HOW DO RESEARCHERS DEFINE HIERARCHY WITHIN THE SOCIAL SCIENCES? A SYSTEMATIC REVIEW

Stan L. Rhodes[ab], Stefani A. Crabtree[b], and Jacob Freeman[c]

[a]Cooperative Institute for Research in the Atmosphere, Fort Collins, CO, United States;

[b]Department of Environment and Society, Utah State University, Logan, UT, United States;

[c]Anthropology Program, Utah State University, Logan, UT, United States

Abstract

Social science does not use the word *hierarchy* consistently. We find the term may be used to describe qualitatively different social relations and systems such as rank and prestige, nested organizational structures, and top-down control structures; placing all of these meanings under one term causes misunderstandings and misinterpretations. To map a way forward, we use a computer-aided systematic quantitative literature review to identify social science papers that define hierarchy, then analyze that set of definitions (n = 1,121) to identify whether they fall within a pre-existing control-nest-rank ontology of hierarchy or some other type. We find that the control-nest-rank typology provides valid coverage for definitions of hierarchy across the social sciences, but is better seen as three different dimensions of hierarchical structure. Few definitions (1%) lay outside these dimensions, consisting mostly of network measures of hierarchy. While fields may emphasize one dimension more than others, in most fields the majority of definitions of hierarchy are unclear. This inconsistent use obscures the important aspects of social behavior that authors are drawing attention to, causing confusion and leaving uncertain foundations for further inquiries. Fortunately, we found that nearly all the definitions of

hierarchy we extracted referred to one or more distinct dimensions of social relationship—rank, nested, or control relations—that have specific meanings. We analyzed these meanings further by looking at words that co-occur with particular definitions of hierarchy, and show that different sets of terms support control, nest, and rank as distinct dimensions of hierarchy even when they are mixed in particular definitions. Thus, we recommend that researchers use the control-nest-rank ontology to explicitly identify the hierarchical relations of interest in their work and increase the consistency and clarity of their work within and between social science fields.

1. Introduction

Literature across the social sciences defines hierarchy—either implicitly or explicitly—in qualitatively different ways. Consider the variety of definitions given in Table 2.1, sampled from papers among several fields. In these examples, and more generally, most definitions agree that hierarchy is a property of a system, and that it relates to a system's structure. However, as seen in Table 2.1, they do not agree whether to define this structure as, for example, control, levels, rank, nestedness, or the presence of subsystems. These key concepts refer to different types of relational structure, not just differences in units of the same relational structure, preventing valid like-to-like comparisons of systems. Such inconsistencies can lead to researchers talking past one another about topics where they use *hierarchy* to describe system behavior. In the best case, one wonders which properties of hierarchy are implied by a particular use of the term; in the worst case, one assumes what property is intended. Without explicit descriptions, the stage is set for misinterpretation, not only of conclusions, but arguably, of associated theories and evidence. Similar problems plague the use of terms like *resilience* (Martin-Breen & Anderies

2006), *complexity* (Ladyman et al. 2013), and *tipping point* (Milkoreit et al. 2018), where scholars have made crucial strides in sorting through their uses and identifying what they mean conceptually.

Table 2.1. A selection of definitions of hierarchy from papers in the social sciences.

Definition of hierarchy	**Source: Author(s), Date, Page**
'A system that is composed of interrelated sub-systems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem.' [...] 'generally [refers] to a complex system in which each of the subsystems is subordinated by an authority relation to the system it belongs to'	Simon, 1962, pg 468
'hierarchies of the familiar sort in which system integration is achieved through the exercise of control and regulatory functions by a relatively small proportion of the population. Such functions may be exercised simultaneously at a number of hierarchically structured levels of control. As such, the entire control hierarchy "exists" at any given time.'	Johnson, 1982, p. 396
'Whether or not they exhibit hierarchies in power or wealth, human societies typically exhibit a nested structure that may be termed "hierarchical" in the more limited sense that units at each scale are nested within units at more inclusive scales'	Crabtree et al., 2017, p. 74
'the structural, top-down aspect of hierarchies has tended to dominate theory and application, reinforced by the standard dictionary definition of hierarchy as a system of vertical authority and control. Therefore, the dynamic and adaptive nature of such nested structures has tended to be lost.'	Holling, 2001, p. 396
'Hierarchical organization—the recursive composition of sub-modules—is ubiquitous in biological networks, including neural, metabolic, ecological, and genetic regulatory networks, and in human-made systems, such as large organizations and the Internet.'	Mengistu et al., 2016, p. 1
'in the heart of hierarchy we find control of behaviour [. . .] A system is hierarchical if it has elements (or subsystems) that are in dominant-subordinate relation with each other.'	Zafeiris and Vicsek, 2017, p. 12
'Hierarchies—stable sets of dominance relationships among individuals—structure many human and animal societies. Among animals, hierarchical rank may determine access to resources such as food, grooming, and reproduction. Among humans, rank shapes the epistemic capital and employment prospects of researchers, susceptibility of adolescents to bullying, messaging patterns in online dating, and influence in group decision-making'	Kawakatsu et al., 2021, p. 1
'dynamical hierarchies define a system that is structured by part-whole relationships between objects, where each whole can exhibit properties and can interact in ways different from its parts.'	Lenaerts et al., 2005, p. 403.
'Hierarchy is a type of systemic organisation into levels that are ordered with reference to criteria of a normative character, and fully or partially subordinated by relationships of power, influence, or control.'	Pumain, 2006, p. 1.

It is time, in the words of William James (1907), to be "mindful of the scholastic adage that whenever you meet a contradiction you must make a distinction." Control, rank, and nestedness are each conceptually and structurally different, even if a system may exhibit all of them. The goal of this paper is to build an *ontology of dimensions*, in the sense of a set of concepts with particular properties and relations, that will allow researchers to increase the consistency and clarity of research into critical systemic processes. While we are not the first to distinguish among explicit types—see Lane (2006) and Zafeiris and Vicsek (2017)—of hierarchy, in this paper we create a broad map of past understandings to guide new ones, focusing on conceptions of hierarchy within a large corpus of social science texts.

To show how different definitions of hierarchy can make important distinctions, we start with three examples: chess ratings as rank hierarchy, the nesting of departments within divisions and divisions within companies as nested hierarchy, and the chain-of-command structure represented in an organizational chart as control hierarchy. These types were established within the classification of Zafeiris and Vicsek (2017), who revised Lane (2006). Rank hierarchy orders things in relation to one another by the value of a defined variable. Nested hierarchy uses relations among entities to assign them to nested sets, whether to categories (e.g., taxonomy) or systems (e.g. organs within a body). Control hierarchy defines a graph of influence relations among entities that is directed and acyclic—nodes in the cascade do not influence nodes preceding them (See Figure 2.1). Although these terms describe ideal forms, one can still apply them to real systems that exhibit some degree of their structure, and use them in combination to describe a system.

