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Evolution of word meanings through metaphorical mapping: Systematicity over the past millennium

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ABSTRACT

One way that languages are able to communicate a potentially infinite set of ideas through a finite lexicon is by *compressing* emerging meanings into words, such that over time, individual words come to express multiple, related senses of meaning. We propose that overarching communicative and cognitive pressures have created *systematic directionality* in how new metaphorical senses have developed from existing word senses over the history of English. Given a large set of pairs of semantic domains, we used computational models to test which domains have been more commonly the starting points (source domains) and which the ending points (target domains) of metaphorical mappings over the past millennium. We found that a compact set of variables, including *externality*, *embodiment*, and *valence*, explain directionality in the majority of about 5000 metaphorical mappings recorded over the past 1100 years. These results provide the first large-scale historical evidence that metaphorical mapping is systematic, and driven by measurable communicative and cognitive principles.

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1. Introduction

Every natural language faces the challenge of having to express a potentially infinite range of ideas through a finite set of words (cf. von Humboldt, 1836; Chomsky, 1957; Pustejovsky, 1995). One way in which languages meet the challenge of maintaining a compact lexicon is by compressing emerging, yet to be lexicalized ideas, into existing word forms. The most common form of compression in the lexicon, both in English and in other languages, is *polysemy*: Cases where a single word has multiple, related senses (e.g., Breal, 1897; Brugman, 1988; Geeraerts, 1997; Lakoff & Johnson, 1980; Pustejovsky, 1995; Srinivasan & Rabagliati, 2015; Sweetser, 1991). One prominent mechanism that generates polysemy over the course of history is *metaphorical mapping* (e.g., Lakoff & Johnson, 1980), whereby new word meanings are created by mapping an existing sense of a word from its own *source domain* to another *target domain*, based on structural similarities between the domains. For example, the English word *grasp* originally conveyed a physical action (source), as in "grasp a fruit," and was later extended to express an abstract sense of understanding (target), as in "grasping an idea," thus construing ideas as objects that can be held and controlled. In the present study, we test whether there is *systematic directionality* in how new metaphorical senses have developed over the history of English. That is, given a pair of semantic domains, can we predict which

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domain served historically as the source and which as the target of metaphorical mapping, based on considerations of broader communicative and cognitive pressures?

Consistent with the idea that metaphorical sense extension is systematic, prior research (e.g., Lakoff & Johnson, 1980; Sweetser, 1991) has suggested that mappings between semantic domains tend to be *asymmetric*: They occur in one direction but not the other (e.g., for *grasp,* it is "action"→"knowledge" but not "knowledge"→"action"). However, directionality in historical metaphorical mappings has not been evaluated *at scale* against records of historical semantic change, leaving open whether metaphorical mappings truly reflect predictable patterns. Using an historical corpus of the English lexicon, we seek to investigate – at a large scale – the historical directions of metaphorical mapping by testing whether some domains have more commonly served as the starting points of historical extensions (the source domains) while others have more commonly served as the ending points (target domains). For example, in the case of *grasp*, the "physical action" sense first appeared in English around 1300 CE, preceding the abstract sense of "understanding" that emerged around 1600 CE (Kay, Roberts, Samuels, Wotherspoon, & Alexander, 2015a). Our analysis examines systematicity in the directionality of historical metaphorical sense mappings in the English lexicon.

Directions of metaphorical mapping need not be systematic: Instead, the evolutionary path of meaning change could be varied and unpredictable across words. Although some words, like *grasp*, may have begun with a relatively concrete sense that was subsequently extended to a more abstract sense, other words may have been extended in the opposite direction, from abstract to concrete senses. For instance, *irritable* initially conveyed an abstract sense of "anger," as in an "irritable person" (1662 CE; Kay et al., 2015a), but it was subsequently used to convey a more concrete, physical meaning, as in "irritable skin" (1791 CE; Kay et al., 2015a). A particular word's path could be shaped by the ever-changing cultural conditions and resultant communicative needs that have caused words to develop new meanings across history (cf. Aitchison, 2001). The contributing factors may be variable across words and across eras of history, resulting in little systematicity on a large scale.

However, an alternative possibility is that the direction of metaphorical sense extension is systematic, because it is shaped by enduring functional pressures on language evolution. Recent work in computational cognitive science has suggested that many aspects of language and cross-linguistic variation can be understood in terms of general design principles, such as the need for linguistic structures to minimize cognitive effort and support informative communication and language learning (Zipf, 1949; see also Kemp & Regier, 2012; Kirby, Tamariz, Cornish, & Smith, 2015; Piantadosi, Tily, & Gibson, 2011; Regier, Kemp, & Kay, 2015). Applying this perspective to polysemy, systematic directionality in mappings may result from language users minimizing the costs associated with communicating novel ideas and learning a lexicon: Mappings will tend to be driven by their ease of construction, their effectiveness as communication devices, and/or their learnability by children. The mappings should thus provide a cognitively economic and hence *efficient device* for compressing new ideas into an existing lexicon. If there is a consistent set of cognitive principles and processes underlying ease of construction, effectiveness for communication, and/or learnability, recurring patterns of mappings should arise across domains and time.

But this perspective says little about what the underlying *constraints* on the directionality of metaphorical mappings might be. An independent line of research, from cognitive psychology and linguistics, provides suggestions about the specifics: Namely, that the processes that give rise to metaphorical polysemy may reflect conceptual structure (Lakoff, 1987; Sweetser, 1991). One prominent proposal in this vein is *Conceptual Metaphor Theory* (CMT; Lakoff & Johnson, 1980; Reddy, 1979), which posits that people reason about abstract concepts – such as "understanding" – via metaphorical mappings from knowledge domains that are more concrete and tied to bodily experience – such as "physical action." Although CMT is controversial as a theory of cognition, other theories also predict that concrete and embodied word senses will be extended to more abstract senses because this type of extension may be the most useful for communication and learning (Murphy, 1997; Srinivasan & Carey, 2010; Thibodeau & Durgin, 2008). For example, it could be easier to communicate about something abstract – for which achieving shared reference is difficult – by analogically referring to a more concrete meaning, for which shared reference is easier, and this advantage may apply in word learning as well as discourse processing. Further, because concrete and embodied meanings tend to be frequent (Hanley, Hunt, Steed, & Jackman, 2013; cf. Winter, Thompson, & Urban, 2014), they may be more readily retrieved as sources for meaning extension by speakers who need to communicate a new idea.

Prior research has not explicitly linked the perspective of efficient language design with the study of the cognitive foundations of polysemy or metaphorical mapping. We bridge this gap by analyzing directionality in a large set of metaphorical mappings between source and target domains spanning 1100 years, dating from Old English to the present. To our knowledge, this is the first large-scale study to evaluate the systematicity of the directionality in polysemous metaphorical mappings against the record of historical change in a lexicon. We expect that if metaphorical mapping provides an efficient cognitive device for compressing ideas into a communicative and learnable lexicon, the historical directions of change through which new senses are created for words should be highly systematic, and they should be explained by a compact set of variables relevant to the cognitive processes involved in generating, learning, and using word meanings.

