13

Imaginative Frames for Scientific Inquiry

Metaphors, Telling Facts, and Just-So Stories

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In theories of scientific representation and investigation, metaphor has long been treated as a form of alchemy, with one of two divergent attitudes. The celebratory camp, led by the likes of Vico, Shelley, and Mary Hesse, takes metaphor to be distinctively equipped to achieve a mystical communion with nature—a mode of representation that unlocks the universe's secrets and even creates new worlds. Often, subscribers to this view take all language and thought to be ultimately metaphorical, or at least take metaphor to be the truest embodiment of the basic mechanisms by which reference, truth, and understanding are achieved. The dismissive camp, helmed by the likes of Hobbes, Locke, and Zenon Pylyshyn, rejects such representational and ontological profligacy, and instead treats metaphor as superstitiously positing occult, non-referring forces and entities. At best, metaphor is a decorative trope or a mechanism for inspiration; at worst, it spins bubbles of self-confirming pseudo-science.

This opposition appears especially stark given a positivistic conception of science as the logical subsumption of observation sentences under general theoretical laws. Few endorse this conception today. Since at least Quine (1951) and Kuhn (1962), philosophers have noted that scientists bring a host of only partially articulated theoretical, practical, and empirical assumptions to bear in investigating the world, and that distinct patterns of attention and explanation can motivate distinct interpretations of any given bit of data. A more recent trend, exemplified by Ronald Giere, Peter Godfrey-Smith, Roman Frigg, and Michael Weisberg, points to the crucial role of intermediate constructions—"models"—that are known to differ from the actual world in significant ways.

Both developments have had the salutary effects of dispelling a false picture of scientific theories as transparent descriptions embedded in purely

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logical structures, and of connecting our theoretical understanding of scientific investigation, representation, and justification more closely to actual scientific practice. Less directly, they have also enriched our understanding of rationality, by demonstrating an essential role for imagination within a paradigm case of rational inquiry. However, theorists who advocate a less simplistic view of scientific theorizing often lump together multiple types of indirect representation under the general banner of "models." Further, some of these theorists, in their zeal to oppose a naively descriptivist realism, have sometimes concluded that all theories are mere fictions levied in the service of competing pragmatic interests. Thus we seem to return full circle to the claim that allrepresentation is essentially figurative, but with fiction now occupying the preeminent role once accorded to metaphor.

In this chapter, I distinguish among a range of representational tropes, which I call "frames," all of which guide our overall interpretation of a subject by providing a *perspective*, or an intuitive principle for noticing, explaining, and responding to that subject. Frames play a theoretical role closely akin to that commonly ascribed to models. But where much of the discussion of models focuses on their ontological status and representational relation to reality, I focus on the cognitive structures and abilities that are generated by frames, and on the imaginative activities that exploit them. Further, where many theorists of modeling have aimed to explain models by positing a single common representational relation, I focus on distinct ways that scientific representations can fruitfully depart from representing "the truth, the whole truth, and nothing but the truth." Specifically, where recent discussion of models draws inspiration from fiction, I focus on metaphor.

My aim here is primarily descriptive: I want to identify the shared features of frames that make them powerful interpretive tools, distinguish among various ways they can work, and draw out similarities and differences between their application to everyday cognition and scientific inquiry. I believe the discussion of frames here also provides the resources for identifying central norms on frames' epistemic aptness, in both general and particular cases. Further, I think that once we assess frames for epistemic aptness, we can justify a significant epistemic role for frames within scientific inquiry, and even at the putative end of inquiry. However, establishing these normative consequences is a task for another occasion (Camp 2019).

I start by using metaphor to introduce the broader family of perspectival frames, and distinguish metaphor from some of its close cousins, especially telling details, just-so stories, and analogies, as they function in the context

of ordinary discourse. I then illustrate these various species at work within scientific inquiry, and use them to identify key differences in the sorts of gaps that models can open up between representation and reality. I conclude by advocating a mild ecumenicalism about scientific models: although most models are deployed in support of importantly similar cognitive and epistemic functions, there is no single ontological status or representational relation common to all.

13.1 Frames, Perspectives, and Characterizations

Begin with perhaps the most influential metaphor about metaphor in recent analytic philosophy, from Max Black:

> Suppose I look at the night sky through a piece of heavily smoked glass on which certain lines have been left clear. Then I shall see only the stars that can be made to lie on the lines previously prepared upon the screen, and the stars I do see will be seen as organised by the screen's structure. We can think of a metaphor as such a screen, and the system of "associated commonplaces" of the focal word as the network of lines upon the screen. We can say that the principal subject is "seen through" the metaphorical expression—or, if we prefer, that the principal subject is "projected upon" the field of the subsidiary subject. (Black 1954, 288)

I think this passage expresses an insightful and basically correct view of metaphor. But it is unsatisfying as it stands, in two ways. First, there is the problem of explicitness. Because it is itself a metaphor, Black's image of smoked glass etched with clear lines does not directly articulate a claim about how metaphor works; further, the subsequent paraphrases or elucidations introduce additional metaphors, not all of which are clearly consistent. So at a minimum we need to spell out what talk of "screens" and "projections," of "seeing through" and "organizing structure," amounts to.

Second, there is the problem of distinctiveness. In the paragraph preceding the quoted passage, Black articulates the core idea in less metaphorical language, saying that "the . . . metaphor suppresses some details, emphasizes others—in short, organizes our view of [the topic]." While this is more explicit, it also characterizes a range of other rhetorical tropes that "frame" and "filter" thought, including fictions, slurs, and telling details. I think this is an

important positive insight to be gleaned from Black's remarks, rather than (just) a weakness. In this section, I spell out Black's talk of metaphors as "organizing structures" in my own terms, as it applies to all these cases. In section 13.2, I tackle the question of how to differentiate among them.

In everyday cognition, we frequently engage with the world using complex, intuitive ways of thinking about a subject, which I call *characterizations* (Camp 2003, 2015). The most familiar instances are stereotypes—Black's "systems of associated commonplaces." But where stereotypes are culturally ubiquitous, characterizations can be more culturally restricted: limited to a subdiscipline, a clique, even interlocutors in a particular conversation. In many cases, especially those relevant to science, characterizations are close to what philosophers call "conceptions": a set of beliefs about an individual or a kind, which need not be extension-determining, or constitutive of conceptual competence, or even reflectively endorsed by the agent, but which are easily evoked in thinking about the subject and provide the intuitive "mental setting" (Woodfield 1991, 551) or background against which specific beliefs and questions are formulated.

Most characterizations are relatively inchoate and largely tacit: an intuitive patchwork of more or less unreflective and unarticulated assumptions. They also tend to be highly malleable, depending on the issues, interests, and contrasts that happen to be operative within the current context. In order to impose more coherence and stability on our own intuitive thinking, and in order to coordinate on common intuitive assumptions in communication, we frequently employ interpretive *frames*. As I will use the term, frames are representational vehicles—a slogan, say, or a diagram, or a caricaturing cartoon—under an intended interpretation that itself functions as an open-ended principle for understanding a target subject.

