Which subfield of Physics is More Influential?

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$$\frac{e^{\pm\beta H}}{Z}$$

A table of contents

What are we interested in?

- Question 1: How one field is related to others? Given a field, what are fields that it supports/is supported the most
- Question 2: Which are the most influential fields and measure of their relative importance to the whole discipline (or even the whole science)

Very simple ideas

- Both direct and indirect input-output relations among the fields should be considered
- Similar ideas have been proposed and developed in Leontief's Input-Output Analysis (LIOA) in Economics and in Google's PageRank Algorithm
  - Not all citations are equal, links from the more important/influential websites are weighted more
  - Eigenvectors (PageRank) or inverse (LIOA) of matrices take both direct and indirect relation into consideration

Why considers only subfields of Physics

- In principle, we need the BIG input-output system about academia: Records of scientific publication, patents, funds, or even the economy and research grants

- However, we have only records of publications in APS journals from APS

- In any studies, we have to truncate the targeted system from the whole system

- The ideas and the mathematics defined in the following should be more generally applicable

Key ideas in the Input-Output Analysis

- Economists ask: Among industrial sectors, which one is more important to the economy, which one is closely related to a given sector
- Open system approach:
  - Definition, x_j^i means the amount of input from the sector i to the sector j
  - Definition, total output from the sector i

$$X^i = \sum_{j=1}^{N-1} x_j^i + y^i = \sum_{j=1}^{N-1} b_j^i X^j + y^i, \forall i \neq N. \tag{1}$$

$$b_j^i = x_j^i / X^j. \tag{2}$$

  where $X = (X^1, X^2, \ldots, X^{N-1})^T, Y = (y^1, y^2, \ldots, y^{N-1})^T$.
  - Thus that in order to supply enough Y, X has to be

$$B^{(N-1)} X + Y = X \Longleftrightarrow X = \left(1 - B^{(N-1)}\right)^{-1} Y \tag{3}$$

$$L_B \triangleq \left(1 - B^{(N-1)}\right)^{-1} \tag{4}$$

HEM: what if one sector is removed

- Removing sector i from the whole matrix $B^{(N-1)}$ while keeping Y as the same except the demand on sector i itself:

$$\hat{X}^{-i} = L_{B^{(N-1-i)}} Y^{-i} = \left(1 - B^{(N-1-i)}\right)^{-1} Y^{-i} \qquad (5)$$

- Difference between X and $\hat{X}^{-i}$ tells the importance of sector i
- The components which change the most correspond to the closely related sectors

Why not simply X^i?

- Yes, one can do that however, without indirect influence of sector i
- Google's PageRank takes indirect influence into considerations too

Applicable to subfields in physics?

- No. In the case of subfields in Physics, there is no such a well-defined exogenous sector, so a closed system modification is required
- Turn to eigenvectors of the closed system, i.e. matrix $B^{(N)}$ (simply B in the future) instead of $B^{(N-1)}$
- We still have

$$X^i = \sum_{j=1}^{N} x_j^i = \sum_{j=1}^{N} b_j^i X^j, \forall i. \tag{6}$$

$$BX = X. \tag{7}$$

- B is a non-negative (element) matrix with maximum eigenvalue 1, corresponds to a unique maximum eigenvector (for simplicity) X
- However, Eq. (7) and X are trivial. Not much information can be extracted from them

Close-system Input-Output Analysis

- Since X is the maximum eigenvector of B, what are the intuitive meaning of the maximum eigenvector of B^{-i}?
- Let us denote them as λ_{max}^{-i} and $\left| \lambda_{max}^{-i} \right\rangle$, in a sense $\left| \lambda_{max}^{-i} \right\rangle$ corresponds to the max output of the system B^{-i}
- From this intuition, we define

$$S_{IO}^{j} = 1 - \lambda^{(-j)}, \tag{8}$$

$$\Delta_{k}^{j} = \frac{\langle k \mid X \rangle - \lambda^{(-j)} \left(\sum_{l \neq j} X^{l} \right) \langle k \mid \lambda^{(-j)} \rangle}{\langle k \mid X \rangle}. \tag{9}$$