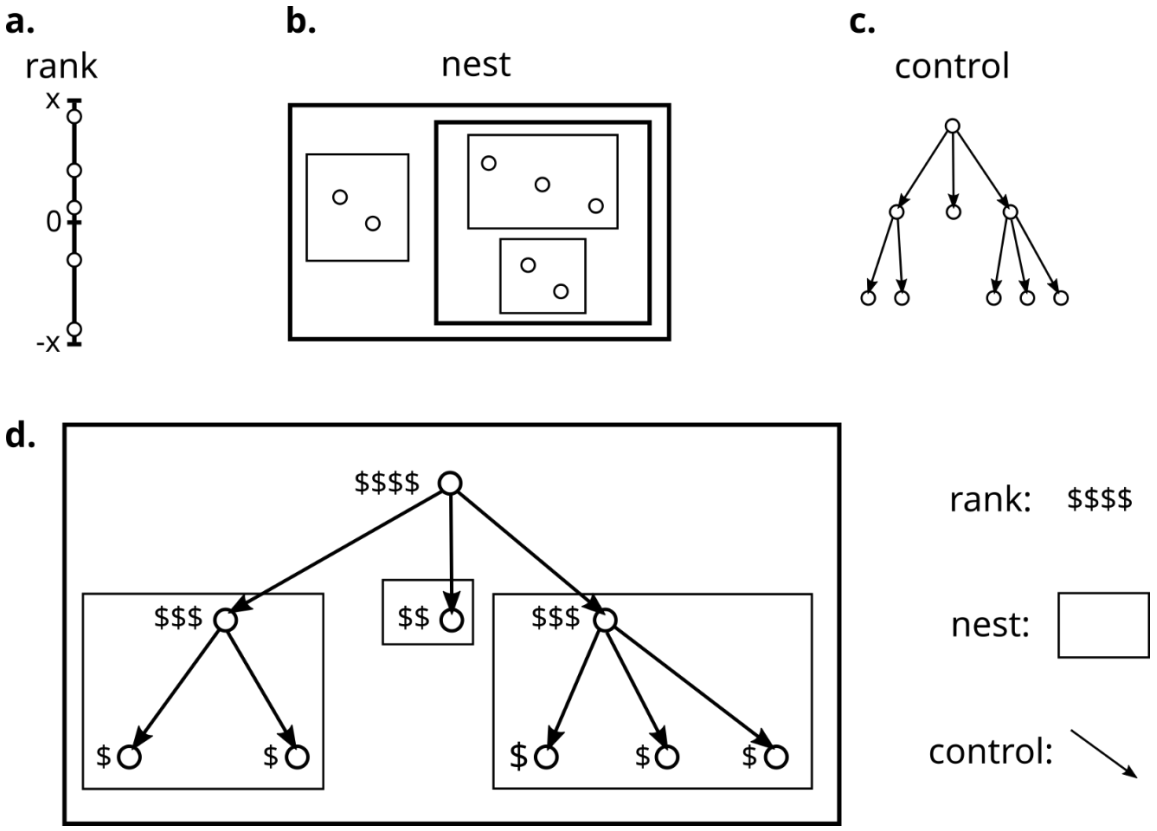


Figure 2.1. The three types of hierarchy proposed by Zafeiris and Vicsek (2017). Each type is shown as separate diagrams of systems (a, b, c) and as separate views of the same system (d). a. Rank focuses only on ranking the entities ordinally or on a number line based on some variable. b. Nest focuses only on which categories contain which categories, or which systems contain which subsystems. Control focuses only on which entities influence which entities. d. Shown as an example, a firm may be viewed with each type of hierarchy: employees ranked by salary, employees nested by department and department by division, and employees as a network of control (who manages whom). Each view identifies different dimensions of hierarchy within the firm.

We view the unqualified term *hierarchy* as a meta concept that encompasses qualitatively different dimensions of hierarchy because they often occur together in real, messy social systems containing a multitude of real, messy social relations. The situation is similar to the use of *diversity* in the sciences. When scientists reference diversity, they may mean variation in some attribute, diversity of types, or differences in configuration (Page 2011). However, our initial review found that when researchers use the term *hierarchy* they are usually implicitly emphasizing one or two dimensions over the others because they are drawing attention to a particular aspect of a relationship, as is generally the case in Table

2.1. These fuzzy definitions that conflate dimensions of hierarchy make it difficult to compare systems and answer important scientific questions related to social behavior, such as the emergence of social class, or the emergence of command-and-control relations in organizations. Thus, we seek to improve clarity with standardized definitions for the dimension of hierarchy studied by social scientists.

We use the rank-nesting-control typology of Zafeiris and Vicsek (2017) as a starting point because it was sufficient for the definitions we found in our review. However, as shown in Figure 2.1, these types of hierarchy are better seen as dimensions in an ontology than exclusive types. For this systematic review, we test the broad applicability of this ontology to a large corpus of papers. Our research questions map the definition and usage of the term *hierarchy*, identify variation and anomalies among dimensions within disciplines, and identify terms that frequency co-occur with discussion of hierarchy. Together, these inquiries should reveal whether the rank-nesting-control ontology of hierarchy needs more refinement, more dimensions added to the set, or some combination thereof, to be adequate boundary concepts—concepts that bridge disciplines and scales. Our goal with the resulting ontology is to improve the ability of researchers, both within and among disciplines, to be sure of which conceptual structure they wish to reference, and be sure of those which others are referencing. To that end, we must both test the ontology and map the concept of hierarchy in a sample of the literature.

1.1 Research questions

RQ 1: When social science literature explicitly defines hierarchy, how often are the definitions covered with the rank-nesting-control ontology?

RQ 2: For those definitions that do not fall within the rank-nesting-control ontology, what additional dimensions or categories would describe them, if any?

RQ 3: How do definitions of hierarchy vary within and among disciplines?

RQ 4: What other terms tend to co-occur with hierarchy in the social science literature?

2. Methods

2.1 Overview of computationally-assisted systematic quantitative literature review

Our research questions require identifying definitions of hierarchy within papers, which presents some unique challenges to typical literature searches. Definitions of hierarchy will not be in titles, and are highly unlikely to be in abstracts; the full text of articles are where most definitions of hierarchy will be found. Further, identifying definitions requires identifying phrases that signal definitions within a sentence—definitional phrases such as "hierarchy refers". This type of searching, performed on many thousands of papers, is only feasible using an automated approach.

We develop and use a computationally-assisted version of the systematic quantitative literature review (SQLR) (Pickering and Byrne 2014) to identify, collect, screen, and analyze a much greater number of papers than traditional SQLR methods would allow. See Figure 2.2 for an overview of the process. We follow the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) (Moher et al. 2019) protocol to clarify the phases of this systematic review. Additional information on our computationally-assisted SQLR approach, including links to our code, can be found in the Supplemental Material.

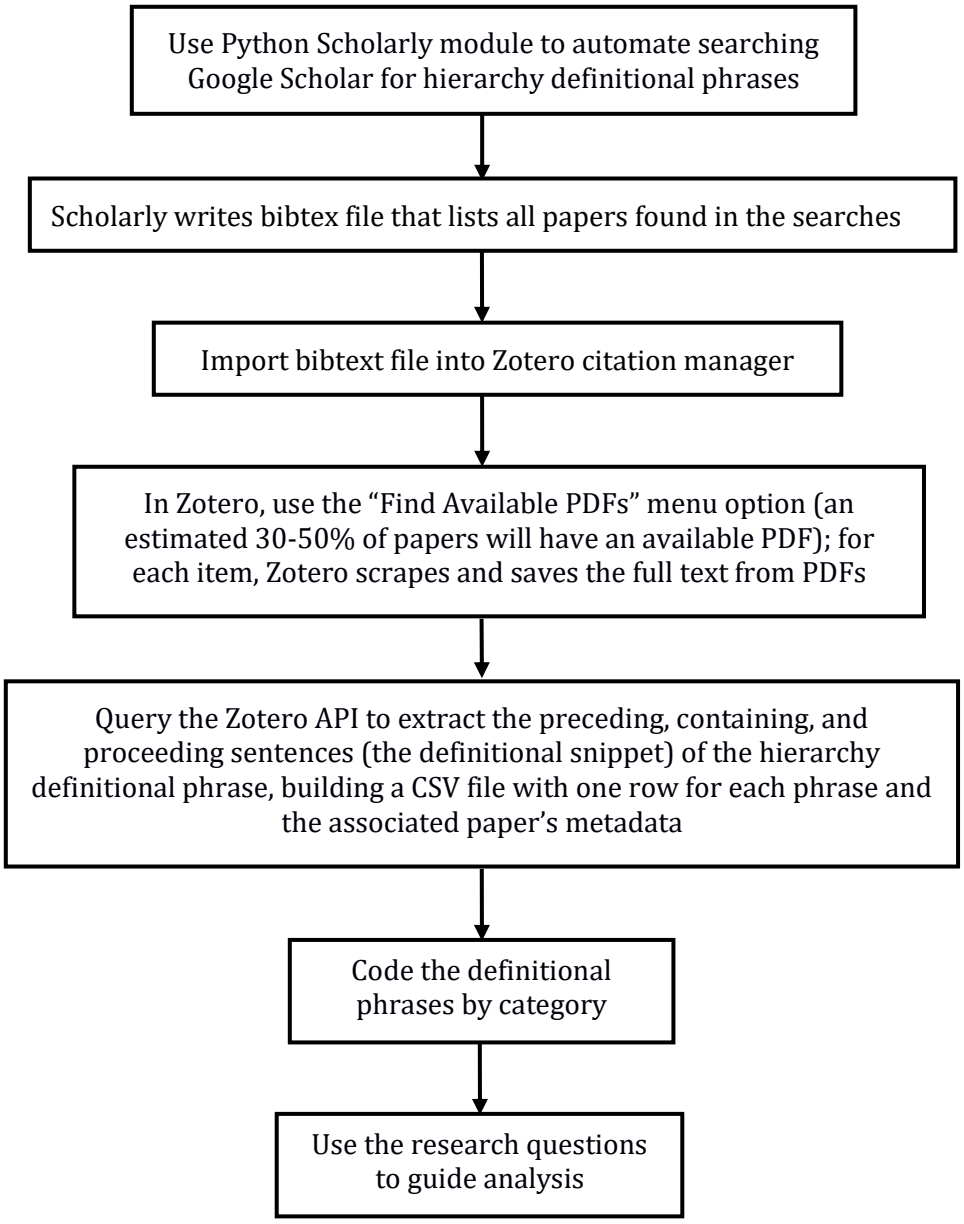


Figure 2.2. The software and data process for data collection and preparation. No one application or library provides all the needed data, so the CSV datafile must be built over a series of steps. Thousands of papers define hierarchy, so we employ an automated search approach (using the Python module Scholarly) to build a list of those papers. Once we have the list of papers, we use the Zotero citation manager as an intermediary tool to retrieve the full text for papers where it is available.