2. Methods

We identified six candidate variables from the literature that could explain directions of metaphorical mapping based on communicative and cognitive considerations. We used human participants' ratings of these variables to try to predict directions in metaphorical domain mappings recorded in the history of English. In the following, we describe: (1) each of the

candidate variables, (2) the historical dataset of metaphorical domain mappings we used, and (3) a survey through which we elicited ratings of the domains on each of the candidate variable dimensions.

2.1. Candidate variables

Three of the variables we considered as predictors are suggested by Conceptual Metaphor Theory (Lakoff & Johnson, 1980; Reddy, 1979; Sweetser, 1991) and supported by other perspectives suggesting that certain types of meanings should more commonly serve as sources of metaphorical extensions (e.g., Srinivasan & Carey, 2010, and Thibodeau & Durgin, 2008, as discussed above; see also Traugott, 1990).

1. *Concrete → Abstract.* Word senses that refer to things perceived through the sensory systems should serve as a source of metaphorical mappings, relative to ones labeling less perceptible referents.
2. *Embodied → Disembodied.* Word senses that refer to things that are more directly experienced through our bodies should serve as a source of metaphorical mappings, relative to ones that label referents that are less directly experienced.
3. *External → Internal.* Word senses that refer to entities in the external world should serve as a source of metaphorical mappings, relative to ones that label internal, mental entities, such as emotions or feelings.

An additional three variables were identified, based on the idea that metaphorical extensions tend to be communicatively expressive:

4. *Animate → Inanimate.* Word senses that refer to animate entities may carry more expressive power than ones referring to less animate entities, and may thus serve as a source of metaphorical mapping to convey salient features of target inanimate entities (Silverstein, 1976; Traugott, 2003).
5. *Less valenced → More valenced.* If metaphorically-derived senses arise in part because of their expressive power, derived senses should be more emotionally valenced than originating senses. This predicts that when word senses from source domains are extended, the resulting senses in the target domain will have stronger valence (whether positive or negative; Osgood, Suci, & Tannenbaum, 1964; Ullmann, 1957; cf. Hollis & Westbury, 2016).
6. *More Intersubjective → Less intersubjective.* Intersubjectivity refers to the degree to which people experience something the same way (Traugott, 1989, 2003). Word meanings that are more intersubjective (e.g. "wooden") could be easier to understand and establish shared labels for than ones that are less so (e.g., "beautiful"). They might thus serve as a source of metaphorical mappings, relative to less intersubjective meanings.

Some of these variables are likely to be correlated, e.g., many of the same word meanings could be external, concrete, intersubjective, and embodied. However, they are not identical. For example, "arm" and "table" are both highly concrete, but arms are more directly and viscerally experienced than tables. Our analyses tease apart the relationships among these variables in accounting for metaphorical mappings in the history of English.

2.2. Historical dataset of metaphorical mapping

We obtained data from the Metaphor Map of English (MME) database (Kay, Roberts, Samuels, Wotherspoon, & Alexander, 2015b), which identifies metaphorical mappings of senses classified by semantic domains over more than a millennium. The MME database is derived from the Historical Thesaurus of English (HTE; Kay et al., 2015a), which records 793,742 word form-sense entries as attested in the history of English. The HTE is, in turn, based on the second edition of the Oxford English Dictionary (Simpson & Weiner, 1989).

All word senses in the MME database are classified into 415 distinct semantic domains (e.g. "textiles," "digestive organs," "anger," "pride") in rough accordance with the standard of semantic classification adopted by the HTE and Oxford English Dictionary. All semantic domains from the database are sub-fields from three broader ontological domains: I. The external world; II. The mental world; III. The social world. Section 1 includes semantic domains that concern readily observable phenomena of the universe, such as the earth and sea. Section 2 includes domains that concern cognitive processes such as perception and emotion. Section 3 includes domains that concern social systems such as the law and morality. Each specific semantic domain defines a category of meaning that word senses can evolve from (source domain) or towards (target domain), and a single domain can include multiple but distinct word senses. The construction of these domains has been derived carefully from lexicographical data and gradually refined over a period of 40 years. For details of domain classification, see work by the lexicographers of the HTE (*p xviii-xx*, Kay, Roberts, Samuels, & Wotherspoon, 2009).

The MME database records metaphorical mappings that have occurred between domains and provides a sample of words that exemplify these domain mappings. Our analyses examined historical metaphorical mappings at the level of these semantic domains – specifically between pairs of domains (and not at the level of individual words), evaluating whether there has been systematicity in the directionality of domain-to-domain mappings. Each attested domain-to-domain mapping reflects the historical extension of word senses between two domains. Together, these mappings span an 1100 year period, from the Old English period around AD 800 through to the present era, around 1950 CE. Within the MME database, metaphorical mappings are summarized separately for the Old English period (i.e., before 1100 CE), and in 50-year steps

for the subsequent 800 years, providing 18 unique historical time points for our analysis. For further details regarding the MME database, we refer the reader to the "About the project" page provided at http://mappingmetaphor.arts.gla.ac.uk/about-the-project/.

Researchers of the MME database have found evidence for over 10,000 metaphorical domain mappings: Cases where words in one domain were consistently used to describe another domain. Some of the records of domain mappings do not contain full information about when the mappings occurred and what words were involved, and so they were eliminated for purposes of our analyses. The final data set we used includes all of the approximately 5,500 recorded metaphorical mappings (downloaded as of October 21st, 2015, at http://mappingmetaphor.arts.gla.ac.uk/about-the-project/categories-completed/), among 400 semantic domains, that had complete information. See Supplemental Material for these domains. Each entry in our data set records an attested metaphorical mapping between a pair of semantic domains that includes: (1) source domain, (2) target domain, (3) earliest of period of extension between these domains, and (4) some sample words that participated in this metaphorical extension.

The database indicates the historical direction of sense extension among each pair of semantic domains. Three types of directions are recorded: (1) $A \rightarrow B$, i.e. A is source domain and B is target domain; (2) $A \leftarrow B$, i.e. A is target and B is source; (3) $A \leftrightarrow B$, i.e. a bidirectional mapping. The bidirectional mapping constitutes only a small portion of the dataset ($\sim$7.5%), so we focused on the directional cases (4960 unique pairs of domain-to-domain mappings) for our analyses. We examined whether the mapping directions among semantic domains could be predicted from empirical ratings of the domains along the six candidate variable dimensions, based on an on-line survey that we describe next.

2.3. Survey for rating elicitation

We elicited ratings of the 400 semantic domains along the six candidate variables through an on-line survey (see Supplemental Material for experimental instructions). For each variable, participants rated each of the 400 domains on a seven-point scale. Participants first read a definition of each domain (e.g., "Plant - A living thing that grows in the ground, usually has leaves or flowers, and needs sun and water to survive"), assembled by consulting the Merriam-Webster Dictionary. Participants then rated the domain on one of the six variables. For example, for concreteness, participants selected a number between 1 and 7, where 1 represented "highly abstract," 7 "highly concrete," and 4 "intermediate." Because of the large number of ratings we needed to elicit (400 domains x 6 variables), each participant only rated a random sample of 40 domains along a single variable dimension.