Construction of the Input-Output matrix

- PACS code as subfields, not exact, but works
- Citations from papers turned into input-output relations among fields
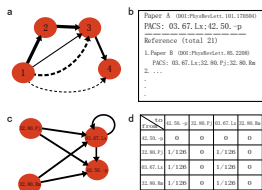
$$x_j^i (A \to B) = \frac{1}{P_A P_B C_A}. \qquad (10)$$

Figure : P_A (P_B) is the number of PACS codes of paper A (B), C_A the number of references of A

Results on IOF, S_{IO}^j

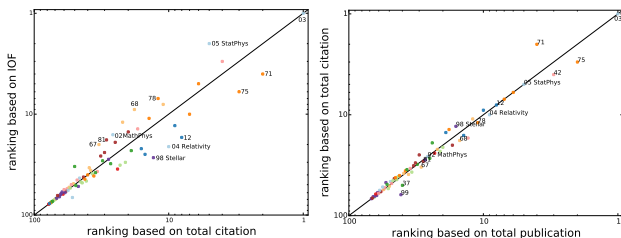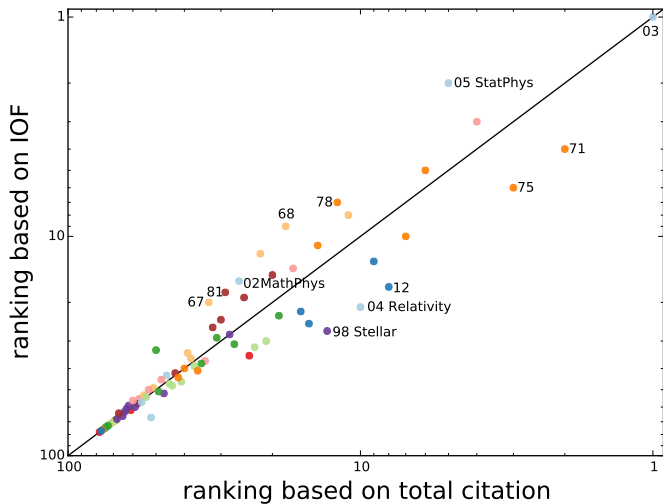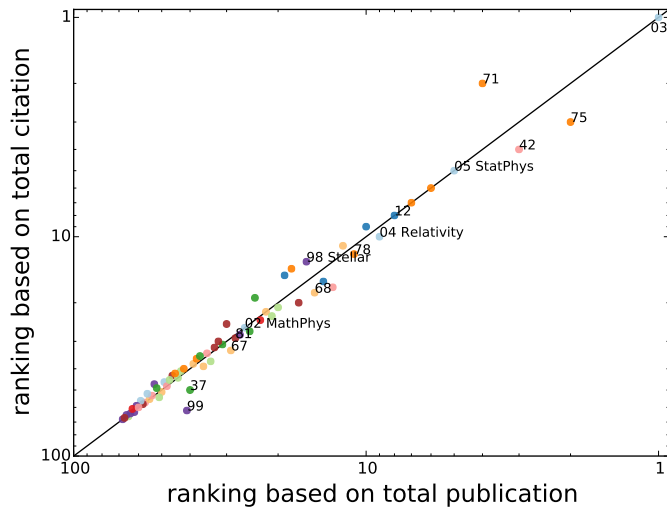- Fields are ranked according to their *IOF* and simply number of papers and citations

Figure : Please focus on 05(StatPhys), 02(MathPhys), 04(Relativity) and 98(Stellar)