2.2 Data Collection Methods

2.2.1 Database selection

We used Google Scholar because it is the only database encompassing a broad variety of disciplines that indexes and enables searching the full text of articles. See Supplemental Material for a list of other databases and why each did not meet our inclusion criteria. Google Scholar truncates author and journal fields so extensively that citation retrieval and analysis tools like Publish or Perish (Harzing 2007) are not sufficient to retrieve the metadata we need. Fortunately, due to the inclusion of key data such as full titles, Scholarly—a Python library developed to retrieve author and publication information from Google Scholar (Cholewiak et al. 2021)—enables us to retrieve that data.

2.2.2 Paper selection using definitional phrases and search terms

We searched for definitions of *hierarchy* using a list of definitional phrases likely to occur within the sentence defining hierarchy (e.g., "define hierarchy" and "hierarchy we mean"). We also use phrases to prevent irrelevant results (e.g., "analytic hierarchy process"). See Supplementary Materials for a full list of definitional phrases and search terms. We performed the searches from July 4 to July 11th, 2022, which resulted in 11223 total results.

2.2.3 Obtaining full text for the papers and extracting the definition

Although Google Scholar searches the full text it has internally indexed, it does not provide the full text of articles for users to download. We worked around this using the free and open-source citation manager Zotero. We took the lists of papers from the Scholarly searches, screened them, imported them into Zotero as bibtex files, and used Zotero to find publicly-available PDFs for as many of those items as possible. Of the 11223 items imported into Zotero, 6857 had full text available for Zotero to retrieve. We then queried the Zotero

API to extract the full text surrounding the definitional phrase that Google Scholar found in the first place.

For every definitional phrase, we programmatically extracted from the full text a definitional snippet of three hundred characters preceding and following the definitional phrase. This provides context for the definition while keeping the text-per-entry short enough that manual review is still feasible. In the case of multiple definitional phrases, we create an entry for each definitional phrase found within the paper.

2.2.4 Paper screening and eligibility

We removed duplicate papers and those that do not have full-text available, and identified eligible papers by manually reviewing each definitional snippet to determine if it is germane and warrants inclusion. Definitional snippets must pertain to social relations or social systems in some way to be included, otherwise the entry is excluded; see Table 2.2.

Table 2.2. Examples of judging the eligibility of definitional snippets about hierarchy.

Definitional snippet of the preceding, including, and proceeding sentences where the definitional phrase (bolded) appears	**Reasoning for inclusion or exclusion.**
'The fact takes some wonder and is worth pondering, for the young Hegel was intent on totality and had finally reached a hierarchical definition of it when he wrote, in his last fragment in Frankfort, that Life was "the union of union and nonunion" (Verbindung und Nichtverbindung). Here is, if anywhere, that "encompassing of the contrary" through which I proposed to **define hierarchy**. This formula of the young Hegel is no obiter dictum.' (Dumont 1985)	Exclude. No social relations are referenced. It is unclear what hierarchy refers to.
'Many data sets analyzed in human and social sciences have a multilevel or hierarchical structure. By **hierarchy we mean** that units of a certain level (also referred micro units) are grouped into, or nested within, higher level (or macro) units. In these cases, the units within a cluster tend to be more different than units from other clusters, i.e., they are correlated.' (Valente & Oliveira 2011)	Include. A borderline case that seems to be referring to datasets containing social relations.
'An additional important set of contingency factors that may determine whether teams are helped or harmed by hierarchical differentiation are aspects of the hierarchy itself. We **define hierarchy** in this paper broadly as vertical differences in socially valued resources. However, hierarchies may vary widely in the basis and structure of these vertical differences, and some	Include. Hierarchy clearly refers to a social relation associated with resources.

forms and bases of hierarchy are more likely to be contested than others.' (Greer, de Jong, Schouten, & Dannals 2018)	

2.3 Data Coding and Labelling Methods

2.3.1 Coding definitional phrases

We manually coded definitional snippets that mention hierarchy using these tags: rank, nest, and control dimensions (Zafeiris and Vicsek 2017), other-definition category, unclear category, not-a-definition exclude, and duplicate exclude. Each definitional snippet can have more than one coding: e.g., rank and control. See Table 2.3 for examples of definitional phrases and the labels we assigned them. Table 2.3 is not exhaustive of our coding combinations; see Supplemental Materials for our code handbook and the full set of coding data. After screening the initial 11,223 items found with Google Scholar searches, and excluding definitions that were not applicable, we were left with a corpus containing 1,121 definitional snippets of hierarchy belonging to 988 text documents, some of which defined hierarchy multiple times.

Table 2.3. Examples of coding the dimension of hierarchy for definitional snippets.

Definitional snippet (with source in parentheses)	**Hierarchy category**
In L. catta groups the linearity of avoidance based hierarchy derives from the highest frequency of unidirectional dyadic avoidance behavior in L. catta groups and it can indicate greater acceptance of the inferior social rank to dominants by subordinates (deference), greater intolerance by dominants to subordinates, or both. We **define hierarchy** here as aggression-based if it is exclusively unveiled by overt aggressions and submission-based if its detection does not necessarily depend on an arena of aggressive encounters. According to this definition, linear hierarchy is both aggression- and submission-based in L. catta groups and aggression-based in P. verreauxi and E. rufus x collaris groups. (Norrscia & Palagi 2015)	rank
Many data sets analyzed in human and social sciences have a multilevel or hierarchical structure. By **hierarchy we mean** that units of a certain level (also referred micro units) are grouped into, or nested within, higher level	nest

(or macro) units. In these cases, the units within a cluster tend to be more different than units from other clusters, i.e., they are correlated. (Valente & Oliveira 2011)	
An additional important set of contingency factors that may determine whether teams are helped or harmed by hierarchical differentiation are aspects of the hierarchy itself. We **define hierarchy** in this paper broadly as vertical differences in socially valued resources. However, hierarchies may vary widely in the basis and structure of these vertical differences, and some forms and bases of hierarchy are more likely to be contested than others. (Greer, de Jong, Schouten, & Dannals 2018)	rank
The hierarchical method of organizing is characterized by centralized information and the use of behavior constraints. (Recall that we **define hierarchy** as a method of organizing-hierarchy is not synonymous here with "firm" nor with "upper level managers".) Thus, while information is decentralized with prices, it is centralized with hierarchy. (Hennart 1993)	other-definition (centralization)
In this research, we are interested in the hierarchical structure of a group (=power hierarchy) and how it affects group performance and whether group performance only increases if the power hierarchy reflects the group members' individual task-competence differences. By power **hierarchy, we mean** the relative power difference between group members. Power is understood as the extent to which a person can influence or control other group members. (Frauendorfer, Schmid Mast, Sanchez-Cortes, & Gatica-Perez 2015)	control, rank

2.3.2 Updating item metadata

Many of the items imported into Zotero did not contain full metadata because of the limitations of the bibtex files created from Google Scholar search results. Once items marked for exclusion (non-definitions and duplicates) were removed, we retrieved more substantial metadata for the updated set: 988 documents (1,121 definitional items). The additional metadata saved for papers includes: item type, title, author(s), abstract, publication name, volume, issue, pages, date, DOI. All-together, this results in a detailed full-text corpus of papers that define hierarchy, including their exact definitions, and the surrounding context for those definitions.

2.3.3 Coding the discipline of each paper

We used the R package sjrdata (Kashnitsky 2019) to match and apply Scopus® Subject Areas and Subject Categories to each entry appearing in the SCImago database.