Our research protocol was approved by the Institutional Review Board at the University of California, Berkeley. Data were collected from 1439 participants who self-reported as native English speakers, using the online Qualtrics experimental platform (http://www.qualtrics.com/), disseminated via Amazon's Mechanical Turk (https://www.mturk.com/mturk/). Following standard protocol (Oppenheimer, Meyvis, & Davidenko, 2009), responses were excluded from participants who did not respond correctly to three "catch" trials assessing attention to the task ($n = 94$). On average, we obtained 18 ratings (SD = 2) for each of the domain-variable questions. Across all variables and domains, the mean standard deviation of ratings was 1.6 (SD = 0.32), indicating a high level of inter-rater agreement. No substantial discrepancies in inter-rater agreement were observed across the variables. For Animacy, the mean standard deviation across the different domain ratings was 1.8 (SD = 0.4); for Concreteness: mean = 1.6 (SD = 0.4); for Embodiment: mean = 1.9 (SD = 0.4); for Externality: mean = 1.3 (SD = 0.5); for Intersubjectivity: mean = 1.8 (SD = 0.3); for Valence: mean = 1.1 (SD = 0.3). See Supplemental Material for the mean variable ratings for all 400 domains.

3. Computational analyses and results

To evaluate the hypothesis that the directionality of metaphorical mappings in history is systematic, we performed three analyses: (1) We tested the extent to which directions of metaphorical extensions recorded in the historical data set are predicted by ratings along the six dimensions described above, either in isolation or in combination; (2) We then examined whether the same ratings can be used to identify the semantic domains that have served as sources vs. targets of metaphorical extensions, by collapsing data across time; (3) Finally, we examined the most dominant variable in explaining metaphorical mappings across time, to assess whether its explanatory power has been consistent over the course of history. Next, we describe the computational methods and results for each of these analyses.

3.1. Analysis I: Predicting directions of metaphorical mappings over history

In the first analysis, we examined whether rating differences along the six candidate variables might account for the directionality of metaphorical mappings in history. That is, given a pair of domains for which metaphorical mapping has been recorded, does knowing how each domain is rated on some variable dimension predict which domain will be the source, and which the target? We performed this analysis by first treating each variable in isolation. We then combined the variables to see if their combination could further account for the historical data.

To examine the explanatory power of the six candidate variables individually, we created a parameter-free model for each of the variables that predicts the direction of metaphorical mapping between a given pair of semantic domains recorded in

HTE. This simple model calculates the difference in average ratings of a pair of domains along the variable dimension of interest. It then makes a corresponding prediction about the direction in which meaning extension should take place in history (according to that psychological dimension), without requiring any adjustable parameter.

Apart from the valence model, the five other models predict that the domain with the higher mean rating along a certain variable will be the source of metaphorical mapping, and the domain with the lower mean rating will be the target. For instance, for the animacy variable, we predicted the direction of mapping to be *Animate → Inanimate,* such that between any pair of domains (*A*,*B*) recorded in the historical data set, the domain that was rated as more animate on average (from the survey described before) would more commonly serve as the source, and the domain that was rated as less animate on average would serve as the target:

$$A = source,\ B = target,\ \text{iff}\ \mathrm{E}[Animacy(A)] > \mathrm{E}[Animacy(B)] \tag{1}$$

Similar models were constructed for the concreteness, embodiment, externality, and intersubjectivity variables. We constructed the valence model slightly differently because the underlying variable is polarized (i.e. a domain can be either positive or negative). Thus we instead calculated the absolute value of valence ratings. Concretely, a domain rated 7 (highly positive) on the 7-point scale would be treated as equally-valenced as a domain rated 1 (highly negative). For this model, we predicted the direction of mapping to be: *Less valenced → More valenced,* such that between any pair of domains in the data set, the domain that was rated as more valenced on average would serve as the target, and the domain that was rated as less valenced on average would serve as the source:

$$A = target,\ B = source,\ \text{iff}\ \mathrm{E}[Valence(A)] > \mathrm{E}[Valence(B)] \tag{2}$$

Table 1 specifies the predicted directions of each model along with example mappings from the historical database that the models successfully accounted for.

We used 50% as the baseline representing the possibility that sources and targets are random with respect to our six variables. The results appear in Fig. 1a. Overall, all models predicted directions in historical mappings above chance. In particular, externality (accuracy = 73.9%) and concreteness (73.5%) were most accurate and roughly equivalent to one another. These were followed by intersubjectivity (60.7%), valence (59.6%), embodiment (56.7%), and animacy (52.6%). These results indicate that historical metaphorical mappings follow systematic and predictable directions, such that between a pair of domains, the domain that is rated higher (or lower for the valence dimension) on these variables is more likely to be the source, and the remaining domain is more likely to be the target.

We next examined the degree of correlations among the six variables, seeking to understand which of these variables might be redundant with each other, and which variables might be less correlated and hence might offer complementary explanatory power to each other. Fig. 1b shows the Pearson correlations between all pairs of variables. As can be seen, externality and concreteness were most strongly inter-correlated ($r(400) = 0.84$, $p < 0.001$). For this reason, we expected these variables to make similar predictions about mapping directions and for one to make little independent contribution to explaining the directionality of metaphorical mappings over the other. Intersubjectivity was most strongly correlated with both externality ($r(400) = 0.44$, $p < 0.001$) and concreteness ($r(400) = 0.47$, $p < 0.001$) among the remaining pairwise correlations. Animacy, embodiment, and valence were generally less correlated with other variables.

To take into account these patterns of inter-correlation, we investigated how well the six variables in combination predict the historical directions of metaphorical mappings, and the extent to which each variable contributes towards these predictions. We first formulated the problem using standard logistic regression. For each instance of the 4960 domain-to-domain mappings (indexed by i) recorded in the database, we coded the direction of mapping – the observation to be predicted (denoted by y) – between a pair of domains (*A*,*B*) as '0' if the mapping was $A \rightarrow B$ (i.e. domain *A* serves as source) and '1' if the mapping was $A \leftarrow B$ (i.e. domain *A* serves as target). We then created a 6-dimensional predictor $\mathbf{x}$ from the six candidate variables by taking the differences in mean ratings along these variable dimensions for all corresponding instances recorded:

$$\mathbf{x} = [\mathrm{E}[Animacy(A)] - \mathrm{E}[Animacy(B)], \ldots, \mathrm{E}[Valence(A)] - \mathrm{E}[Valence(B)]] \tag{3}$$

If our predictions about these variables are correct, we should expect some subset of them to account well for the historical directions of metaphorical mappings, and in ways consistent with our proposals about preferred directionality. To test this, we regressed y against $\mathbf{x}$ by minimizing the standard logistic loss function:

$$L(\beta) = \sum_i \log(1 + \exp(-\beta^{\mathrm{T}}\mathbf{x}_i y_i)) \tag{4}$$

Here β (or beta) is a vector of weights to be determined from the data. Each weight represents the relative contribution of each of the variable dimensions in accounting for the historical data, as an assessment of the theoretical proposals formalized in Eqs. (1) and (2). For example, if a higher mean rating along a variable dimension predicts a domain to be the source of metaphorical mapping (e.g. in the case of externality), we would expect the corresponding weight to be positively valued and significantly above zero if the contribution of the variable in question is substantial. In contrast, if a lower mean rating along a variable dimension predicts a domain to be the source (e.g. valence), we would expect the corresponding weight to be negatively valued and significantly below zero.