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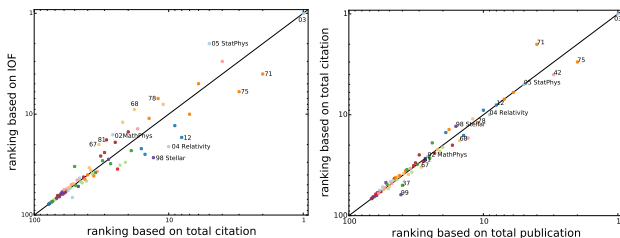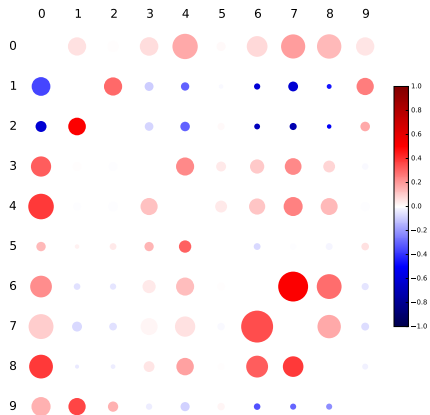

Figure : Please focus on 05(StatPhys), 02(MathPhys), 04(Relativity) and 98(Stellar)

Results on IOF, S_{IO}^j, continued

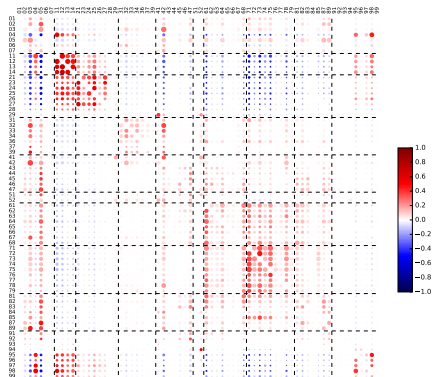- Animated version of the above figure

Figure : Time evolution

Results on interrelations, Δ_k^j

- Among all level-1 subfields

Results on interrelations,continued

- Among all level-2 subfields

Results on interrelations,continued

- Given a field, say for example 98(Stellar systems) and 03(Quantum Mechanics), what are other fields that closely related to it
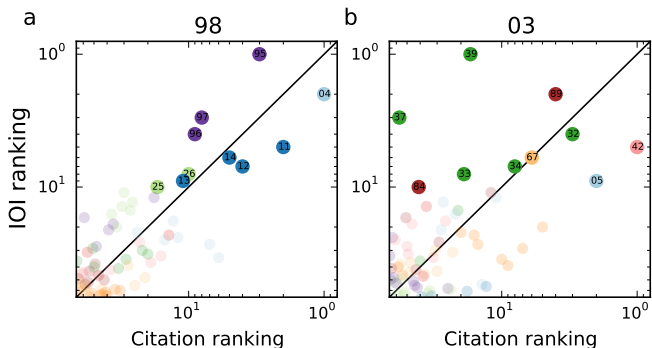

Figure : For 03, firstly, the plot is further away from the diagonal line and secondly, 37(atomic control) and 39(instruments, later merged to 37) have closer relationship that what would have been seen simply from counting citations.

An overview

- Divide the whole level-3 fields into 4 group according to their IOF every year (25% for each group)
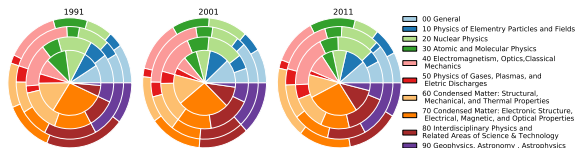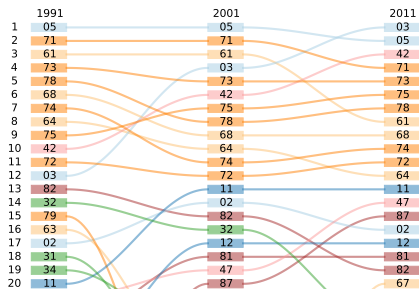

Figure : You May take a look at General Physics (00)and interdisciplinary (80) in the top 25%

Results:shift of subfields' ranks

- Top 20 Level-2 subfields every year

Conclusions and discussion

- A new approach to describe influences of elements in a system with input-output relation
- Both direct and indirect effects are considered
- Some fields stand out (deviate from the diagonal line), and more importantly, meaningfully
- Method is more generally applicable
- Applications to other more detailed and more specific fields for studies of policy makers should be done (by others using the proposed analysis)

Acknowledgement and time for questions

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