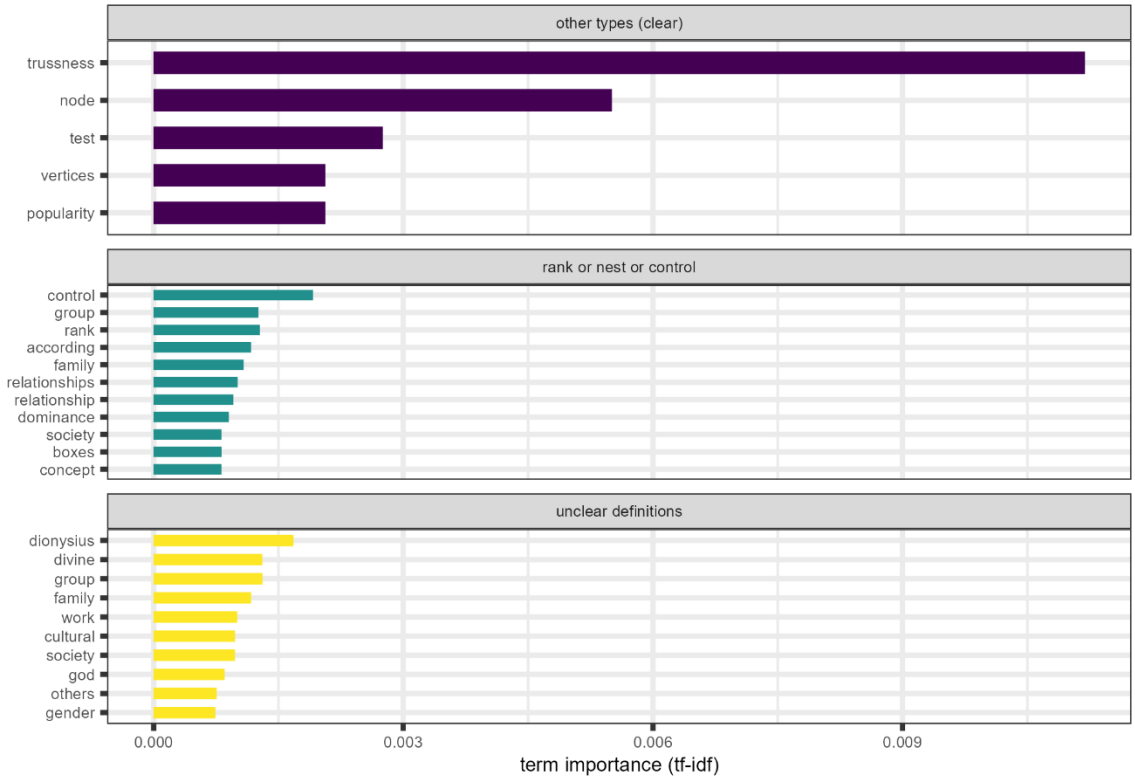
Scopus does not limit these labels to one per journal, so any given journal might have several categories, and those sets of categories may change slightly year-over-year. We consolidated these categories into one set for each journal, regardless of year, and irrespective of Scopus' quartile ranking system for the journals. This left us with a smaller set of consistent labels for the disciplines/fields covered by each journal: e.g., Political Science and International Relations, Law, Economics and Econometrics, etc.

2.4 Data Analysis Methods

We use a *term frequency inverse document frequency* (tf-idf) algorithm to investigate term importance for different categories of definitional snippets (e.g., *control-rank* and *other*), which provides a way to quantify how much particular words are associated with a particular dimensional category of definition (e.g., what are the most important words for categories of hierarchy that are clearly *other*). The tf-idf algorithm works by calculating the relative frequency of words in particular texts and then comparing that frequency to the inverse proportion of that word over the entire corpus of texts (Ramos 2003). This means that words that are generally common have low scores, but words that are uncommon in a particular text score highly. In our case, the individual texts are the combined set of snippets for each category (e.g., *control-rank* and *other*). Essentially, all snippets classified as control-rank are thrown into one bag of words for that category, and those words are assessed in relation to all words in the total corpus of definitional snippets. A comparatively high tf-idf score for a word suggests it has a strong relationship with the category it occurs in. We use the tidytext R package (Silge et al. 2022) to calculate the tf-idf for the terms in our corpus of definitional snippets.

3. Results

3.1 The rank-nesting-control ontology covers most definitions of hierarchy in social science literature



The majority of the 1,121 texts—83% (933)—in this review were categorized as defining hierarchy as one or more of the categories within the control-nest-rank ontology of dimensions. However, 56% (624) were classified as unclear definitions; still, of these, 71% (440) included words that implied one or more of the dimensions in the control-nest-rank ontology. The breakdown of types suggested by the definitions can be seen in Figure 2.3. Definitions labeled as clear did include some combinations of the control, nest, and rank dimensions: 19% (95) of the clear definitions contained some mix of the three dimensions. Most of these mixed definitions (79%; 75) were the combination of control and rank hierarchy.

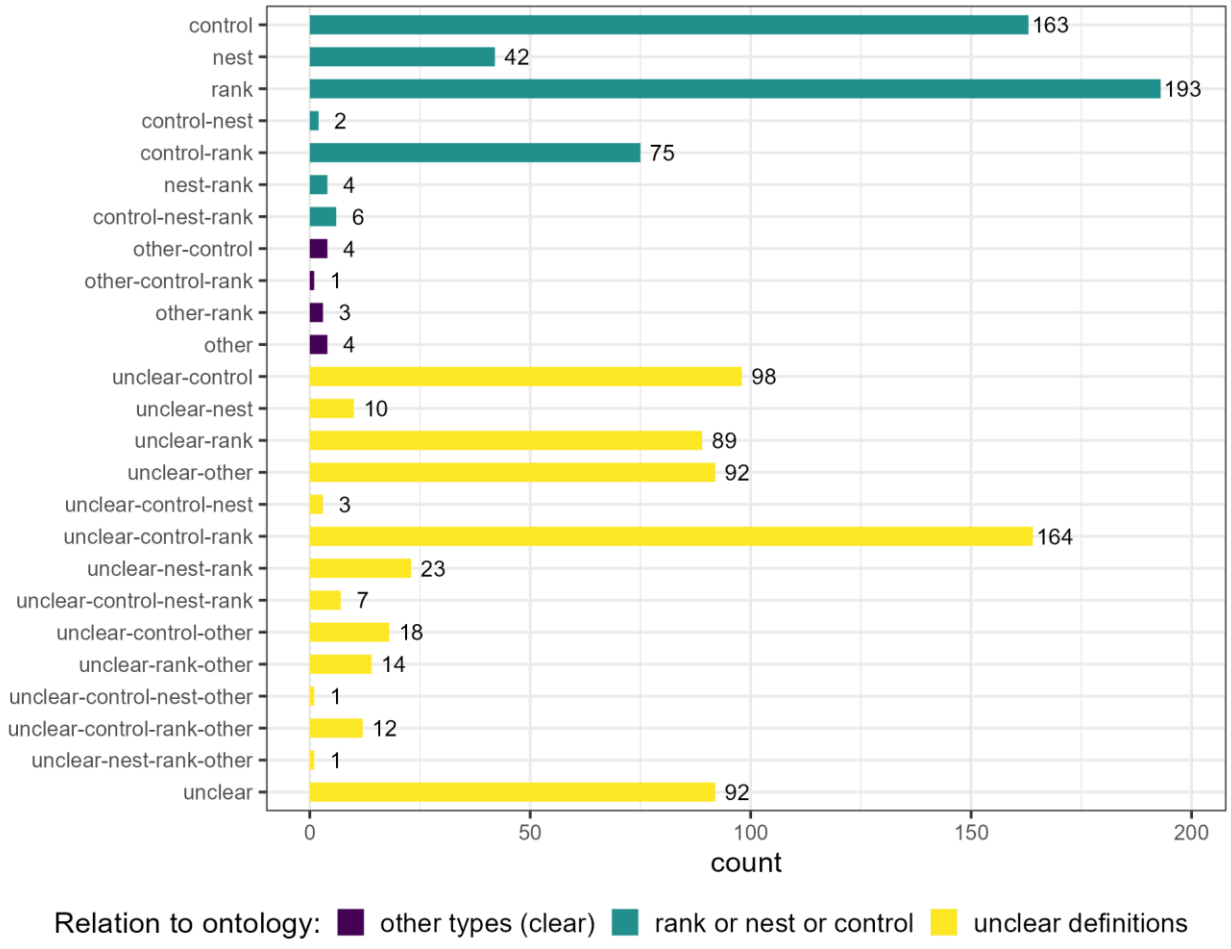


Figure 2.3. Charting definitions by unique tag combinations and broad categories. Teal bars are clearly defined and fit within the control-nest-rank ontology; deep purple bars are clearly defined but contain dimensions of meaning clearly outside the ontology; yellow bars are unclearly defined with only hints at meaning. Definitions are grouped by their unique tag combinations (e.g., control and rank). Control, rank, and control-rank meanings dominate both clear and unclear definitions. Very few clear definitions have dimensions that fall outside the control-nest-rank ontology of dimensions (deep purple bars).

To assess the coverage of the control-nest-rank ontology, we were particularly interested in how many definitions clearly belonged outside of the ontology. Only 1% (12) of the total definitions contained aspects that were clearly outside of the control-nest-rank ontology, and of those, only 4 were wholly outside of it (pure *other* in Figure 2.3). If we include unclear definitions, 13% (150) suggested definitions outside the ontology, but

roughly a third (46) of those contain some meaning related to the control-nest-rank ontology. We explore these outsiders (i.e., the purple *other types* in Figure 2.3) below.