Table 1
Examples of metaphorical sense mappings predicted by each model (ordered alphabetically).

Model	Source Domain (rating) → Target Domain (rating)	Sample Words	Attested Period
Animacy	Male person (6.5) → Courage (2.0)	Manly	Old English
Animate → Inanimate	Reptiles (6.4) → Bad (1.9)	Serpent	1350–1400
Concreteness	Reflection (of light) (6.0) → Virtue (1.6)	Clear	1350–1400
Concrete → Abstract	Plants (6.8) → Pride(2.5)	Flourish	1350–1400
Embodiment	Sense & speech organs (6.5) → Rivers & streams (2.6)	Mouth	Old English
Embodied → Disembodied	Strength (5.9) → Politics (2.2)	Stalwart	1850–1900
Externality	Light (6.4) → Thought (1.1)	Reflect	1550–1600
External → Internal	Textiles (6.7) → Belief & opinion (1.0)	Spin	1950–2000
Intersubjectivity	Textiles (5.7) → Difficulty (3.3)	Mesh	1500–1550
Agreeable → Disagreeable	Birth (5.4) → Faith (3.3)	Reborn	1550–1600
Valence	Relative position (4.1) → Excitement (6.4)	Up	1300–1350
Neutral → Valenced	Semi-fluidity (4.3) → Moral evil (1.3)	Slime	1550–1600

Note. Each row shows (1) a type of model, (2) examples of metaphorical domain-to-domain mappings consistent with the predicted mapping directions of that model, (3) sample words that have senses within each of the domains, and (4) the first attested time period in which senses exemplifying the domain-to-domain mapping emerged.

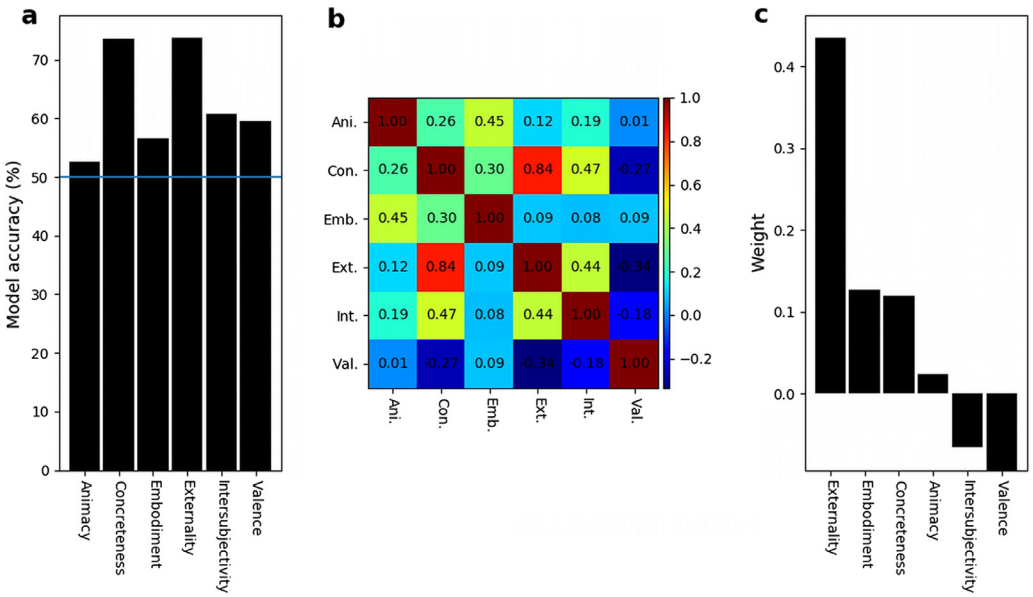

Fig. 1. Summary of results on predicting historical directions in metaphorical sense mapping: (a) Model accuracy in accounting for historical directions of domain-to-domain mappings. Bars indicate individual model performances, and the horizontal line indicates chance accuracy; (b) correlations among average empirical ratings of the variables; (c) weights on the six variables from multiple logistic regression.

To assess the degree to which the variables in combination predict the data, we applied 10-fold cross validation, which is a common technique for evaluating predictive accuracy (e.g., Kohavi, 1995). At each round, we held out 10% of the data for the model to make predictions about, while fitting the model using the remaining 90% of the data. We repeated this procedure 10 times, holding out a different set of data during each round, and computed the predictive accuracy on the held-out sets. The mean cross-validated accuracy of the logistic model was 77.1%, indicating that there is a small advantage of predicting the historical data by allowing the variables to contribute simultaneously to explaining each mapping, as compared to fitting the data by treating the variables in isolation (recall that in the latter single-variable method, the most accurate model was externality, at 73.9%).

To understand the contributions of the variables in accounting for the data, we visualized the distribution of their weights from the logistic regression analysis by fitting the data (Fig. 1c). To evaluate the significance of these weights, we performed statistical bootstrapping by resampling the data 10,000 times and re-estimating the weights from these bootstrapped trials. The results indicated that externality is the dominant factor underlying historical metaphorical mappings, as it received the largest weight among the six variables ($p < 0.0001$, beta = 0.436, 95% CI [0.380, 0.492]). The results also revealed that although embodiment ($p < 0.0001$, beta = 0.127, 95% CI [0.078, 0.176]), valence ($p < 0.01$, beta = −0.093, 95% CI [−0.164, −0.023]) and concreteness ($p < 0.002$, beta = 0.119, 95% CI [0.047, 0.191]) received smaller weights than externality, their contribution was nevertheless significant. Finally, animacy ($p = 0.24$, beta = 0.025, 95% CI [−0.016, 0.065]) and intersubjectivity ($p = 0.121$, beta = −0.065, 95% CI [−0.147, 0.017]) did not have significant weights.

Because the standard logistic model did not incorporate variable selection, it is possible that the set of significant variables we described might contain redundancy. For example, the correlation analysis we described showed that externality is highly correlated with concreteness. To address this issue, we performed an additional analysis by incorporating variable selection within logistic regression, via an L1-penalized sparsity constraint. In particular, instead of minimizing the loss function in Eq. (4), we imposed a penalty term in the minimization procedure:

$$L_{L1}(\beta) = L(\beta) + \lambda \sum_j |\beta_j| \quad (5)$$

Here j indexes the weights on the six variable dimensions, and by summing $|\beta_j|$ over these dimensions this formulation introduces a sparse penalty on the L1 norm of the weights (hence this penalty will shrink variable weights towards zero if the corresponding variables contribute trivially or redundantly towards explaining the data, effectively incorporating variable selection in the minimization procedure). λ determines the relative weighting between the original loss function $L(\beta)$ and the L1 norm and is typically a tuning parameter. To probe the key variables in a comprehensive way, we examined the full regularization path by varying the λ value systematically from 1 to 1000 in 50 equal steps in the log space.

