Grand Challenges and emergent modes of *Convergence Science*

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Convergence science is a transdisciplinary paradigm defined by its originators as "the coming together of insights and approaches from originally distinct fields" (**US National Research Council [1]**) in order to address complex boundary-spanning problems and support the emergence of potent hybrid disciplines, such as genomics and human brain sciences **[2-6]**. Consequently, convergence has become integral to national innovation systems charged with developing mission-oriented policy aimed at grand societal challenges **[7]**.

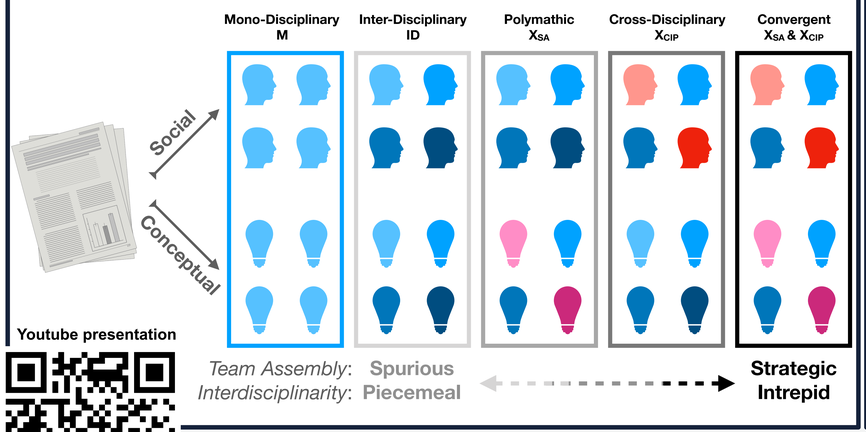
With the success of the genomics revolution **[2]**, national innovation systems are keen to spur competition by way of grand challenges that are capable of catalyzing innovation and economic growth. Presently, nowhere is this more evident than massive 'flagship' brain science funding initiatives launched globally circa 2013 — in the US (BRAIN project), EU (Human Brain Project) and Asia (China Brain Project and Brain/MINDS). As such, we constructed a representation of the Human Brain Science (HBS) ecosystem over 1945-2018 comprised of 650,000+ articles collected from 9000+ Scopus Author profiles.

Yet analyzing the status and impact of HBS convergence first requires a metric distance for identifying neighboring -vs- distant disciplines. We address this methodological challenge by developing a framework that draws on hierarchical ontologies to delineate "originally distinct fields". Our results show that convergence science ($X_{SA\&CIP}$) features a 16% citation premium in excess of a mono-disciplinary baseline, and is essential for integrating across large epistemic distances. Yet we also identify a competing mode, characterized as research utilizing cross-topic exploration alone (X_{SA}) — a *convergence shortcut* — growing in prevalence at roughly 3% per year, and attributable to competitive pressures associated with Human Brain funding initiatives **[3]**.

Objective 1: Develop a measure of "disciplinary distance" **[3,5]** to operationalize measuring convergence according to its original definition as an intrepid form of interdisciplinarity capturing "the coming together of insights and approaches from ***originally distinct*** fields" **[1]** — in contradistinction to spurious inter-disc. integration.

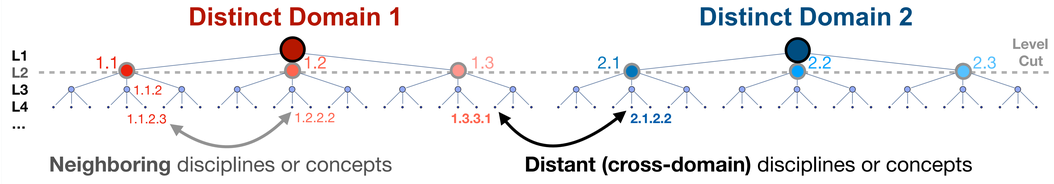
Our framework for defining disciplinary distance draws upon two existing ontologies — *Classification of Instructional Programs* (CIP) and *Medical Subject Heading* (MeSH) — each comprised of thousands of well-defined entities **[5]** that respectively capture two fundamental dimensions of research:

(i) **social** — cross-disciplinary collaboration **[2,3]**;
(ii) **conceptual** — multi-domain research topic/method/tech. integration **[3,4]**.