3.2 Definitions for hierarchy wholly outside the control-nest-rank typology tend to be network-measure-based definitions

Definitions of hierarchy that do not fall within the control-nest-rank ontology are few but important, and can be seen as one of two groups: those adding an additional meaning to an existing dimension, and those which lie purely outside the control-nest-rank ontology. Assessing the meaning of these latter definitions is particularly important for checking the general validity of the ontology, so we compared terms and term importance for *other* types, measured by the tf-idf measure calculated by tidytext (Silge et al. 2022), as shown in Figure 2.4.

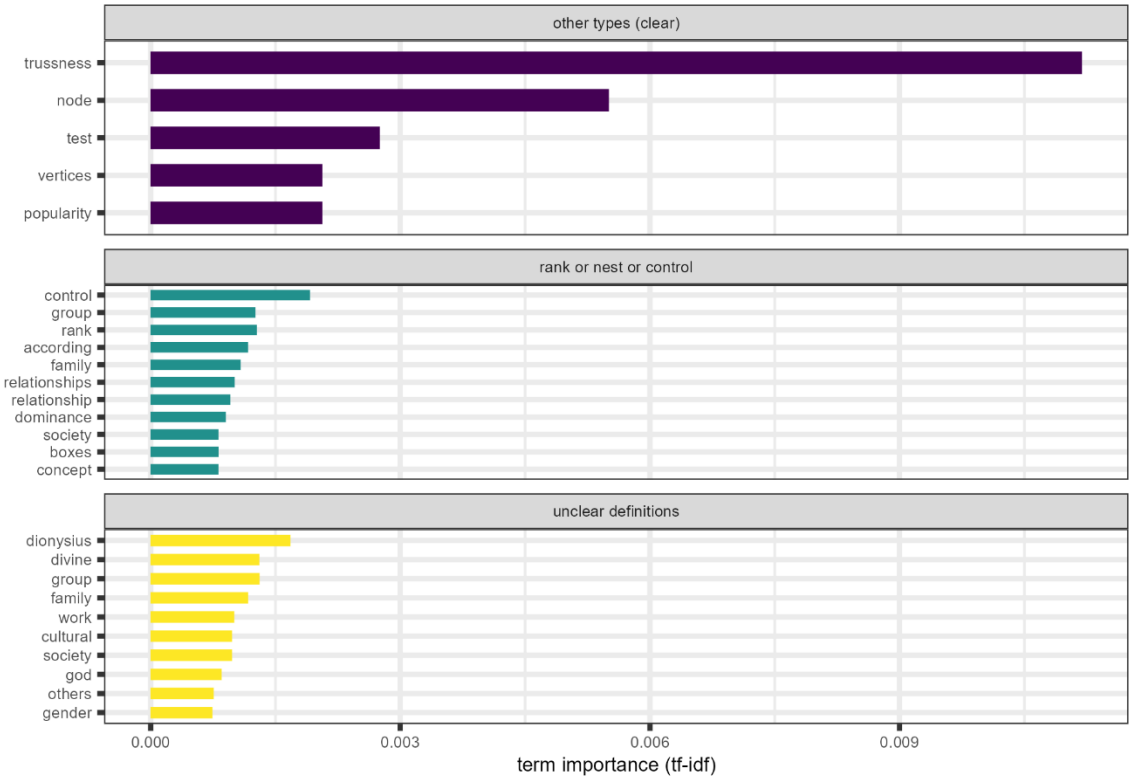


Figure 2.4. Comparison of the important terms for definitions coded as other versus all remaining definitions. Network science terms dominate the *other* definitions, and terms clearly connected to the control-nest-rank typology dominate the clear definitions.

Most definitions lying purely outside the control-nest-rank ontology define hierarchy with network measures: trussness and/or network centrality. In both cases, these measures are used to create a ranking of nodes that suggests their importance to the network. However, these definitions were different enough from the social notion of ranks-as-social-relations that they were not coded as being rank type. Semantically, while the researchers are ranking the nodes according to these network measures, there is no implication that the nodes (as people, or agents) are perceiving or using this ranking to inform social relationships or behavioral norms, as one might with, for example, social ranks related to class or prestige.

Definitions coded as *other* that also include labels from the control-nest-rank ontology tend to emphasize an additional relation within the control hierarchy relationship, specifically, the flow of information up the hierarchy as well as the flow of command and control downward.

3.3 The majority of social science fields use control or rank definitions, with important exceptions

Out of our 1,121 definitions, 201 (18%) appeared in journals indexed with Scopus® Subject Areas and Subject Categories, giving us enough of a sample to sort types of hierarchy by social science discipline. Scopus applies multiple labels to each journal, and this overlap is important to keep in mind when considering our results; roughly 5 categories (median) apply per journal, and thus per definition. Our items have been labeled with 101 distinct Scopus categories in total. The top 20 Scopus Subject Areas/Categories and the types of hierarchy definitions they contain are shown in Figure 2.5.

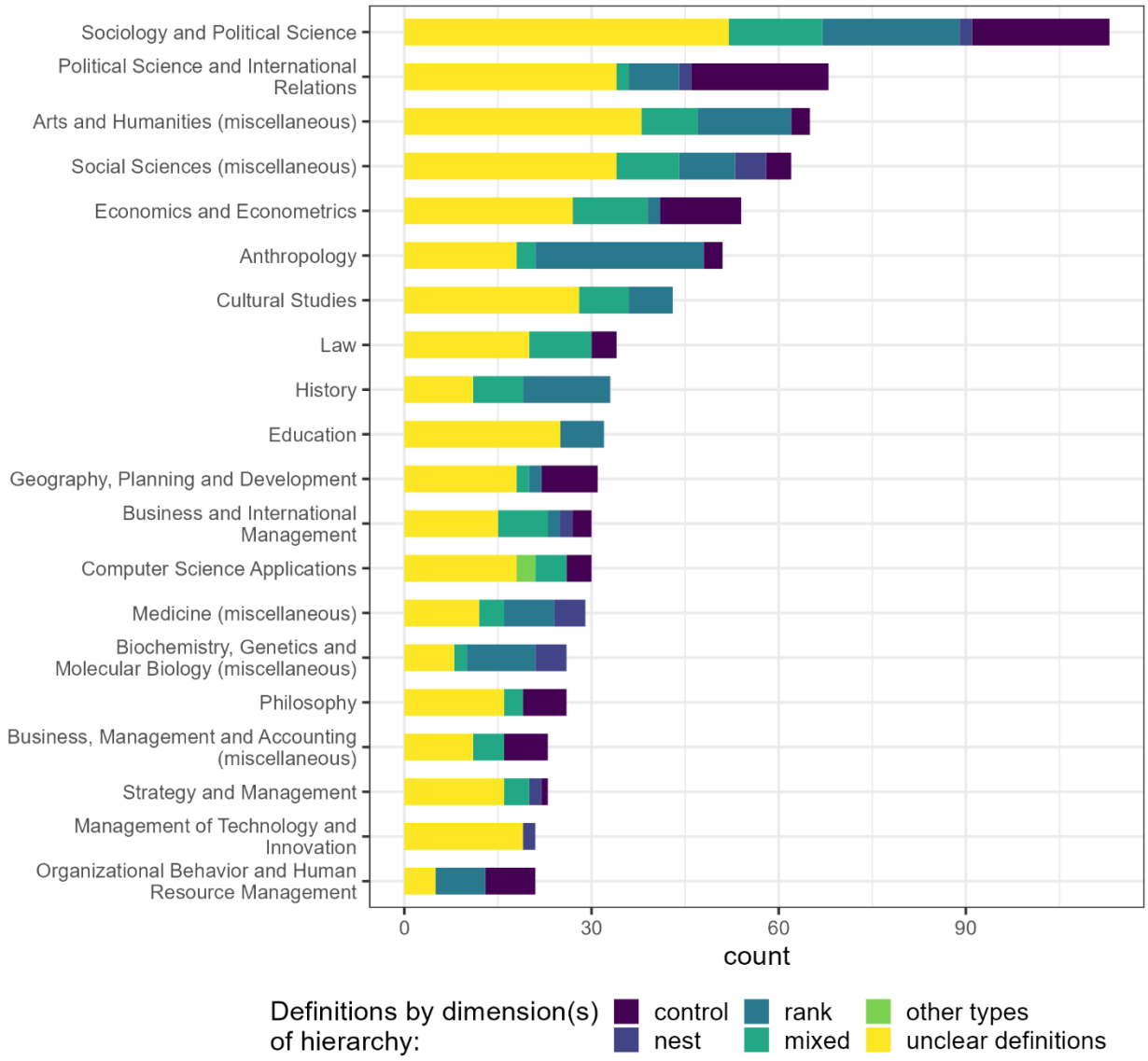


Figure 2.5. Hierarchy definitions per the top 20 Scopus Subject Areas/Categories identified per item. Each bar stratifies the definitions by dimension within the control-nest-rank ontology, and whether the definitions are mixed (e.g., control-rank), other (contain a definition that falls outside the ontology), or unclear. As seen originally in Figure 2.3, unclear definitions are the majority, however, disciplinary areas vary in their proportions. Computer science contains the majority of definitions that include other. Scopus applies multiple labels to each journal, so journals may be in more than one of these top 20 Scopus Subject Areas/Categories.