Metaphors constitute a canonical class of framing device, but there are many other types of frames, even just among verbal representations. Notable cases include slurs, as in "He'll always be an *S*" (Camp 2013); telling details, as in "Obama's middle name is Hussein. I'm just saying" (Camp 2008); and just-so stories, as in "It's as if Jane had a puppy who died when she was little, and she's still convinced it was her fault" (Camp 2009). These tropes differ in their rhetorical operations and effects in ways we'll discuss later. But what they all have in common, in virtue of which they function as frames, is that they proffer a principle for organizing one's overall intuitive thinking about the target—what I call a *perspective*. Perspectives determine what information an agent *notices* and remembers about the subject; they guide how the

agent assimilates and *explains* that information within the context of her other assumptions; and they guide how the agent evaluates and *responds* to it (Camp 2019).

Thus, the function of frames is to express perspectives, which function to generate and regulate characterizations, which are themselves intuitive structures of assumptions about particular subjects. Not all perspectives are expressed by frames; some are too multivalent to be crystallized into a single slogan, or no one has yet happened or needed to do so. When a frame does express a perspective, though, that perspective goes well beyond the representational content encoded by the framing vehicle itself. Perspectives are principles for interpretation rather than particular thoughts or contents in themselves. As such, they are open-ended, in two senses: they provide principles for updating characterizations over time, as new information comes along, and they generate characterizations of not just one but multiple, indefinitely many, different particular subjects.

Frames are ubiquitous in ordinary life: in political discourse, intimate interpersonal arguments, informal commentaries on movies—anywhere that intuitive interpretation is at stake. Three features of frames, and the perspectives they express, are especially important for understanding their operations in general and within science.

First, a frame presupposes a *taxonomy*: a basic level of analysis that partitions a domain of relevant entities into a space of contrasting possibilities (often also entailing superordinate and subordinate classifications relative to that basic level [Rosch 1978]). As we will see, this taxonomy in turn determines, at least roughly, what sorts of features are relevant for classifying individuals and kinds, and which features can and should be ignored.

Second, at least in everyday cognition, frames frequently raise to attention or impute experientially vivid representations of highly specific features: for instance, that George has *this* sort of nose, or that people of group *S* have *that* kind of eyes. Ordinary characterizations also often represent features in ways that are affectively and evaluatively loaded: that noses like *this* are elegant, or that George is snobby. Different frames thus "color" the features they attribute to their subjects differently, by linking experiential, affective, and evaluative responses in intimate, intuitive ways (Camp 2015).Third and most important, frames *structure* our intuitive thinking about a subject. A metaphor, slogan, image, or diagram functions as a frame insofar as an agent uses it to organize and regulate her overall intuitive thinking about one or more subjects. In playing this role, a frame doesn't merely select certain features

from the teeming mass of details as classificatorily relevant, nor does it merely evaluate or color a particular subset of features. Rather, it purports to determine, for any feature that might be ascribed to a subject, both *whether* and *how* it matters, by embedding that feature within the larger network constituted by the agent's characterization of the subject.

There are (at least) two distinct ways in which a feature can differ in the role it plays within a characterization (Camp 2003, 2013, 2015). First, some features ascribed to a subject are more *prominent* than others, in being more initially noticeable and quicker to recall. Following Tversky (1977), I analyze prominence (which he calls "salience") as a function of two factors, each of which is contextually relative in a different way. On the one hand, a feature is *diagnostic* to the extent that it is useful for classifying objects in a given context, as the elliptical shape of a snake's pupils might be useful for determining whether it is venomous. Because diagnosticity is taxonomy-relative, frames that employ distinct taxonomies will draw intuitive attention to distinct features, and/or assign distinct diagnostic implications to the same feature. On the other hand, a feature is *intense* to the extent that it has a high signal-to-noise ratio. What an agent counts as "noise"—as the relevant background against which the current signal is measured—varies widely, both in how locally restricted it is and in how cognitively mediated it is. So, for instance, the perceptual intensity of a light's brightness relative to the ambient lighting in a room is fixed by a background that is both highly local and directly physical, while for a knowledgeable viewer the intensity of a pigment's tonal saturation in a painting will be determined not just relative to the other colors in that particular picture but also against her assumptions about typical saturation levels in other paintings within that genre and from other historical periods. The total prominence of a given feature in an agent's intuitive characterization of the subject is a function of both diagnosticity and intensity, where these interact both with each other and with the larger context in complex ways.

Where prominence selects *which* features matter, the second dimension of significance, *centrality*, concerns *how* they matter. Characterizations connect features into rich explanatory networks, and centrality is a measure of a feature's connectedness to other features. Some connections are conceptual, in the sense of being inferences that a competent thinker finds compelling (Peacocke 1992). However, conceptual status is neither necessary nor sufficient for a feature to play a central role in a characterization. On the one hand, many robustly conceptual inferences are too obvious and general to

be relevant for explaining why a particular target subject is as it is. And on the other hand, we often intuitively connect features in ways that are highly contingent. In ordinary cognition, these connections can be emotional, ethical, even aesthetic (Camp 2017). But especially in science, the explanatory connections we impute are causal. A good measure of centrality is *mutability*: how much the agent's overall thinking about the subject would alter if she no longer attributed a given feature *f* to the subject (Murphy and Medin 1985; Thagard 1989; Sloman et al. 1998).[1]

Prominence and centrality are structurally distinct ways in which a feature can matter intuitively. For instance, Barack Obama's ears or Donald Trump's hair may be highly prominent in our thinking without being represented as at all central to who that person is. Similarly, we might find it notable that a certain species of fox exhibits patches of white fur without according that feature any explanatory significance beyond random mutation within a limited gene pool. However, the two dimensions of cognitive mattering are not entirely disconnected. In particular, when a feature *f*'s intensity departs markedly from a contextually determined baseline, this fact intuitively calls out to us for explanation. Sometimes we (justifiedly) dismiss such departures as mere anomalies, but often we seek to explain it in terms of the subject's other features. Thus, for some people, Obama's protruding ears are connected with his Spock-like nerdiness, or Trump's swooping hair with his grandiosity. More seriously, in the case of white fur, depigmentation has been correlated with hormonal and neurochemical changes associated with docility (Belyaev 1978; Trut 1999). In general, the desire to explain a prominent but apparently non-central feature may lead an agent to seek out explanations that make it more central. And conversely, a high degree of centrality tends to increase a feature *f*'s diagnostic relevance and can lead us to raise our intuitive estimate of its actual intensity or statistical frequency and of the probability that the subject will possess other connected features (Diekman 2002; Judd and Park 2003; Ryan et al. 1996).