Youtube presentation

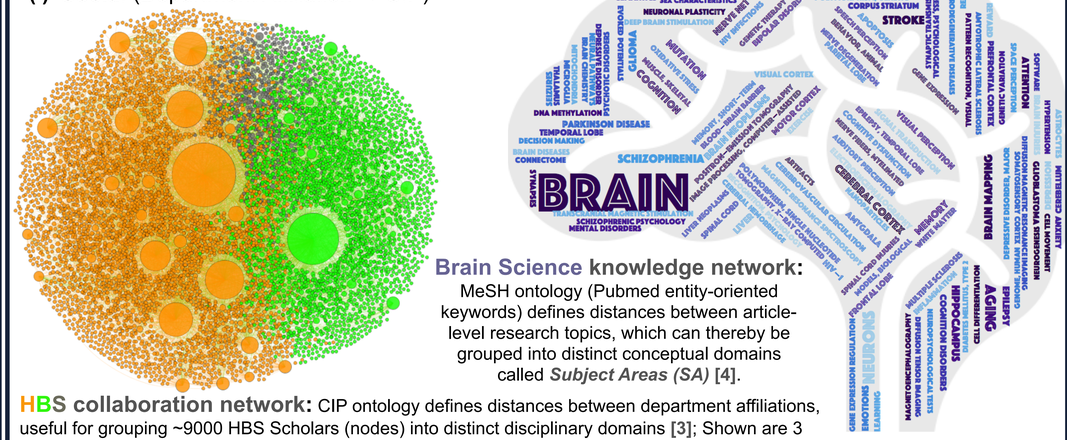
Objective 2: Apply this framework to the global ecosystem of Human Brain Science (HBS), which is a testbed for evaluating various modes of cross-domain integration (social & conceptual) in response to massive flagship funding programs centering around select target problems, ie *Grand Challenges* **[7]**.



A hierarchical **Ontology** facilitates consistent measure of distance between entities

(i) Social (Department Affiliation ⇒ CIP)

(ii) Conceptual (MeSH ⇒SA)

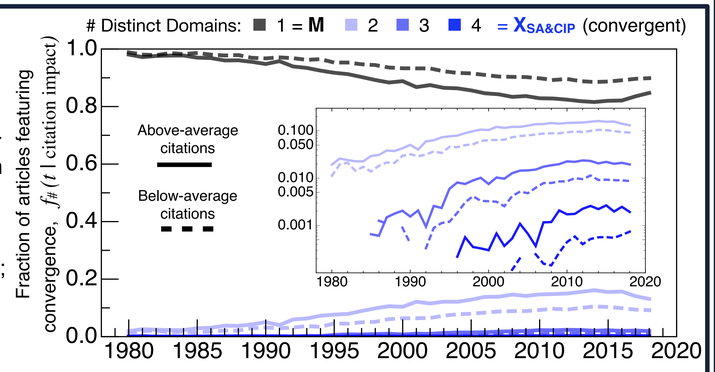


Brain Science knowledge network: MeSH ontology (Pubmed entity-oriented keywords) defines distances between article-level research topics, which can thereby be grouped into distinct conceptual domains called *Subject Areas (SA)* **[4]**.

HBS collaboration network: CIP ontology defines distances between department affiliations, useful for grouping ~9000 HBS Scholars (nodes) into distinct disciplinary domains **[3]**; Shown are 3 convergence domains: **Neuro-Biological Sciences**; **Health Sciences**; **Eng. & Informatic Sciences**

Research Question (RQ) 1:
How prevalent is convergence; Is the frequency changing?

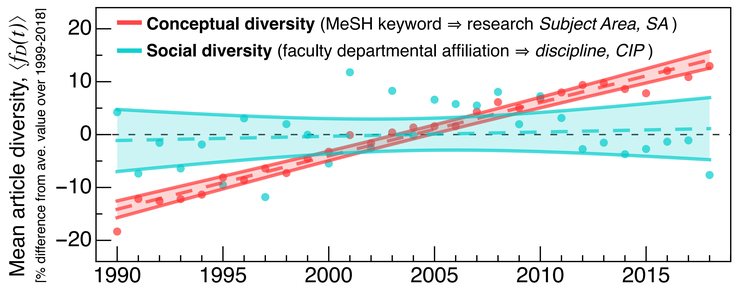
Result: Still minority; Increasing — Two robust pattern observed for complementary groups of research articles (those w/ above or below-average citations):
(a) increasing prevalence of convergence, reaching ~10% level;
(b) higher prevalence of convergence in research with above-average citation impact. **[3]**



RQ 2: Are social & conceptual convergence one in the same — ie they follow a common pattern?