Generally, those fields with a greater focus on organizations (e.g., political science, business) included definitions that were control, rank, or some mix of the two. Fields with a greater focus on societal and cultural behavior (e.g., history, anthropology, cultural studies)

tended to employ rank definitions of hierarchy. We would have expected to see this confirmed by looking at the most important terms for each type, and we did, which we will discuss in the next subsection. Still, most fields contain multiple or mixed dimensions. We see that hierarchy definitions that fall outside of the control-nest-rank ontology occur almost entirely in computer science journals, which makes sense, since these *other* definitions are rooted in network science concepts of hierarchy.

3.4 Related terms that co-occur with defining hierarchy

We identified key terms that co-occur with various single or mixed hierarchy definitions using term importance, represented by the tf-idf measure (Silge et al. 2022). The top ten terms for each type are shown in Figure 2.6. Note that control-nest and nest-rank categories had few entries, resulting in fewer than ten terms above the tf-idf cutoff at zero; control-nest-rank had tie-scores among a set of terms, resulting in thirteen terms displayed instead of ten.

The sets of terms validate the control-nest-rank ontology, and suggest key touch-points in social science topics more broadly. Control, rank, and control-rank all share the term *power* as a common term and theme, yet there the similarities end. Control hierarchies relate to *governance*, *chain* of *command*, *authority*, and being *organized*. Rank hierarchies relate to *status*, *position*, and *caste*. Control-rank, those definitions that combine the two types, tend to mention *relationships* and *organizations*, suggesting that those circumstances necessarily include both.

The nest dimension of hierarchy shares little thematically with control and rank dimensions, as evidenced both by a lack of common terms and, as seen previously, the small number of mixed categories that include nest. *Subsystems* and *boxes* relate to this type, and perhaps most telling, *simon*, as in Herbert A. Simon. Herbert Simon's research spanned

many disciplines, and so too has his definition of hierarchy as systems with subsystems (1962) or a set of nested Chinese boxes (1977) broadly influenced the literature. The term *dumont*, for Louis Dumont, also makes an appearance for the nest-rank type. Authors of these works were invoking Dumont's definitions of hierarchy (part of his inquiry into the Indian caste system), which range from clear to quite unclear: e.g., "the principle by which the elements of a whole are ranked in relation to the whole" (1970, p. 66); "a relation that can succinctly be called 'the encompassing of the contrary'" (1980, p. 239).

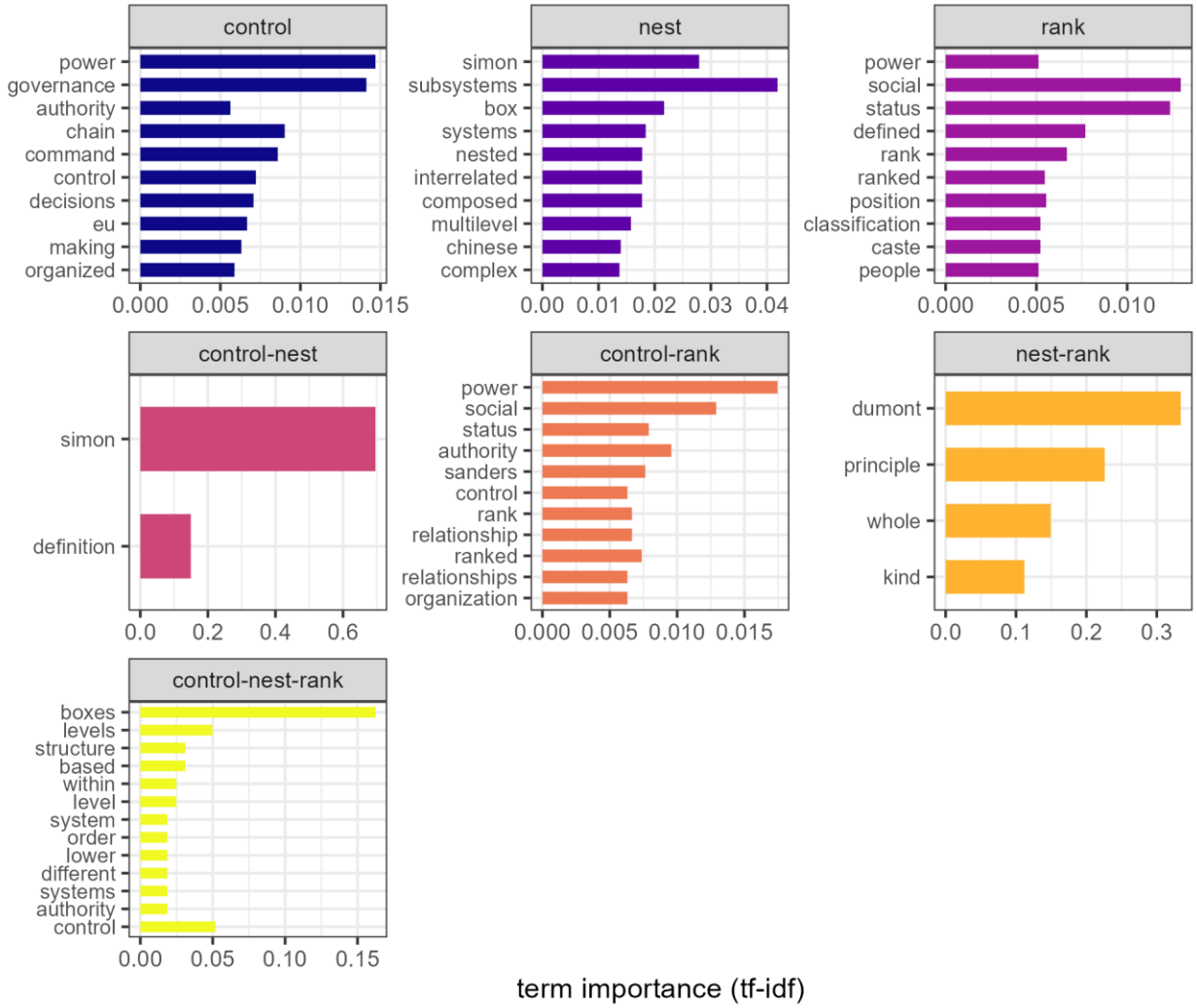


Figure 2.6. Important terms that co-occur with definitions of hierarchy. Power is an important theme for control and rank hierarchies, but few other terms are shared, suggesting that power may have

foundationally similar but manifestly different conceptions in these two types. Terms related to the nest type of hierarchy are most linked to Herbert Simon's definition of hierarchy in complex systems as subsystems within systems, or nested Chinese boxes. Other terms suggest mixing of the types, or draw on previous authors mixing the types, e.g., Louis Dumont.

4. Discussion

4.1 The control-nest-rank typology of hierarchy is valid across fields

This computer-aided systematic quantitative literature review suggests that the control-nest-rank ontology for hierarchy should be seen as a useful, standard ontology that can increase consistency and clarity for disciplinary and interdisciplinary discussion of hierarchy in the social sciences. A number of findings support this claim. We find that when social science scholars define the term hierarchy clearly within their work, they usually refer to types of hierarchy that match the control-nest-rank ontology. Of those definitions which are unclear—which is just over half—most implicitly invoke one or more dimensions within this same ontology. The categories cover nearly all clear definitions of hierarchy in the social sciences literature we reviewed. Most unclear definitions suggest one or more dimensions from the ontology, suggesting that the dimensions retain conceptual relevance for these authors' considerations of hierarchy as well. When definitions are analyzed by dimensions, including pure and mixed definitions, their associated terms further support the validity of the ontology as distinguishing three distinct dimensions of hierarchy.