These two dimensions of "mattering," prominence and centrality, generate a complex, intuitive organizational structure for all characterizations. However, most ordinary characterizations are only loosely

[1] At least in a scientific context, a psychological criterion of mutability fits smoothly with an analysis of causal explanation that invokes "difference makers" (Strevens 2008; Woodward 2003). Roughly, an agent treats *f* as causally important to a subject *A* if the agent treats *f* as making a difference to *A* in ways that matter given the presupposed taxonomy, and *f* is central to the extent that the agent takes its potential alteration to affect many features that matter.

organized: different features have different weightings of prominence and are variously connected to other features, but those weightings and connections are inchoate, jumbled, and—as attested by the vast experimental literature on affective and cognitive priming—highly contextually malleable (Camp 2015). By contrast, a frame constitutes a unified interpretive principle that organizes the characterizations to which it applies into more coherent and stable wholes.

So far, I have translated Black's metaphor for metaphor as a network of clear lines etched on smoked glass into a view of frames in general as overarching principles for selecting, classifying, and connecting a subject's features into a multidimensional, intuitive cognitive structure. But what does it mean to say that a frame imposes an intuitive structure on a characterization? The crucial insight that I take to be implicit in the quote from Black, and more generally in the ubiquitous talk of "perspectives," is that neither the perspective expressed by a frame nor the characterizations it generates *represents* an organizational structure. Rather, that structure must be *implemented* or instantiated within the agent's actual intuitive cognitive processes, so that the agent really is more likely to notice and quicker to recall features that are weighted as more prominent, and does intuitively connect central features with many others. As it is often put, frames offer cognitive Gestalts, much as the concepts "old lady" and "young lady" provide perceptual Gestalts for Figure 13.1.

Thinking of frames as cognitive Gestalts, and explaining this in terms of implemented as opposed to merely represented structure, allows us to identify an important sense in which characterizations, perspectives, and frames are all non-propositional. In principle, with sufficient reflection and effort, an agent might be able to explicitly articulate the complete set of features she intuitively associates with a given subject. Likewise, with even more reflection

Figure 13.1 Ambiguous figure of old and young woman.

and effort, she might spell out the structure in which she intuitively arrange those features, perhaps by assigning numerical weights to reflect prominence and drawing directed graphs to illustrate explanatory connections. However, it is neither necessary nor sufficient for having a characterization that one explicitly entertain or endorse the propositions that specify that structure. Instead, having a characterization requires "getting" the Gestalt, so that the operative characterization actually structures one's intuitive cognition. Likewise, "getting" a frame involves being actually, if only temporarily, disposed to form the relevant characterizations.

Further, "getting" a characterization or frame in this sense is partly but not entirely under voluntary control. Sometimes, as with slurs, insinuations, and stereotype threat, frames impose themselves on our thinking when we would rather resist (Camp 2013). Conversely, we may endorse a frame's cognitive utility but be unable to deploy it intuitively for ourselves. First encounters with scientific frames such as Feynman diagrams are frequently quite effortful, even when their primary advantage for those who are fluent with them is the way in which they foster an ability to navigate easily and flexibly about the topic. In cases where we want to but don't yet intuitively "get" a characterization, any finite bit of advice—for instance, being told that the young lady's necklace in Figure 13.1 is the old lady's mouth—may help it to "click," but no one such bit is guaranteed to succeed.

In virtue of its intuitive Gestalt function, applying a frame is importantly a matter of imagination, but primarily in the synthetic sense (identified by Kant) of uniting a manifold of disparate elements into a coherent whole. It is distinct from the sort of imagination typically discussed by philosophers interested in make-believe or pretense (e.g., Currie and Ravenscroft 2003; Friend 2008; Walton 1990). In particular, where make-believe is a matter of experientially or abstractly conjuring contents that are taken not to be actually present, trying on a frame involves temporarily adopting a new perspective on a set of assumptions that are taken to be fixed (Camp 2009): as Wittgenstein says of Jastrow's duck-rabbit figure, "I *see* that it has not changed, and yet I see it differently" (1953, 193). Altering the intuitive prominence or centrality of a single feature can induce pervasive, complex alterations to the structural relations among other elements, "tipping" them into new clusters of explanatory and other dependence relations and new weightings of prominence. But the effects of applying a new frame can also extend beyond structural realignment, producing alterations in the significance of the basic features themselves.

13.2 Metaphors and Other Framing Devices in Ordinary Discourse

In the previous section, I deployed Black's central metaphor for metaphor as an etched smoked glass to explicate the idea of frames in general. Theorists who draw attention to the selective, interpretive, and imaginative aspects of scientific theorizing sometimes assimilate all frames into a single type. Thus, Mary Hesse appears to treat models, narratives, fictions, analogies, and metaphors as fundamentally equivalent when she writes that "scientific theories are models or narratives, initially freely imagined stories about the natural world, within a particular set of categories and presuppositions which depend on a relation of *analogy* with the real world as revealed by our perceptions" (1993, 51; emphasis in original). While I share Hesse's emphasis on the role of imagination and presupposition in scientific theorizing, and while I agree that models, fictions, metaphors, and analogies all employ imagination and presupposition to frame their subjects, I reject the assumption that all scientific theorizing inherently involves modeling or framing in a substantive sense of the term. More important, I will argue that there are important differences among these various species of frame, and only some rely on analogy. In this section I identify some of these key differences, and argue that they matter to how different frames guide everyday cognition and communication. In section 13.3 I will apply these distinctions to a variety of scientific models.

13.2.1 Internal and External Frames

While all frames provide overarching principles of interpretation for their target subjects, I take a crucial differentiating feature of metaphors to be that they frame their subjects in terms of something *else* (Camp 2003, 2006, 2008). Broadly, I advocate a story roughly along the lines of Black's "interactionism." A metaphor is a representation that triggers initial characterizations of both a subject, *A*, and a framing topic, *F*. Thus, in the canonical example, the sentence "Juliet is the sun" triggers characterizations of the subject, Juliet, and the frame, the sun. (Coextensive expressions—e.g., "sweat" and "perspire"—may be associated with distinct characterizations, and the same lexical expression may trigger at least somewhat different characterizations in distinct conversational contexts.) The metaphor works by taking the most prominent

and central features in the characterization of *F* and seeking matches to them within the characterization of *A*, for as long as interest warrants effort. Matched features are raised in prominence and centrality, producing a restructured characterization of *A* (and to a lesser extent of *F*). In certain circumstances, when it would be plausible for *A* to possess a feature *f* that could be matched to a prominent and central *F*-feature, but where no *f*-like feature is currently included in the *A*-characterization, *f* may be introduced into the characterization of *A*. When a metaphor is employed assertorically, the speaker claims that *A* possesses those features that are most tightly matched to the most prominent and/or central features of *F*.