Fig. 2 shows how the distribution of weights varied in the regularization path we probed. The result indicated the emergence of three key variables – externality, embodiment, and valence – which retained their weights as the λ value increased. At the same time, other variables were either minimal (e.g., animacy contributed trivially towards explaining the data and hence its weight was minimal) or shrunken towards zero as a result of the sparsity constraint (e.g., concreteness correlates highly with externality and its weight tended towards zero as the λ value increased). The signs of weights on the key variables were also informative and consistent with our theoretical predictions, indicating that domains receiving high ratings along externality and embodiment dimensions have commonly served as sources of metaphorical mapping, whereas domains receiving low ratings along valence (i.e. neutral domains) commonly served as targets of metaphorical mapping.

Taken together, these analyses indicate that externality (or concreteness, with which it is highly correlated) plays a dominant role in predicting the directionality of historical metaphorical extension. Also, these analyses suggest that externality, embodiment, and valence together define a relatively orthogonal space that helps explain the directionality of the majority of recorded metaphorical mappings. These findings provide the first large-scale evidence for the idea that metaphorical senses have developed across history in systematic and predictable ways, constrained by a relatively compact set of psychological dimensions.

Fig. 3 visualizes trends in the historical metaphorical mappings among the 400 semantic domains in a binary matrix. Each non-zero entry (i.e., white dot) in the matrix records the presence of a recorded mapping between a pair of domains. To verify that variables such as externality best explain the data, we took a bottom-up, data-driven approach, and applied a principal components analysis to this matrix and correlated the first eigenvector – the dimension that accounts for the most variability in the data – against the domain ratings of the six variables. Our independent measures of externality ($r(400) = 0.349$; $p < 0.0001$, Bonferroni-corrected) and concreteness ($r(400) = 0.342$; $p < 0.0001$, Bonferroni-corrected) – but not

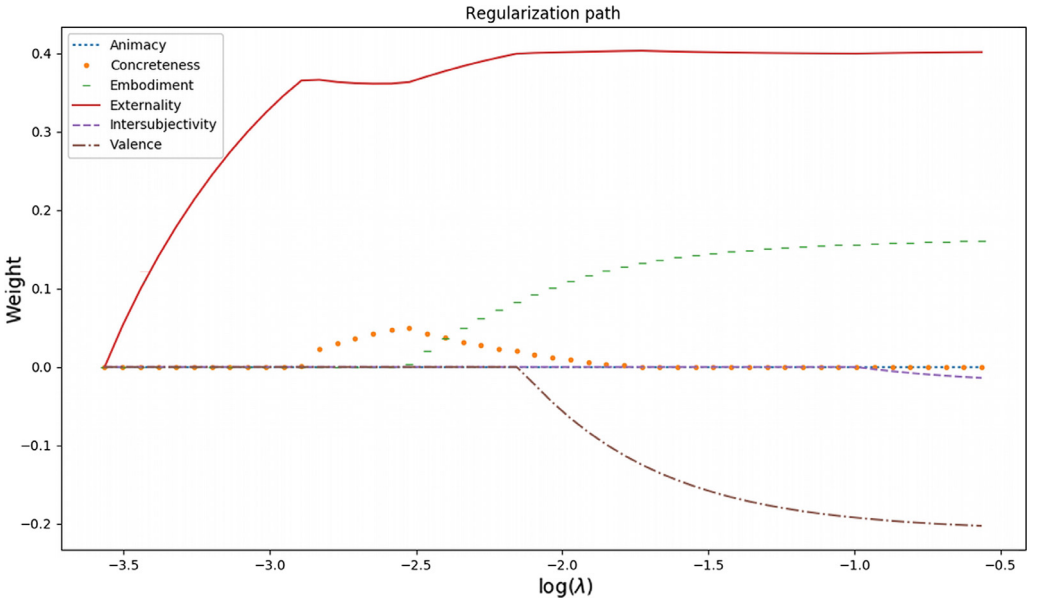

Fig. 2. Visualization of variable weights in the regularization path of sparse logistic regression. Positive weights indicate that domains rated higher along a variable dimension (e.g., externality) tend to serve as source in metaphorical mapping. Negative weights indicate that domains rated lower along a variable dimension (e.g., valence) tend to serve as target in metaphorical mapping.

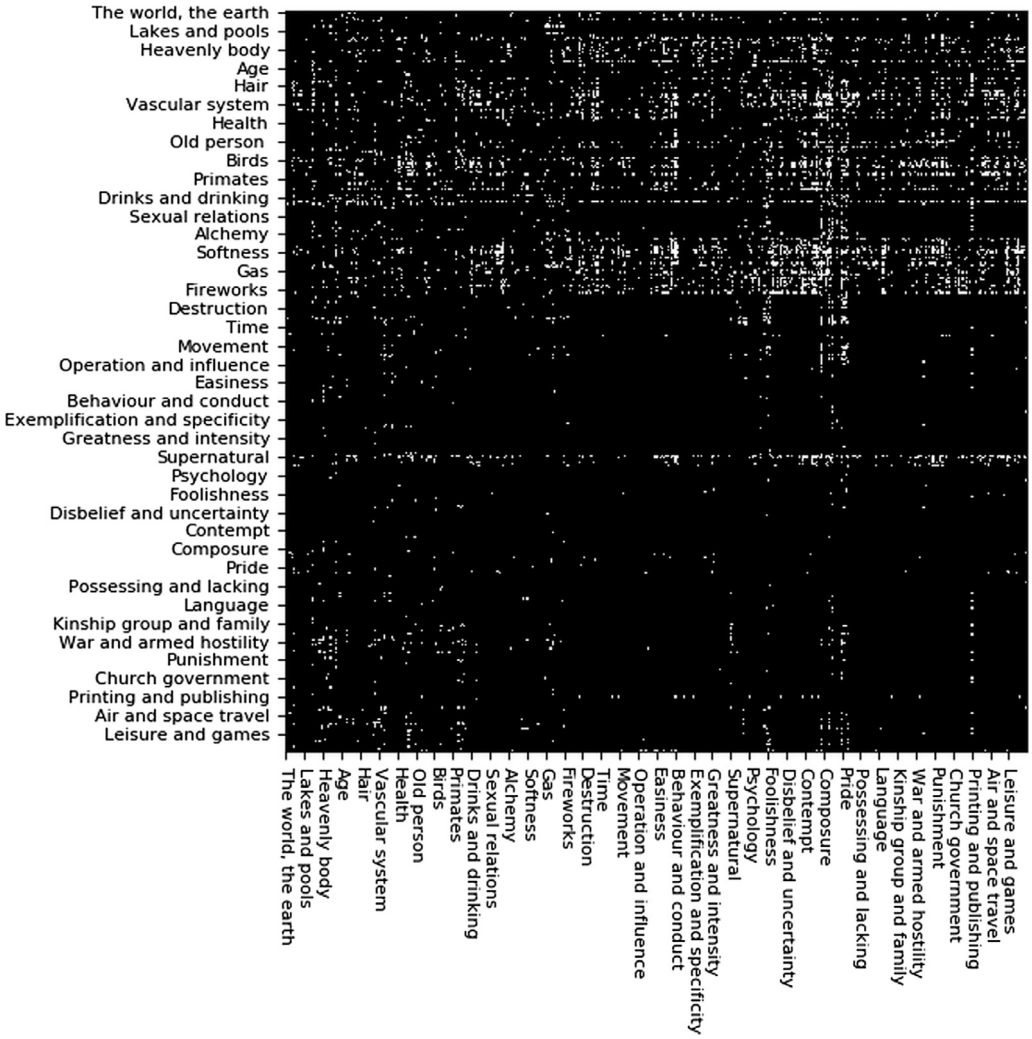

Fig. 3. Visualization of source-target mappings among the 400 domains. Each white dot in the matrix shows a source domain (in the rows) that has been metaphorically mapped to a target domain (in the columns). Due to the large number of domains, we only plot every tenth domain (following the order in the MME database).

the other variables ($p > 0.05$, all Bonferroni-corrected) – were significantly correlated with the first eigenvector, confirming the dominant role of these psychological dimensions in explaining the directionality of metaphorical mappings in history.