4.2 The network science definition of hierarchy is the only clear outsider

Very few clear definitions of hierarchy laid outside the control-nest-rank ontology, but those that did tended to be network science definitions related to ranking nodes according to network structure to help describe network structure: i.e., trussness and centrality. While centrality and trussness network measures may suggest this social knowledge, they themselves are not how people (excluding perhaps network scientists)

356 think of hierarchy. The strength of network-structure approaches lies in mapping particular
357 structural aspects of social phenomena in social groups, making otherwise intractable
358 cross-comparisons tractable. Network science measures of hierarchy have approached
359 defining hierarchy from this direction (e.g., Mones 2013, Mengistu et al 2016, Jo et al. 2020,
360 Bloch et al 2021, Diggans et al. 2021). Thus, social scientists and network scientists should
361 proceed carefully when engaging with work that mixes networks and the more common
362 control-nest-rank dimensions of hierarchy.

363 ### 4.3 All fields would benefit from defining hierarchy more clearly

364 The volume of unclear definitions of hierarchy suggests room for improvement
365 broadly across the social sciences. All fields contain a substantial proportion of unclear
366 definitions of hierarchy, and some fields contain, proportionally, many more unclear
367 definitions than clear definitions. In some cases—e.g., strategy and management versus
368 business and international management—two related fields have drastically different
369 proportions of unclear definitions; the reasons for this are not clear. Researchers should
370 strive to describe the dimensions of hierarchy that matter for their research's focus,
371 ensuring more valid and consistent interpretations of their work within and beyond their
372 field. This matters for associated theories and evidence as well as conclusions.

373 ### 4.4 The role of power in control versus rank hierarchies needs more inquiry

374 Power is an important theme for control and rank hierarchies, but few other terms
375 are shared between the two dimensions. Control hierarchy definitions often include
376 *governance*, *chain* of *command*, *authority*, and being *organized*. Rank hierarchy definitions
377 often include *status*, *position*, and even *caste*. This rift between co-occurring terms suggests
378 that power may play different roles, or perhaps even be of different varieties, within control
379 and rank hierarchies. This difference may also be related to the differences in dominance

and prestige (Maner 2017, Cheng 2020), which then create different subtypes of hierarchies (Jimenez and Mesoudi 2021; von Rueden 2020). These inquiries begin to dig at hierarchy formation, while we have focused solely on definitions of hierarchy. However, the signs are there: our analysis also found that mixed control-rank definitions tended to mention *relationships* and *organizations*, which are necessarily built and maintained. At these intersections—where the power of prestige and the power of dominance help shape the formation of social ranks and chains of command—we may find the dynamics that explain functional or dysfunctional hierarchies (Greer et al. 2017, Greer and Chu 2020), but only if we continue to make careful distinctions.

4.5 Limitations and Future Directions

Since this study contains much more literature than a standard systematic quantitative literature review, we do trade some depth for breadth. A more thorough analysis of the texts we identified in our searches may help explain why researchers chose to emphasize a particular dimension of hierarchy. Each researcher has their own angle and motivation, and these factors were simply ignored. Given the size of the full-text corpus, additional text-mining methods such as topic modeling may provide additional insight into perspectives and topics that are more conceptually complex than single terms suggest.

However, the single terms we highlighted were instructive, and a deeper investigation into important terms that co-occur with hierarchy—such as *power*—could yield insights into their role within hierarchy and help bridge research dealing with dominance and prestige in organizations and society. Conceptions of power, prestige, and dominance as social relations existing within dimensions of hierarchy may provide individual-level mechanisms for bridging different fields and varied insights into human organization.

Finally, our search was limited by the use of definitional phrases—e.g., "hierarchy refers"—that signaled a possible definition. Those researchers that explicitly defined hierarchy without using these particular definitional phrases were not picked up by the search, and not included. Future computer-aided systematic quantitative literature reviews would benefit from a better understanding of fine-tuning this net and improving the quality of the catch.

5. Conclusion

When researchers use the same term to refer to different things, which we show is frequent with the term *hierarchy*, confusion is inevitable. However, we also find three distinct and consistent meanings underlie most uses of the term. These rank-nest-control dimensions of hierarchy provide excellent coverage for the large sample of definitions we extracted from across the social sciences, demonstrating conceptual relevance for those aspects of hierarchy that researchers emphasize. Those definitions that clearly fall outside of the dimensional ontology are few, involving network measures of hierarchy.

Terms that co-occur with hierarchy reinforce the validity of the ontology, and also point to concepts that need additional ontological attention to distinguish them from, and situate their role within, hierarchy. Power, in particular, relates to both control and rank hierarchies, but our analysis of term importance suggests conceptual differences in what power is and does in each type of hierarchy. These differences warrant further investigation.

While different social science fields may emphasize one dimension of hierarchy more or less than others, we show that in most fields the majority of definitions of hierarchy are unclear definitions. However, the majority of these unclear definitions do reference one

or more of the dimensions, suggesting they are relevant to the research, but simply lack clarity. A clear, common set of dimensions are crucial for linking disciplines and future interdisciplinary work. We recommend that, when defining hierarchy as an element of study, researchers across the social sciences use the control-nest-rank ontology to increase the consistency and validity of their work within and between fields, and lay a solid foundation for future advancements in understanding social behavior.

3. References

Bess, K. D. (2015). Reframing Coalitions as Systems Interventions: A Network Study Exploring the Contribution of a Youth Violence Prevention Coalition to Broader System Capacity. *American Journal of Community Psychology*, *55*(3), 381–395. https://doi.org/10.1007/s10464-015-9715-1

Bloch, F., Jackson, M. O., & Tebaldi, P. (2021). *Centrality Measures in Networks* (arXiv:1608.05845). arXiv. https://doi.org/10.48550/arXiv.1608.05845

Cholewiak, S. A., Ipeirotis, P., Silva, V., & Kannawadi, A. (2021). *SCHOLARLY: Simple access to Google Scholar authors and citation using Python* (1.5.1). https://doi.org/10.5281/zenodo.5764801

Crabtree, S. A., Bocinsky, R. K., Hooper, P. L., Ryan, S. C., & Kohler, T. A. (2017). How to Make a Polity (In the Central Mesa Verde Region). *American Antiquity*, *82*(1), 71–95. https://doi.org/10.1017/aaq.2016.18

Creswell, J. W., & Creswell, J. D. (2017). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. SAGE Publications.

Diggans, C. T., Fish, J., & Bollt, E. (2021). Emergent hierarchy through conductance-based node constraints. *ArXiv:2102.11774 [Physics]*. http://arxiv.org/abs/2102.11774

Dumont, L. (1970). *Homo Hierarchicus: An Essay on the Caste System. Translated (From the French) by Mark Sainsbury*.

Dumont, L. (1980). *Homo hierarchicus: The caste system and its implications*. University of Chicago Press.

Dumont, L. (1985). German Idealism in a Comparative Perspective: Hierarchy in the Thought of Fichte. *Comparative Civilizations Review*, *10*(10), 12.

Fattorini, L. (2003). Statistical analysis of ecological diversity. *Environmetrics; El-Shaarawi, AH, Jureckova, J., Eds*, 18–29.

458 Frauendorfer, D., Schmid Mast, M., Sanchez-Cortes, D., & Gatica-Perez, D. (2015). Emergent
459 Power Hierarchies and Group Performance. *International Journal of Psychology*, *50*(5), 392–
460 396. https://doi.org/10.1002/ijop.12102

461 Greer, L. L., & Chu, C. (2020). Power struggles: When and why the benefits of power for
462 individuals paradoxically harm groups. *Current Opinion in Psychology*, *33*, 162–166.
463 https://doi.org/10.1016/j.copsyc.2019.07.040

464 Greer, L. L., de Jong, B. A., Schouten, M. E., & Dannals, J. E. (2018). Why and when hierarchy
465 impacts team effectiveness: A meta-analytic integration. *Journal of Applied Psychology*,
466 *103*(6), 591–613. https://doi.org/10.1037/apl0000291

467 Greer, L. L., Van Bunderen, L., & Yu, S. (2017). The dysfunctions of power in teams: A review
468 and emergent conflict perspective. *Research in Organizational Behavior*, *37*, 103–124.
469 https://doi.org/10.1016/j.riob.2017.10.005

470 Harzing, A.-W. (2007). *Publish or Perish*. https://harzing.com/resources/publish-or-perish

471 Hobson, E. A., & DeDeo, S. (2015). Social Feedback and the Emergence of Rank in Animal
472 Society. *PLOS Computational Biology*, *11*(9), e1004411.
473 https://doi.org/10.1371/journal.pcbi.1004411

474 Hobson, E. A., Ferdinand, V., Kolchinsky, A., & Garland, J. (2019). Rethinking animal social
475 complexity measures with the help of complex systems concepts. *Animal Behaviour*, *155*,
476 287–296. https://doi.org/10.1016/j.anbehav.2019.05.016

477 Hobson, E. A., Mønster, D., & DeDeo, S. (2021). Aggression heuristics underlie animal
478 dominance hierarchies and provide evidence of group-level social information. *Proceedings*
479 *of the National Academy of Sciences*, *118*(10). https://doi.org/10.1073/pnas.2022912118