Not all frames work by matching features between distinct characterizations in this way. At the broadest level, we need to distinguish "external" frames, which include metaphor, analogy, similes, and paratactic juxtapositions, from "internal" frames, where the latter directly attribute a feature *f* to the subject *A* and raise that very feature to prominence and centrality within the *A*-characterization. The simplest internal frame is the "telling detail" (Camp 2008), as vividly exemplified by classic cases of insinuation. So, for instance, the speaker who utters "Obama's middle name is Hussein" overtly merely asserts a fact that is itself undeniable, but thereby implicates that Barack Obama instantiates a cloud of more sinister and more dubiously possessed features associated with a presupposed characterization of people named Hussein. Focusing on the name functions both to highlight some known but otherwise unnoticed features and also to suggest other, as yet unknown ones. While many insinuations are insidiously underhanded, invocations of telling details can be quite explicit. Thus, a primatologist might utter "Trump is a primate" and go on to detail just how Trump's behavior can be explained and predicted by an analysis in terms of notable, relevant, and causally influential properties of primates, especially involving social dominance (Camp 2008).

So although both metaphors and telling details provide interpretive frames, they do so in quite different ways. In particular, metaphors differ from telling details in operating "from the outside": as we might put it, where telling details are interpretive keys inserted directly into the subject characterization, metaphors are colored telescopes. More specifically, for example, Romeo doesn't ask us to focus on the proposition that Juliet *is* the sun or that she actually glows. Rather, as his subsequent paraphrase spells out, the sun's luminosity is matched to the distinct feature of her (purported) beauty. Where the insinuating speaker of the telling detail attributes to Obama

the very features purportedly possessed by most people named Hussein—perhaps being foreign, dark-skinned, Muslim, and duplicitous—the features attributed by Romeo's metaphor are identified indirectly, by sharing relevant higher-order properties with features of the sun. Specifically, while both the sun's luminosity and Juliet's beauty are highly intense, the scale of intensity, the specific respect of intensity, and the operative comparison class are quite different in each case: the sun is brighter than themoon, Venus, or Saturn, while Juliet is more beautiful than Rosalind or any other Veronese girl. The sun's luminosity and Juliet's beauty also share other relevant features: both are natural, and a source of energy and life; both produce a feeling of warmth. Again, however, these common higher-level features are implemented in qualitatively different ways within the two domains, and it is this indirect structural match that leads us to notice and impute new features to Juliet—features that the sun itself does not possess, such as making the other girls of Verona jealous.

13.2.2 Metaphor and Fiction

I've argued that an internal frame structures its subject directly and "from inside," while an external frame like metaphor operates indirectly. So far, this might just seem like a new label for the old difference between being literally true or false: absent literal truth, at most indirect truth remains. Against this, I want to argue that some literally false frames are still internal, because they function in imagination *as if* they were true. In particular, I think just-so stories are fictions that function like telling details rather than metaphor (Camp 2009).

So, for example, a speaker might say that Trump acts *as if* he was denied admission to Harvard and has been compensating ever since, while explicitly acknowledging that this is not true.[2] Intuitively, this speaker invites the hearer to pretend that Trump, in all his actual specificity—raised in Queens, having a real estate mogul father, and so on—really does possess the very feature of having been denied admission to Harvard, and to treat that possible-but-in-fact-unrealized feature as an imaginative key to unlocking what really matters about him. More generally, the hearer of a just-so story is asked to

[2] Dan Evon, "Donald Trump's Harvard Rejection Letter," Snopes. August 18, 2016, www.snopes.com/donald-trumps-harvard-rejection-letter. Apocryphal facts are in effect just-so stories masquerading as telling details.

pretend that a fictional feature *f* is actually instantiated by and explanatorily central to *A*, and to restructure her overall characterization of *A* by introducing and elevating other features from the *F*-characterization that *A* really would possess if it did actually instantiate *f*. Once this imaginative exercise is accomplished, the hearer drops the pretended ascription of *f*, leaving the characterization as close as possible to what it would be if *A* were in fact *f*.

The contrast between fictional and metaphorical frames is clearest when a single sentence can be plausibly deployed in either way. Consider as an example "Jane is a nurse." On the one hand, employing the sentence as a just-so story involves pretending that Jane really is a nurse. Here, what we might call the "direction of imaginative fit" is from the actual reality to an imagined possibility (Levin 1988): the interpreter starts with actual-Jane and uses her as an imaginative prop to construct the fiction. This involves transforming Jane imaginatively in two ways: first, adding features that actual nurses do prominently possess (for instance, listening to multiple people's symptoms, monitoring vital signs, administering medicine, perhaps being on call at inconvenient times, answering to imperious bosses, and juggling many patients), and second, downplaying features of actual-Jane that conflict with these prominent and central nurse features (for instance, her actual incompetence with machines or the fact that she works regular business hours). Once this imaginative transformation is accomplished, the pretense that Jane really is a nurse is dropped, but the highlighted features remain prominent and central. Thus, a natural use for offering "Jane is a nurse" as a just-so story might be to elucidate first-order respects in which Jane's job involves performing key functions of a nurse, even though she doesn't have a BSN or RN.

On the other hand, if the speaker employs the sentence as a metaphor, then interpretation begins with a characterization of nurses and seeks to identify respects in which Jane, as she already currently actually is, is nurse-*like*. Rather than directly attributing actual nurse features to an imaginatively transformed Jane, the interpreter of a metaphor reconstrues actual-Jane in a nurse-like way. As with Juliet, this focuses attention on actual current features of Jane's that are not actually possessed by nurses but that share higher-order structural similarities with prominent and central features in the stereotype of nurses. Plausible such features might then include consistently lending a sympathetic ear (but for friends rather than assigned patients), checking on those friends' emotional and psychological well-being (rather than their physical symptoms and statistics), or nudging them toward avenues of

emotional and psychological improvement (rather than delivering pills and injections).

In cases of escapist fiction, an imaginative "prop" like Jane is merely a springboard for make-believe. Other fictions, such as just-so stories, are "prop-oriented" (Walton 1990): we engage in the pretense in order to learn something about the prop itself—perhaps something about its counterfactual possibilities, or about what it's actually like—that makes it apt for serving as a prop in this pretense. In focusing imaginative attention on their props, just-so stories are importantly like metaphors. Partly for this reason, Kendall Walton (1993) argues that metaphors *are* invitations to engage in prop-oriented make-believe, by pretending that the subject possesses the feature explicitly mentioned in the metaphorical sentence (see also Hills 1997 and Yablo 2001).

