities, modularity 0.39

Knowledge Domains

Definition of Knowledge Domains, extending [Livet et al., 2010]

- **Empirical.** Empirical knowledge of real world objects
- **Theoretical.** Conceptual knowledge, implying cognitive constructions
- **Modeling.** The model as the formalized *medium* of the perspective [Giere, 2010]
- **Data.** Raw information that has been collected
- **Methods.** Generic structures of knowledge production
- **Tools.** Implementation of methods and supports of others domains


Theoretical
Tools
Modeling
Methods
Data
Empirical
Requirements
Extension
Adequation
Falsification
Suggests
Quantification
Modeling
Validation
Languages
Requirements
Measure
Specifications
Implementation
Test
Extension
Frameworks
Instrumentation
Experiment
Calibration
Synthetic Data
Induces
Constraints
Induces
Suggests
Induction
Stylized Facts
Data Mining
Protocol

Towards a quantification

$\rightarrow$ Citation and semantic network analysis can *in some cases* provide insights into types of papers (data, methodological, case study, model)

$\rightarrow$ Semi-supervised approach with full-texts to quantify knowledge domains *within* papers

$\rightarrow$ Dynamics of knowledge domains (see e.g. reflexive analysis in [Raimbault, 2018]

Issues:

- Practices (and domains) specific to disciplines - transferability and comparability?
- Limitations of machine learning regarding interpretations
- Data: open access papers, sci-hub?

Conclusion

$\rightarrow$ Network analysis provides useful theoretical (knowledge production) and practical (literature mapping) insights

$\rightarrow$ Complementarity of methods

$\rightarrow$ Open tools and methodologies to foster Open Science and reflexivity

Some open repositories

Patents: `https://github.com/JusteRaimbault/PatentsMining`

Data collection: `https://github.com/JusteRaimbault/BiblioData`

Interdisc.: `https://github.com/JusteRaimbault/HyperNetwork`

Cybergeo: `https://github.com/Geographie-cites/cybergeo20`

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Le chemin de fer et la ville dans les processus de territorialisation en Afrique du Sud : de la séparation à l'intégration territoriale ?
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