480 Holling, C. S. (2001). Understanding the Complexity of Economic, Ecological, and Social
481 Systems. *Ecosystems*, *4*(5), 390–405. https://doi.org/10.1007/s10021-001-0101-5

482 Jiménez, Á. V., & Mesoudi, A. (2021). The Cultural Transmission of Prestige and Dominance
483 Social Rank Cues: An Experimental Simulation. *Evolutionary Psychological Science*, *7*(2),
484 189–199. https://doi.org/10.1007/s40806-020-00261-x

485 Jo, W. S., Park, J., Luhur, A., Kim, B. J., & Ahn, Y.-Y. (2020). Extracting hierarchical backbones
486 from bipartite networks. *ArXiv:2002.07239 [Physics]*. http://arxiv.org/abs/2002.07239

487 Johnson, G. A. (1982). Organizational Structure and Scalar Stress. *Theory and Explanation in*
488 *Archaeology*.

489 Kashnitsky, I. (2019). *sjrdata: All SCImago Journal & Country Rank data, ready for R*.

490 Kawakatsu, M., Chodrow, P. S., Eikmeier, N., & Larremore, D. B. (2021). Emergence of
491 hierarchy in networked endorsement dynamics. *Proceedings of the National Academy of*
492 *Sciences*, *118*(16). https://doi.org/10.1073/pnas.2015188118

493 Koski, J., Xie, H., & Olson, I. (2015). *Understanding social hierarchies: The neural and*
494 *psychological foundations of status perception*.
495 https://www.tandfonline.com/doi/abs/10.1080/17470919.2015.1013223

Ladyman, J., Lambert, J., & Wiesner, K. (2013). What is a complex system? *European Journal for Philosophy of Science*, *3*(1), 33–67. https://doi.org/10.1007/s13194-012-0056-8

Lane, D. (2006). Hierarchy, Complexity, Society. In D. Pumain (Ed.), *Hierarchy in Natural and Social Sciences* (pp. 81–119). Springer Netherlands. https://doi.org/10.1007/1-4020-4127-6_5

Lenaerts, T., Chu, D., & Watson, R. (2005). Dynamical Hierarchies (Guest Editors' Introduction). *Artificial Life*, *11*(4), 403–405. https://doi.org/10.1162/106454605774270606

Maner, J. K. (2017). Dominance and Prestige: A Tale of Two Hierarchies. *Current Directions in Psychological Science*, *26*(6), 526–531. https://doi.org/10.1177/0963721417714323

Martin-Breen, P., & Anderies, J. M. (2011). *Resilience: A Literature Review*. https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/3692

Masuda, N., Kawamura, Y., & Kori, H. (2009). Impact of hierarchical modular structure on ranking of individual nodes in directed networks. *New Journal of Physics*, *11*(11), 113002. https://doi.org/10.1088/1367-2630/11/11/113002

Mengistu, H., Huizinga, J., Mouret, J.-B., & Clune, J. (2016). The Evolutionary Origins of Hierarchy. *PLOS Computational Biology*, *12*(6), e1004829. https://doi.org/10.1371/journal.pcbi.1004829

Milkoreit, M., Hodbod, J., Baggio, J., Benessaiah, K., Calderón-Contreras, R., Donges, J. F., Mathias, J.-D., Rocha, J. C., Schoon, M., & Werners, S. E. (2018). Defining tipping points for social-ecological systems scholarship—An interdisciplinary literature review. *Environmental Research Letters*, *13*(3), 033005. https://doi.org/10.1088/1748-9326/aaaa75

Mones, E. (2013). Hierarchy in directed random networks. *Physical Review E*, *87*(2), 022817. https://doi.org/10.1103/PhysRevE.87.022817

Norscia, I., & Palagi, E. (2015). The socio-matrix reloaded: From hierarchy to dominance profile in wild lemurs. *PeerJ*, *3*, e729. https://doi.org/10.7717/peerj.729

Page, S. (2010). Diversity and Complexity. In *Diversity and Complexity*. Princeton University Press. https://doi.org/10.1515/9781400835140

Parker, M. A. (2014). *Social Network Determinants of Self-Perceived Influence among Minority and Non-Minority STEM Faculty*. University of Illinois at Chicago.

Pumain, D. (2006). *Hierarchy in natural and social sciences*. Springer.

Ramos, J. (2003). Using tf-idf to determine word relevance in document queries. *Proceedings of the First Instructional Conference on Machine Learning*, *242*(1), 29–48.

Saxena, R., Kaur, S., & Bhatnagar, V. (2018). Social centrality using network hierarchy and community structure. *Data Mining and Knowledge Discovery*, *32*(5), 1421–1443. https://doi.org/10.1007/s10618-018-0582-x

Silge, J., Fay, C., Hvitfeldt, E., Mastny, T., Benoit, K., Erickson, J., Hester, J., Kanishka, Robinson, D., Henry, L., Sousa, L. de, Dobbyn, A., McNamara, A., Smith, A., Lependorf, D., Childers, D., Pennec, E. L., Keirstead, J., Bryan, J. (Jenny), … Kross, S. (2022). *juliasilge/tidytext: Tidytext 0.3.4*. Zenodo. https://doi.org/10.5281/zenodo.7011558

Simon, H. A. (1962). The Architecture of Complexity. *Proceedings of the American Philosophical Society*, *106*(6), 467–482.

Simon, H. A. (1977). The Organization of Complex Systems. In H. A. Simon (Ed.), *Models of Discovery: And Other Topics in the Methods of Science* (pp. 245–261). Springer Netherlands. https://doi.org/10.1007/978-94-010-9521-1_14

Valente, V., & Oliveira, T. (2011). Application of HLM to data with multilevel structure. *Discussiones Mathematicae Probability and Statistics*, *31*(1–2), 87–101.

Zafeiris, A., & Vicsek, T. (2017). Why we live in hierarchies: A quantitative treatise. *ArXiv:1707.01744 [Nlin, Physics:Physics]*. http://arxiv.org/abs/1707.01744

APPENDICES

A. Supplemental Materials

A1.1. Databases that did not meet the criteria for inclusion

Google Scholar is the only full text index available. All other databases of scholarly literature available index only the abstract and/or title.

Table A.1. Bibliographic research databases, the content indexed, and their search capabilities.

Database	Booleans	Title	Abstract	Full text	Exact phrase
Crossref	or	title	no abs	no full	no exact
Google Scholar	*or and not*	*title*	*no abs*	*full*	*exact phrase*
MS Academic	or and	title	abs	no full	no exact
Scopus.com	or and not	title	abs	no full	exact phrase
Scopus API	or and not	title	abs	no full	exact phrase
Web of Science	No USU access	No USU access	No USU access	No USU access	No USU access

A1.2. Full list of definitional phrases and search terms

Definitional phrases are included with a search for social, e.g. social AND "hierarchy is defined". Exclusionary phrases are constructed with a negative sign before the phrase, e.g. -"analytical hierarchy process". See Table S1.2 for the full list.

Table A.2. The full list of definitional phrases and exclusionary phrases for searching Google Scholar.

Definitional phrases	Exclusionary phrases
"hierarchy is defined"	"analytic hierarchy process"
"hierarchy meaning"	"analytical hierarchy process"
"hierarchy refers"	"response hierarchy"
"defines hierarchy"	"polynomial-time hierarchy"
"hierarchy defined"	"polynomial hierarchy"
"define hierarchy"	"gauge hierarchy"
"hierarchy means"	"geometric hierarchy"
"hierarchy we mean"	"hierarchy of needs"
"hierarchy i mean"	"hierarchy of effects"
"hierarchy they mean"	"boundary hierarchy"

"hierarchy it means" "hierarchy definition" "definition for hierarchy" "defining hierarchy" "definition hierarchy" "hierarchy meaning" "definition of hierarchy" "hierarchy is a" "hierarchy is the" "hierarchy meaning" "hierarchy refers"	"toda hierarchy" "mass hierarchy" "hamiltonian hierarchy" "hierarchy of effects" "fuzzy hierarchy" "semantic hierarchy" "image hierarchy" "cognitive hierarchy" "response hierarchies" "polynomial-time hierarchies" "polynomial hierarchies" "gauge hierarchies" "geometric hierarchies" "boundary hierarchies" "toda hierarchies" "mass hierarchies" "hamiltonian hierarchies" "fuzzy hierarchies" "semantic hierarchies" "image hierarchies" "cognitive hierarchies"

A1.3. Data, process, and code repository

Available at https://github.com/stanleyrhodes/dis1_casqlr_hierarchy

A1.4. Code book

Available at https://github.com/stanleyrhodes/dis1_casqlr_hierarchy