I agree that the two kinds of imagination overlap, and that many utterances invite a mixture of both modes of interpretation (Camp 2009). Both frames are indirect, in the sense that we imaginatively step away from our actual assumptions about *A*. And both are guided by our intuitive characterizations about *A* and *F*s. However, as I've argued, there is an important difference between the two tropes. With a just-so story, we temporarily transform the prop *A* into a counterfactual counterpart by imputing actual *F*-features to *A*; only then do we consider what this reveals about *A* as it actually is. By contrast, with metaphor we hold our understanding of how *A* actually is as fixed as possible, and we match features of *A* and *F* that are merely similar. Because they differ in their direction and directness in this way, the two types of frames often end up highlighting and introducing different features within the ultimate characterizations of their subjects (Camp 2009).

13.2.3 Metaphor and Analogy

In drawing the contrast between "external" and "internal" frames, I have distinguished metaphors from telling details and just-so stories, and emphasized that metaphors are indirect, relying on abstract structures of higher-order similarities between distinct lower-level features. This view is closely akin to Dedre Gentner's "structure-mapping" theory of analogy (e.g., Markman and Gentner 1993). In this section, I argue that metaphor differs from analogy in two important ways.

First, while both metaphors and analogies rely on abstract, higher-order similarities, metaphors also frequently employ qualitative matches between first-order features, often ones that are experientially rich and embodied (Lakoff and Johnson 1980). For instance, while the core match between the sun's luminosity and Juliet's beauty is a structural one, Romeo's metaphor also suggests that being near Juliet produces a physical feeling in him that is not just structurally but qualitatively similar to the glow produced by the sun on a warm spring day.

Second, metaphors permit a looser preservation of structure in the mapping from framing to subject characterization. In analogy, potential matches that are not embedded within more complex structures tend to be ignored even if they are topically relevant (Gentner and Jeziorski 1993); by contrast, metaphors often happily permit isolated matches. Analogies also require consistency in mapping: the operative structure within the frame must be replicated in the subject for the analogy to be sound; and known, relevant failures of match compromise the analogy's plausibility. By contrast, metaphors can be quite unsystematic. For instance, Othello's description of Desdemona as "false as water" suggests myriad distinct respects in which Desdemona is deceptive: formless and unstable; running whichever way is easiest; reflecting whatever is around her; showing things within as different than they really are (as water does a bent stick); seemingly clear but potentially poisonous. These various matches don't align neatly with one another, but the lack of systematicity does not undermine the metaphor's effectiveness, since it suggests such a rich range of matches with robust affective and imagistic elements, which themselves constellate into a coherent overall characterization of Desdemona.

Metaphors'greater permissiveness makes their interpretation more imaginatively intuitive and holistic. Rather than puzzling out a precise, consistent formal mapping between complex, abstract, articulate structures, we more often feel our way through tacit clusters of matches involving largely inchoate features at a variety of levels, drawing on images and attitudes, and coloring and connecting those features, along with other, unmatched features that intuitively "fit" with them. Individual matches that are especially relevant to current conversational or cognitive purposes leap to attention and motivate intuitively related matches, even if these are not connected to or even logically consistent with the initial match. And clusters of such matches reconfigure both subject and frame to motivate further matches, in a snowball

effect that can overwrite marked antecedent differences between the two characterizations that would stymie a logical analogy.

13.3 Metaphors and Other Frames in Scientific Inquiry

In the previous sections, I have described framing devices in general and distinguished metaphor from three of its cousins—telling details, just-so stories, and analogies—in terms of the direction, directness, level, and systematicity of imaginative fit between frame and subject. We can now examine how these differences play out in the scientific context and what their implications might be for models and modeling. As an initial point, although use of the term "model" is both varied and contentious, I think we can illuminate the utility and effects of many models by treating them as frames: representational vehicles that guide intuitive overall thinking about a target system by determining both *what* matters about that subject relative to a presupposed taxonomy and *how* those features that do matter are connected within an explanatory structure. Beyond this, our tour through various species of frame in the context of ordinary discourse puts us in a position to identify important sources of variation among scientific models, while illuminating their functional commonalities. In this section, I identify some important types of scientific frame, focusing on the different sorts of gap they assume between representation and reality and the different ways they bridge that gap.

13.3.1 Telling Details and Telling Instances

Many scientific theories employ telling details: they explain a complex phenomenon by treating a single feature, which is itself relatively uncontroversially true and also associated with a rich set of assumptions, as maximally explanatorily central. Differences in which details theorists take to be "telling" can produce pervasive, substantive differences of interpretation.

So, for instance, Longino and Doell (1983) contrast androcentric and gynocentric theories of tool use in hunter-gatherer societies within anthropology. Both theories agree that men hunted and women gathered, and both invoke tool use to explain the development of cognitive characteristics such as flexible intelligence and instrumental reasoning. But the two theories disagree

structurally about which of these facts matter and which data exemplify more general, causally relevant patterns. While androcentric theories focus on hunting behavior and the relative efficacy of stone tools over sticks, gynocentric theories focus on the nutritional stresses of pregnancy and lactation and on the basic utility of sticks and reeds for digging, carrying, and food preparation. These different frames weigh additional data differently, generate different chronologies and causal histories, and implicitly (and sometimes explicitly) offer different predictions about, and affective and normative responses to, sex, tool use, and intelligence among contemporary humans. Insofar as the primary locus of disagreement is a higher-order, interpretive one, it is difficult to adjudicate between the two theories directly at the level of demonstrable facts, because each theory has its own way of taxonomizing and explaining any given bit of information, and can dismiss distinct isolated chunks of (putative) data as mere anomalies or as true but marginal.

Like the telling detail in everyday life, then, the "telling fact" in science takes a feature *F* that is uncontroversially assumed to be instantiated by a subject *A* and treats it as maximally prominent and central in theorizing about *A*, relying on an assumed background characterization of *F*. A closely related type of internal frame focuses directly on a single or limited class of instances—a population of mice, say, or a patch of forest—and treats that particular instance, *a*, as exemplary of a more general kind *F*. Catherine Elgin aptly calls such samples "telling instances," and points out that they serve many of the functions I have identified for frames: the sample "exemplifies, highlights, displays or conveys the features or properties it is a sample of," doing so in a richly context-sensitive way, and thereby functions as "a symbol that refers to some of the properties it instantiates" (2006, 208).

Both "telling facts" and "telling instances" focus on a feature that the target subject is presumed to actually possess, but they differ in their level and direction of interpretive attention. The telling fact operates at a theoretical level, by structuring the overall characterization of the target subject *A* (say, the evolution of tool use) in terms of a characterization of a fact *f* about it (say, that women used sticks to dig for roots). The core investigative work is interpretive, teasing out the theoretical consequences of taking this fact to be central for thinking about this subject. By contrast, the telling instance or sample is itself concrete, and investigation involves probing it directly, in concrete ways—say, by feeding the mouse, or half of the mouse population, more saturated fat—in order to discover more about what properties the instance itself actually possesses.