3.2. Analysis II: Identifying the source and target domains of metaphorical mapping

Our analyses so far have focused on metaphorical mappings arising at different time points in history, but the outcome of these diachronic changes should also be reflected in more global, time-independent asymmetries as to which domains tend to be the sources of metaphorical extension, and which the targets. We next examined the extent to which the candidate variable dimensions explain the source-target asymmetry of specific semantic domains, by collapsing data across time points.

To quantify the degree of source-target asymmetry in the metaphorically mapped domains, we formally defined the asymmetry index (*AI*) as the difference between two probabilities:

$$AI = \mathrm{p}(source) - \mathrm{p}(target) \tag{6}$$

Here, p(*source*) is the probability of a domain (D) serving as a source of metaphorical mappings across all time points (indexed by t) in history (i.e., a synchronic summary of "source" strength), and p(*target*) is the probability of a domain being a target of metaphorical mappings across time points (a synchronic summary of "target" strength).

Table 2
Strongest source and target domains across history.

Strongest sources	Strongest targets
Textiles	Excitement
Supernatural	Pride
Digestive organs	Anger
Hardness	Hatred and hostility
Softness	Bad
Ruminants	Behaviour and conduct
Cultivated plants	Money
Wetness	Literature
Darkness	Fear
Solidity and density	Vigorous action and degrees of violence

We computed these probabilities on a per domain basis by summing all cases of metaphorical mapping where a domain served as a source or target respectively as recorded in the historical data set and normalized them by the total number of mappings:

$$\mathrm{p}(source) = \sum \mathrm{I}(D = source)/\ \text{Number of mappings}, \tag{7}$$

$$\mathrm{p}(target) = \sum \mathrm{I}(D = target)/\ \text{Number of mappings} \tag{8}$$

It follows from this measure of source-target asymmetry that a high positive value of *AI* should indicate a strong source domain, whereas a low negative value of *AI* should indicate a weak source (or strong target) domain. Table 2 lists the strongest source and target domains in the dataset based on the asymmetry index measure we described.

We then computed Pearson correlations between each domain's asymmetry index and its mean empirical rating for each of the variable dimensions. Fig. 4a summarizes the results. Ratings for all variable dimensions except for those of animacy ($r(400) = 0.09$, $p > 0.250$) correlated significantly with the asymmetry indices ($p < 0.01$ for the five candidate variables). Specifically, externality ($r(400) = 0.46$, $p < 0.001$) and concreteness ($r(400) = 0.42$, $p < 0.001$) showed the highest strengths of correlation, consistent with their leading roles in predicting directions of metaphorical mappings (see Section 3.1). Intersubjectivity ($r(400) = 0.22$, $p < 0.001$) and embodiment ($r(400) = 0.13$, $p < 0.009$) were also moderately correlated with the asymmetry indices. These results suggest that domains that are external, concrete, embodied, and share a conceptualization across people tend to serve as sources of metaphorical mappings across history. Finally, valence negatively correlated ($r(400) = -0.19$, $p < 0.001$) with asymmetry, suggesting that more valenced domains tend to be targets of metaphorical mappings, also consistent with the analyses reported in Section 3.1.

Again taking into account the inter-correlated nature of the variables, we performed a multiple linear regression to estimate the relative contributions of the six variables. We expected the most important (and orthogonal) predictor ratings to be weighted the highest when regressed against the asymmetry indices. Fig. 4b shows the relative contributions of these variables as reflected by their weights. The regression fit had a Pearson $r(393) = 0.42$, $p < 0.001$. The candidate variable with the largest absolute weight was externality ($p < 0.001$, beta = 0.007, 95% CI [0.0037, 0.0093]), followed by embodiment ($p < 0.09$,

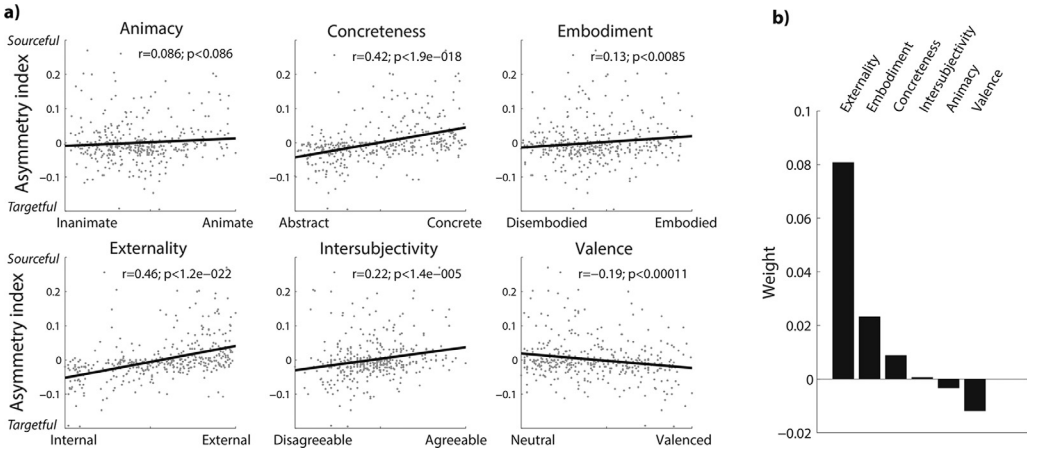

Fig. 4. Summary of results on identifying source and target domains of metaphorical sense mapping: (a) Accounting for the source-target asymmetry of domains from individual variables, (b) the relative weighting of these variables as estimated by multiple linear regression.