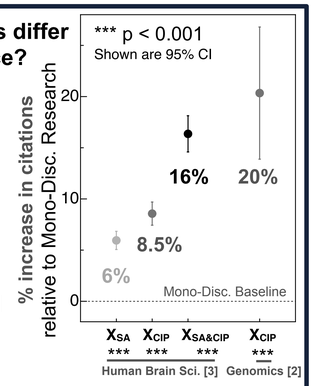
Result: NO — social coordination costs appear to be in excess of expansive learning costs; The flat (social) versus increasing (conceptual) trends highlight the emergence of the "Convergence Shortcut" whereby HBS scholars integrate diverse concepts without achieving convergence in team diversity. **[3,5]**

f_D is an article-level measure of cross-domain diversity leveraging ontological classification **(CIP or MeSH)** to define neighboring and distant entities **(disciplines or concepts)**



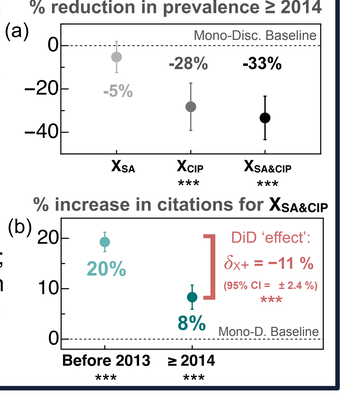
RQ 3: Do research outcomes differ across modes of convergence?

Result: YES — according to panel regression model with scholar fixed-effects: on average, research featuring full convergence (social & conceptual, $X_{SA\&CIP}$) has 16% higher citation rate than the mono-disciplinary baseline, and is also in excess of partial modes (Polymathic, X_{SA}; and Cross-disciplinary, X_{CIP}). **[2,3]**

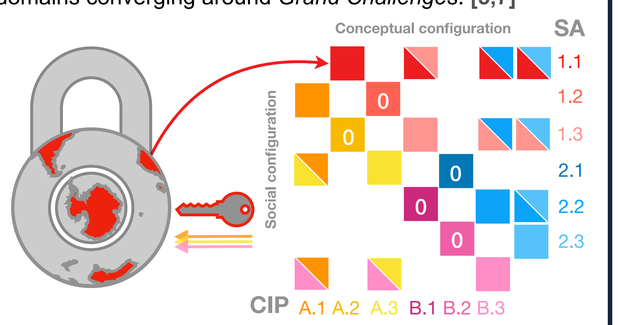


RQ 4: Did flagship HBS initiatives affect convergence?

Result: YES — DiD model specification comparing research activity before vs. after 2013 HBS flagship launch dates. Results indicate: (a) increasing prevalence of **M**ono-disciplinary and X_{SA} research (the latter being the *Convergence shortcut*); and (b) reduction in citation impact for $X_{SA\&CIP}$ research attributable to global HBS initiatives. **[3]**



Outlook— Solving Grand Challenges is a Team-Design Problem: Is the configuration of integrated cross-disciplinary expertise and multi-disciplinary knowledge appropriate for unlocking the solution? Our convergence framework facilitates defining and evaluating the matrix of integrated social & conceptual domains converging around *Grand Challenges*. **[5,7]**



Future RQ: Are convergent teams sufficiently aligned with the grand challenge?

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2. * AM Petersen, D Majeti, K Kwon, ME Ahmed & I Pavlidis (2018). **Cross-disciplinary evolution of the genomics revolution**, *Science Advances*.
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7. D. Helbing (2012). **Accelerating scientific discovery by formulating grand scientific challenges**, *EPJ Special Topics*.

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Without policy adjustments, flagship funding programs may unintentionally incentivize suboptimal cross-domain integration, thereby undercutting the potential for convergence science to address grand societal and environmental challenges.