Second, the two types of telling frame differ in the direction of interpretive attention. In the case of taking early women's use of sticks to dig for roots as a telling fact, just as with the insinuation about Obama's middle name, the overall target subject *A* is framed by a characterization of a particular fact *f*, because *f* is emblematic of a larger constellation of (purported) facts, *F*. This involves making *f* itself prominent and central within the characterization of *A*, which in turn introduces or elevates further features $f_1, f_2, f_3 \ldots$ that are central and prominent role within *F*, and suggests causal connections between those *F*-features and further, non-*F* features within *A*. By contrast, with a telling instance, the focus of attention is directly on the particular sample, *A* itself, and investigation proceeds by observing and manipulating *A*. *F* does provide the frame for thinking about *A*, insofar as *A* matters only as an instance of the general kind *F*, so that assumptions and questions about *F* select only some of *A*'s features as warranting attention in virtue of exemplifying *F*-features. Further, the ultimate goal is to "read back" relevant discovered features from *A* to other instances of *F*. However, the investigation proceeds by probing *A* itself, and using discoveries about *A* to understand *F*.

13.3.2 Abstraction and Idealization

Both telling facts and telling instances are intuitively treated as true, in the basic sense that *F* does indeed apply to *A*. Some theorists, such as Hesse (1993) and Elgin (2006), reject this core intuition, because they take the selectivity inherent in all classification, and in modeling in particular, to render all theories and models literally false, or at least not true. All theories are fictions; some are merely more pragmatically efficacious than others.

I agree that selection and abstraction play a pervasive role in science. Indeed, they are plausibly conditions on the very possibility of conceptual thought: applying a concept is a matter of classifying multiple entities together as alike in some respect, or the same entity as recurring on multiple occasions, both of which require abstracting away from differences between those distinct entities or occasions (Camp 2015). Further, we regularly criticize representers for inappropriate selectivity, either for ignoring features that are diagnostic relative to the representer's own presupposed taxonomy, or because we take the taxonomy itself to falsely assume that certain kinds of features tend to cluster together or have certain causal effects. However, I do not think that representational silence, in the form of selectivity or

abstraction, constitutes falsity. While speakers can mislead and be misinterpreted, a representation itself is only false if it positively represents a state of affairs as obtaining that does not.[3] Moreover, because assessment for truth can only take place against the background of a presupposed taxonomy, the very assumption of a taxonomy cannot itself be grounds for falsity, though it can constitute grounds for inappropriateness of some other variety.

Insofar as abstraction does not introduce falsity, it differs from idealization. Both abstraction and idealization involve "imagining away" known facts that are assumed to be irrelevant (Godfrey-Smith 2009), either temporarily (say, in the service of practical tractability) or permanently (say, to isolate key causal factors) (Elliott-Graves and Weisberg 2014). But where abstraction engages in "mere omission" (Thomson-Jones 2005), by remaining silent about known features, idealization introduces distortion by imagining features that are known to have one value to have a different one, as when the amount of friction between an inclined plane and a rolling ball is imagined to be zero, or the number of possible mates in a population is imagined to be infinite. While some idealizations are straightforward, idealizing in one respect often affects the values of other, related features, in ways that are often not obvious to the interpreting agent. Thus, idealization both involves overt distortion and risks unrecognized distortion in ways that abstraction does not.

The contrast between abstraction and idealization highlights the contrast between telling facts and telling instances. As Elgin emphasizes, treating a telling instance *A* as a sample of *F* employs abstraction in an inevitable and pervasive way: only a limited subset of *A*'s features warrant investigation and are ultimately "read back" into the characterization of *F*s; *A*'s other features not only can but need to be ignored. The use of a telling instance as a model combines uneasily with idealization, however, because idealization involves imaginatively constructing an entity that differs from the actual target, and hence inherently shifts attention away from directly observing and probing the sample itself. By contrast, when telling facts are used as frames, this is fully compatible with both idealization and abstraction. So, for instance, both androcentric and gynocentric theories of the evolution of tool use might acknowledge that a strict segregation into male hunters and female gatherers is

[3] Speakers are especially likely to exploit, and insist on, the difference between active misrepresentation and mere non-representation in strategic conversational contexts (Camp 2018). Assessing falsity is more complex in the context of extended conversations, where representations are embedded within entailed structures of presupposition and relevance (Roberts 2012; Stokke 2016). To the extent that scientific theories (as opposed to inquiry) also exhibit discourse structure, the distinction between semantic falsity and pragmatic implication likewise becomes more complex.

an idealization from more fluid gender roles but still employ starkly differentiated "male" and "female" roles. And in implementing their contrasting frames, the two theories might each invoke highly idealized "agent-based models" that compute the long-term dynamic effects of repeated interactions between individuals who are defined by just a few gender-based traits. Thus, we see that even though telling facts and telling instances are internal, true frames, they differ substantively and systematically in how they connect to and depart from reality.

13.3.3 Fact and Fiction

If idealization, unlike abstraction, introduces a form of known falsity, we might be tempted to infer that all idealizations are therefore fictions. Here again, I think we should resist assimilation to a single trope. The falsification introduced by idealization is still like abstraction in ignoring (purportedly) irrelevant complexities of the target subject, even if doing so involves known and unknown distortion. By contrast, fictions paradigmatically *introduce* features that are known not to apply. While the line between merely "smoothing out" irrelevant complexities and actively introducing alternative properties is not a sharp one, fictionalization involves both a more substantive qualitative departure from the subject's assumed reality and a greater attention to the fictionalized subject in its own right.

Maxwell's demon provides an illustrative case of the difference. Prior to 1871, the second law of thermodynamics, that entropy in a closed system never decreases, had often been interpreted as an absolute law grounded in the nature of "caloric." As a counterexample to such an interpretation and in support of the molecular theory of heat, Maxwell suggested that "we conceive a being" whose perceptual faculties are "so sharpened that he can follow every molecule in its course," but "whose attributes are still as essentially finite as our own." If this being were stationed at a door that divided a vessel into two chambers, he could produce a difference in the temperature of the chambers "without expenditure of work," just by opening and closing the door to allow swift molecules to move into one chamber and slow molecules into the other. From the fact that this possibility is even coherent, Maxwell concluded that the second law holds only at a statistical level—"as long as we can deal with bodies only in mass, and have no power of perceiving or handling the separate molecules of which they are made up" (Maxwell 1871,

338–339). Maxwell, then, asks his readers to imagine a scenario that is obviously false, but in (purportedly) merely contingent respects—the demon is just like us, shrunk to a molecular scale—in order to illustrate (contra the caloric theory) how a perpetual "heat engine" could be physically or metaphysically possible while still being extremely unlikely (Stuart 2016, 27).