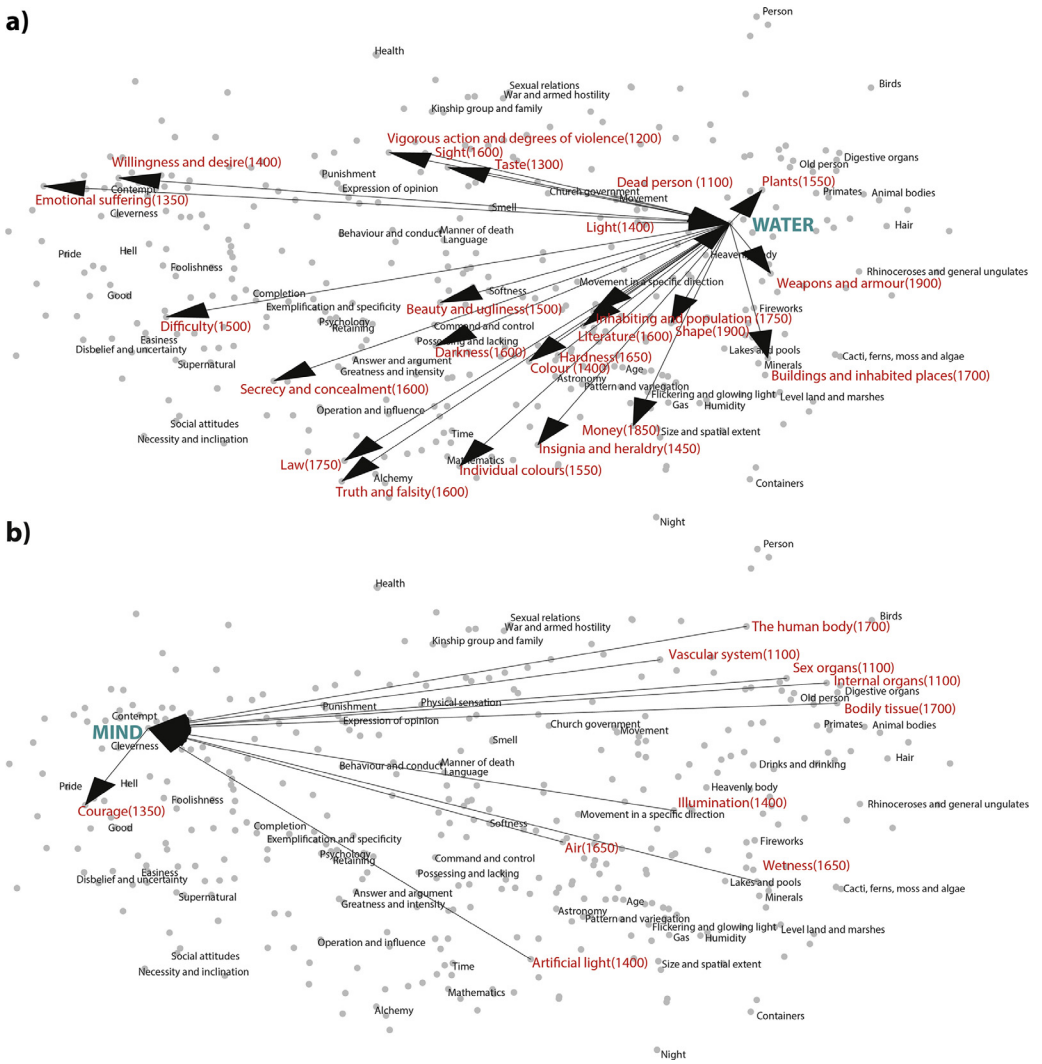

Fig. 5. Visualization of historical metaphorical mappings in two domains: "water" (Panel A) and "mind" (Panel B). Arrows between domains indicate historical directions of metaphorical mapping. The domains linked by arrows have served either as sources or targets to the domain in question. (The year in parentheses indicates the time period of the first appearance of the domain-to-domain mapping in history.) The domains not connected to the arrows are randomly chosen reference domains, a subset of the 400 domains which are shown as gray dots projected onto a low-dimensional space via principal components analysis using the empirical ratings for the six variables. The two principal components correspond roughly to a concrete-to-abstract dimension (from right to left in the horizontal dimension), and an embodied-to-disembodied dimension (from top to bottom in the vertical dimension).

beta = 0.0019, 95% CI [−0.0002, 0.0040]) and valence ($p > 0.250$, beta = −0.001, 95% CI [−0.0026, 0.0007]), although neither of the latter two variables contributed significantly beyond externality. This result provides a synchronic confirmation to the results from the analyses presented in Section 3.1, which found that the same set of variables accounted for most of the variance in explaining metaphorical mapping directions during different historical epochs.

Fig. 5 provides two concrete examples illustrating the power of the externality variable in explaining the direction of metaphorical mappings. "Water" was rated as a highly external domain (mean externality rating = 6.2 out of 7), and as shown, almost all metaphorical mappings involving this domain in our dataset consisted of projections from this domain to other domains, exemplifying the principle that external domains tend to act as sources of metaphorical mappings across history. In contrast, "Mind" was rated as a highly internal domain (mean externality rating = 1.4), and as shown, almost all mappings involving this domain were projections from other domains to this domain, exemplifying the principle that internal domains tend to be the targets of metaphorical mappings.

Taken together, our diachronic (Section 3.1) and synchronic (Section 3.2) analyses suggest that metaphorical sense extensions are highly systematic and constrained by a compact set of variables.

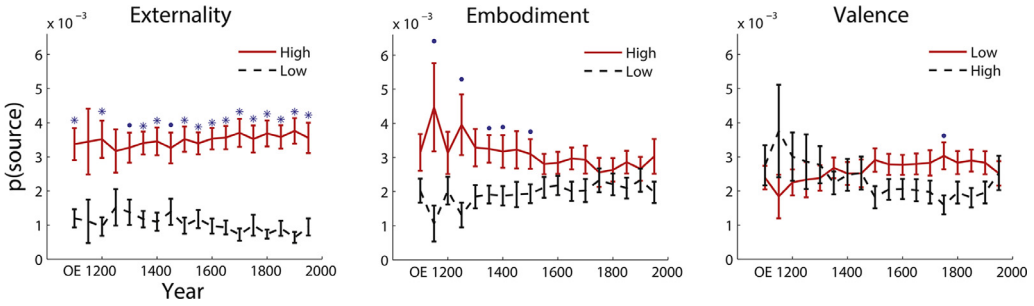

Fig. 6. Mean source probabilities over time for domains partitioned along three variable dimensions: *externality*, *embodiment*, and *valence*. The vertical bars represent standard errors above and below the mean. The dots and stars above the bars indicate significant differences between high and low groups (at a given time point) at $p < 0.01$ (uncorrected) and $p < 0.01$ (Bonferroni-corrected for multiple comparisons across all time points).

3.3. Analysis III: Assessing externality through time

The analyses presented in Sections 3.1 and 3.2 have indicated that externality is the strongest factor in explaining the direction of historical metaphorical mappings. As discussed before, external domains could commonly provide a source of metaphorical mappings if they are the most cognitively available and accessible to extend further. To further understand if the External → Internal mapping is a privileged direction of semantic change, we tested whether external domains have remained a strong source of metaphorical mappings throughout history. An alternative possibility is that externality is a strong predictor only at the very earliest points in history (e.g., because external ideas tend to be lexicalized earlier), such that external domains have only served as sources of metaphorical mappings during these periods.

To distinguish between these two possibilities, we performed a time-course analysis that examined the strength of external domains as sources over times. Specifically, we categorized the available domains in our data set as "external" or "internal" depending on whether the ratings of externality for each domain were higher or lower than "4" (the middle scale value between highly external "7" and highly internal "1"; Our results obtained regardless of the exact threshold used to separate external and internal domains). Then, we computed the source probability (described in Section 3.2) for each of the two groups of domains at each of the available historical time points provided in the corpus. If externality serves as a strong predictor for metaphorical mappings mainly due to the lexicalization of external concepts at the earliest points in history, the source probability for external domains should on average be higher than for internal domains, but this difference should decrease over time. On the other hand, if External → Internal is a privileged direction of semantic change, external domains should have greater source probabilities than the internal domains across time.