Unlike paradigmatic cases of idealization as ignoring or "imagining away," Maxwell's thought experiment directs investigative attention toward a situation that is overtly counterfactual. Much as with a just-so story, we are asked to imagine that this very situation is true just as described, in order to highlight other features that follow directly from the framing proposition but that are actually (purportedly) true. Assessing the fiction's aptness as a frame is thus a matter of determining two things: first, what is true within the fiction, given its operative "principles of generation" (Walton 1990); and second, whether the real world is indeed like the fiction in these unarticulated respects (Frigg 2010, 260). Subsequent discussion of Maxwell's demon has, for instance, challenged Maxwell's conclusion that the demon's operation of the door—or, more important, his measuring individual molecules' speed—does not itself constitute "expenditure of work," and hence whether his thought experiment does successfully demonstrate that actual thermodynamic systems are such that differences in entropy could arise as the result of a sequence of individual random molecular movements.

13.3.4 Metaphor and (or Versus) Analogy

In effect, we have now seen that abstraction, idealization, and fictionalization involve successively greater departures from stating "the whole truth and nothing but the truth" about the target subject. But because telling instances, telling facts, and just-so stories are all internal frames, all of these departures arise in the service of focusing attention on features that both the frame and the target (purportedly) actually instantiate. "External" frames such as metaphor and analogy take the further step of "telling the truth but telling it slant," as Emily Dickinson puts it. In these cases, as I argued above, we do not pretend, even temporarily, that the world really is as the representation literally describes. Instead, we seek to identify relevant respects in which the target is like the frame, where the operative similarities may be not just highly selective but also indirect.

The history of competing models of atomic structure provides an illuminating case of the selective, indirect mapping employed by external frames, and their difference from fiction. A key problem for early atomic theory was how to reconcile the stability of atoms, which are neutrally charged, with the fact that their constituent electrons are negatively charged. Thomson's (1904) "plum pudding" model of the (hydrogen) atom achieved this reconciliation by embedding those electrons within a uniform sphere of positive charge, much as the batter for a Christmas pudding contains raisins. In understanding Thomson's model, we are not asked to pretend that atoms *are* bowls of raisin-studded pudding, in the way Maxwell asks us to pretend that two chambers contain a microscopic demon operating a tiny door. Rather, we are asked to posit, and treat as central, a sphere of positive electric charge that is *like* a bowl of pudding in the respect of functioning as a diffuse stabilizing medium.

Rutherford's (1911) discovery of the existence of a small nucleus of intense positive charge falsified Thomson's "diffuse" model of positive charge and provided an empirical basis for the alternative model of an atomic core. It thereby provided support for Nagaoka's (1904) "Saturnian" model of electrons as akin to the rings around Saturn, which Nagaoka had proposed on distinct theoretical grounds based on the impenetrability of opposite charges. Bohr's (1913) "solar" model then extended and refined Nagaoka's Saturnian model by suggesting that the negative electrons orbit the massive positive core, just as the planets in the solar system revolve around the sun, and that electrons are attracted to the nucleus by electrostatic forces, akin to the sun's gravitational force. Bohr's model is a theoretical improvement in part because it subsumes the disparate empirical results that supported the earlier models into a single coherent model, and in part because it suggests a casual mechanism by which those effects are produced. In particular, shifting to the solar model introduces and explains the notion of an orbit as a discrete, stable path, where previous models were unable to explain either atomic stability or discreteness of energy levels. Thus, Bohr's model explains more prominent features of the target using fewer and more robustly explanatory central features.

For all of these models of the atom, though, the mappings from frame to target are highly selective, abstract, and structural, in the manner characteristic of analogy (Gentner and Jeziorski 1993, 449). Bohr's model in particular identifies an identical higher-level relational feature, an attractive force causing rotation, which is instantiated by quite different lower-level features

within the frame and target: where gravity causes the planets to orbit the sun, electrostatics causes electrons to orbit the nucleus. And it ignores myriad possible matches, such as color and relative temperature, as irrelevant to this causal structure.

As we saw in our discussion of metaphor and analogy in ordinary discourse, such selective focus on "common relational abstractions" (Gentner and Jeziorski 1993, 448) as opposed to lower-order shared features differentiates both metaphor and analogy from fiction. A scientific fiction, as Elgin (2006, 16) says, "sheds light on the way the world actually is" by "exemplifying features that diverge (at most) negligibly from the phenomena it concerns." In this respect, Elgin argues, fictions are like samples—indeed, because she assimilates abstraction and idealization to fictionalization, she argues that samples, such as paint chips, *are* fictions. While I reject Elgin's assimilation, I agree that scientific fictions function like telling instances in drawing attention to features that really are exemplified in both the fiction and the actual world, or that diverge negligibly. By contrast, metaphors and analogies shed light on the world by exemplifying common structures that diverge substantively and relevantly in how they are implemented within frame and target.

The difference between fiction and metaphor or analogy is especially stark if we contrast Maxwell's original thought experiment with a subsequent metaphorical deployment of it. Pierre Bourdieu argues that the (French) educational system functions as an entropy-reversing mechanism that maintains social structures of "difference and order, which would otherwise tend to be annihilated," by sorting students at an individual level in terms of their possession of cultural capital (1998, 20). Bourdieu ignores Maxwell's ultimate point entirely: that the second law of thermodynamics does in fact hold at a global, statistical level because there actually is no demon. But his metaphor does identify a common structure that is (purportedly) shared by Maxwell's fictional situation and actual schools: of an entropy-reversing and therefore "unnatural" mechanism that produces global effects by sorting individuals. However, as with Juliet and the sun, or the solar system and the atom, this common structure is implemented in very different ways in each case. And where Maxwell's fiction directs our attention toward the target phenomenon itself—the trajectory of distribution of heat in a closed volume—and asks us to imagine something literal but counterfactual about *it*, Bourdieu applies that structure to a very different domain.

A proponent of assimilating metaphor, analogy, and fiction to a single interpretive trope might point out that analogy, and to a lesser degree

metaphor, do present the frame and target as possessing identical *higher-level* features: in Bohr's model, an attractive rotation-causing force; in Bourdieu's metaphor, a entropy-reversing mechanism for sorting individuals. Given this, at a suitably high level of abstraction analogical and metaphorical frames do impute to the target features that are actually possessed by the framing subject—in just the same way as a just-so story imputes features possessed by the fictionalized subject to the target as it actually is. The proponent of a unified fictionalist account of scientific models might thus propose that any difference between metaphor and fiction is simply one of the level at which common features are imputed, rather than a difference between pretending that a nonfactual feature *f* really does apply in order to impute further features that would follow from *f*, on the one hand, and identifying matches between merely similar features, on the other.

Unsurprisingly, I want to reject this analysis: I think it distorts the real representational import of analogy and metaphor, in both everyday discourse and science. The claim made by a metaphor or analogy is not merely that the target is somehow like the frame in a common, highly abstract respect, but rather that the target possesses a substantive lower-level feature, one that is identified by way of its instantiating this higher-order feature. For instance, Romeo claims not just that Juliet is comparatively maximally intense relative to the other Veronese girls in some respect or other, but that she is more beautiful than them.