Our analyses support the second possibility (see Fig. 6). Specifically, external domains had significantly higher source probabilities than internal domains throughout the 1300-year period (joint $p < 0.001$, $n = 18$ time points with Fisher's method; time point with minimal $p < 7.71e{-}011$, $t(396) = 6.57$; time point with maximal $p < 0.035$, $t(396) = 1.81$). Also, source probabilities for the external domains did not differ significantly between the initial and end periods ($p > 0.250$, $t(476) = -0.29$).

Fig. 6 shows a comparison of external domains against embodied (vs. less-embodied) and valenced (vs. less-valenced) domains, with results obtained via parallel analyses to those used for externality.[1] In contrast with externality, embodied and valenced domains did not serve as sustained sources for metaphorical mappings across time. Specifically, embodied domains tended to be sources of metaphorical mapping only earlier in history (possibly because concepts in these domains were lexicalized earlier in time), whereas valenced domains acted as weak sources of metaphorical mappings, but only later in historical time. Together, these observations are consistent with the idea that External → Internal is a privileged basis for metaphorical mapping, with concepts from more external domains providing a means for communicating about concepts from more internal domains.

4. Discussion

The present study focused on one of the key mechanisms through which words gain new meanings: metaphorical mapping. By drawing on an historical record of semantic change in English, we evaluated – on a large scale – whether new metaphorical word senses have developed in systematic directions. We discovered that a compact set of variables including externality and embodiment account for directionality in the majority of recorded metaphorical mappings between domains, dating back 1100 years. Specifically, we found that, given a pair of domains, the domain with the higher mean

[1] We found concreteness to be highly similar to externality, and we found no statistical significance for animacy and intersubjectivity. For conciseness, we omit presenting these results.

rating along these variables will more commonly be the source of metaphorical mapping, and the domain with the lower mean rating will more commonly be the target. Furthermore, we found that externality – the strongest predictor – explained the direction of metaphorical mappings throughout the history of English, and not just for an initial period early in English vocabulary development.

Our findings lend strong support to the idea that the evolution of metaphorical polysemy proceeds in systematic ways. The six variables that we explored were motivated by communicative and cognitive considerations, drawing upon theories of cognition and language. Our analyses provide evidence that the large majority of directions of metaphorical extensions over history can be explained by a compact set of variables, which suggests that metaphor provides an efficient way of compressing emerging meanings into an existing lexicon, without requiring the construction of word forms *de novo*. Our work thus extends previous studies about communicative and cognitive constraints on synchronic features of language such as word length (Piantadosi et al., 2011; Zipf, 1949) and semantic structures (Kemp & Regier, 2012; Regier et al., 2015) to explain the evolution of metaphorical polysemy in the lexicon (cf. Blank and Koch, 1999; Geeraerts, 1997). The current work also contributes to a comprehensive assessment of metaphorical thought by connecting previous theories of metaphor such as the Conceptual Metaphor Theory (Lakoff & Johnson, 1980; Reddy, 1979) with historical data of language change at scale.

In many respects, our finding – that the directionality of historical metaphorical sense extensions is highly systematic – is surprising. Due to the ever-changing cultural conditions and resultant communicative needs that have pressured words to develop new senses (cf. Aitchison, 2001), metaphorical sense extensions could have in principle been varied and unpredictable across words. It is clear that cultural conditions and communicative needs have shaped metaphorical extension in many cases. For instance, *mouse* would never have been extended to a computer accessory if the invention of the computer had not come about, nor would *file* or *folder* have been extended from objects held in the hand to virtual ones without specific cultural developments. Our data demonstrate that, in spite of the effects of complex and dynamic cultural conditions, there is an underlying regularity to the direction of metaphorical sense extension driven by measurable communicative and cognitive principles.

Our results leave open exactly why variables such as externality were reliable predictors of directionality in metaphorical mappings across history. On the one hand, these results could be taken to support theories emphasizing the role of metaphor in thought including Conceptual Metaphor Theory. By these accounts, ideas tied to human experience and sensation provide anchors for thinking about more abstract ideas. As such, more external (and embodied) word meanings are predicted to be well understood and richly structured, and to provide a source of mappings for ideas that are more difficult to understand. Alternatively, our results may not reveal that abstract concepts are understood in terms of external and embodied concepts, *per se*, but rather, that external and embodied word meanings are easier to achieve shared reference for and to learn (Srinivasan & Carey, 2010; Thibodeau & Durgin, 2008) because of their salience and physical availability in experience. It is also possible that external meanings tend to be more frequent, and may thus be easier to retrieve for speakers who wish to communicate new ideas (Hanley et al., 2013; cf. Winter et al., 2014). Relatedly, more external concepts may tend to prime more internal concepts than vice versa, contributing to directionality in language change (e.g., Jaeger & Rosenbach, 2008). Regardless of how these issues are resolved, our findings support the idea that metaphorical polysemy has been shaped by cognitive and communicative pressures in ways that facilitate the efficient creation, learning, and use of new word senses.

Our work raises questions for future research in computational approaches to semantic change and polysemy. First, our analyses examined metaphorical sense extensions at the level of semantic domains. In the future, it would be valuable to assess the systematicity of sense extensions at the level of individual words, which would require a different source of data. Second, although the database we examined is large, it is not an exhaustive set of metaphorical mappings in English language history. Ultimately, it would be desirable to have a full record of mappings to assess. Third, we also note that the variable ratings of the semantic domains that we used in our analyses were based on intuitions from subjects living in the present era, as opposed to in the past. Although we see no reason for why this would be the case, in principle these semantic domains could have been perceived differently in the eras in which metaphorical extensions were created (e.g., in terms of their externality, embodiment, etc.). Future analyses could confirm the validity of the ratings we obtained by seeking other converging forms of historical evidence.

More broadly, our analyses focused only on the directionality of metaphorical mappings, and whether some domains more commonly serve as sources, and others more commonly as targets. However, our findings leave open how speakers decide *which* concepts from source domains to employ when they wish to communicate about a new idea in a target domain (e.g., Zhang, Geeraerts, & Speelman, 2015): For example, what led speakers to the choose the physical action meaning of *grasp* – as opposed to some other external and embodied word meaning – to communicate about the comprehension of ideas? Addressing this problem would presumably require in-depth knowledge about structural similarities between concepts in different domains and their retrieval probabilities, to help explain which mappings are possible. Additional work is also required to explore whether the principles that underlie metaphorical sense extension can be applied to explain other mechanisms of word sense extension, such as metonymy and semantic chaining (e.g., Lakoff, 1987; Ramiro, Malt, & Srinivasan, & Xu, 2017; Xu, Regier, & Malt, 2016), and whether models that are successful in predicting English data fare as well in predicting semantic evolution in other languages. The latter is particularly important for supporting the claim of general cognitive and communicative principles as drivers of systematic sense extension. Finally, it will also be important to understand the socio-cultural factors that explain the rise or fall in communicative needs for different semantic domains. The current work provides an empirical approach for further explorations into the evolution and nature of word meaning.

Acknowledgments

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cogpsych.2017.05.005.

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