In the context of science, we might put the point by saying that metaphors and analogies do not typically function as purely abstract models, akin to the Lotka-Volterra equations describing the effects of predator-prey dynamics on population distribution. Such abstract models prescind from messy detail in order to focus attention on general, structural features. By contrast, in metaphor and analogy, the shared high-level features warrant attention only instrumentally, as a means for identifying a more specific lower-level feature within the target. In a pedagogical context—for instance, when explaining electrical current by analogy to the flow of water through a pipe—the speaker will explicitly identify, or ask listeners to identify for themselves, those lower-level instantiating features. In a context of discovery, investigators employ the possibility of a structural match as a principle for investigating what lower-level features the target might possess. In both cases, the structural match focuses attention on basic-level features.

So far, I've been emphasizing ways in which both metaphor and analogy differ from fiction, arguing that they involve a qualitatively greater gap

between representation and reality than fiction, idealization, or abstraction, because they rely on indirect matches between what are conceived of as two distinct domains. But as we saw earlier in application to ordinary discourse, metaphor and analogy also differ from each other. In the context of science, Gentner and Jeziorski (1993) argue that contemporary scientific practice valorizes analogies, such as Bohr's solar model, over metaphors because analogies employ precise, consistent, systematic matches between complex, causally connected systems of features. Further, they claim that this valorization is distinctive to modern Western science. In particular, they argue that alchemists up through the sixteenth century were much more promiscuous in their invocation of similarity, happily citing base-level qualitative similarities, such as the yellowness of both the sun and gold or the whiteness of the moon and silver, and invoking multiple disconnected or even incompatible matches. The birth of modern science, they claim, arises in significant part because of this shift from promiscuous similarity to higher-order structural matching. The upshot is that metaphor in contemporary science is a poor cousin to analogy, as encapsulated by George Pólya's (1954) dictum: "And remember, do not neglect vague analogies. But if you wish them respectable, try to clarify them."

I have largely followed Gentner in emphasizing the ways that metaphor both approximates to and departs from analogy. Further, Gentner and Jeziorski's priority claim about modern scientific practice is right in several important respects. First, metaphors in science, in contrast to literature, are typically more analogy-like, emphasizing fewer, more consistent matches over richer, inconsistent ones—especially in the contexts of pedagogy and theoretical advocacy, which are the cases that Gentner and Jeziorski discuss almost exclusively. Further, it is widely agreed that at least one central aim of science is to develop a precise, articulate understanding of objects, properties, and their relations, and that to accomplish this, we need symbols whose interpretation is "univocal, determinate, and readily ascertained" (Elgin 2006, 212). Insofar as metaphors differ from analogies in relying on tacit, vague, and otherwise inarticulable intuitions of similarity, they are not representationally adequate as they stand.

More substantively, some of the most influential modern scientific metaphors have aimed at identifying abstract, high-level properties, just as Gentner and Jeziorski predict. To take a pair of apt examples, the computational model of mind and the code model of genetic potential both hypothesize key causal operations that are functionally analogous to the

algorithmic execution of a computer program. One reason that both metaphors have been so theoretically and empirically productive is that they encourage a focus on structural relations while remaining fairly neutral about implementational mechanisms, leaving the connection between abstract functional role and underlying physical substrate to be forged only after each level is understood better in its own terms—a strategy that Pylyshyn (1993, 551) calls the "principle of least commitment" or "principle of procrastination."

Thus, Pólya's dictum about making vague analogies respectable by articulating precise structural relations is largely apt. However, this doesn't make metaphors into second-class versions of analogy, as Gentner and Jeziorski suggest. Rather, metaphors often play a theoretically and empirically fruitful role in scientific inquiry precisely *because* they stand in need of clarification: because they are inchoate, intuitive, and only partly consistent. As I argued earlier, metaphors' greater permissiveness engages imagination in a richer, more intuitive, and flexible way. This means they can guide attention and suggest hypotheses in epistemic circumstances where a more precise structural analogy would be stymied. Early advocates of both a computational theory of mind and a code model of genetic potential lacked clear, coherent characterizations of both their target systems *and* framing subjects, since the notions of computation and coding were themselves still nascent. Indeed, as Fox Keller (1995) argues, conceptual and empirical developments within computation and genetics were mutually supporting, with each serving as a frame for the other domain. Thus, at the same time as the metaphor of genes as self-replicating machines drove theoretical, empirical, and technological developments in molecular biology, so did the metaphor of complex machines as organisms orient research within systems analysis and cybernetics, in turn reciprocally influencing theories of biological development and cellular coordination.

In effect, each metaphor provided what Richard Boyd ([1979] 1993, 488) calls an "inductive open-endedness": it guided research by gesturing toward a range of possible matches that had not yet been fully articulated, let alone investigated. Metaphors such as mind as computer, genes as machines, and machine systems as organisms can play this sort of "programmatic research-orienting" role (Boyd [1979] 1993, 489) only because they lack the "univocal, determinate, and readily ascertained" interpretations of paradigmatic scientific symbols: they guide research by pointing to an indeterminate but bounded range of possible matches. Gentner and Jeziorski's

emphasis on "respectable" analogy in the explication and justification of contemporary scientific theories neglects the full, unruly, but ineliminable role of imagination in scientific inquiry.

Our earlier explication of framing devices puts us in a position to make this point about the utility of interpretive indeterminacy in a more precise way. Both the constituent elements and organizational structure of characterizations are typically largely implicit and only partially subject to voluntary control. They are also highly dependent on context, with diagnosticity and centrality in particular depending on an agent's interests and goals. As a result, different scientists will often bring markedly different characterizations and perspectives on their subjects to the interpretive table, especially at the beginning of inquiry. Further, even given a fixed pair of characterizations of both target and frame, there will nearly always be available multiple plausible overall mappings between them that trade off preferences for systematicity against directness in matching, and preferences for identifying new features and connections against preserving already known ones, in different but equally legitimate ways. Beyond this, as we have also seen, frames do more than just interpret a fixed set of assumptions about their targets: they provide open-ended tools for assimilating new information and for generating hypotheses about undiscovered features and causal structures. Finally, in addition to all of these frame-internal factors contributing to interpretive indeterminacy, the actual application of any frame depends in deep, important ways on external factors, including on what alternative theories it is being compared to, and so what expressive and epistemic needs it distinctively addresses (Okruhlik 1994), as well as on its interaction with current technological opportunities and limitations (Fox Keller 1995).

Perhaps the best way to view the relationship between metaphor and analogy in much of contemporary scientific practice is to see metaphor as tracing a trajectory or "career" of precisification (Bowdle and Gentner 2005). This trajectory begins with an intuitive, holistic, and open-ended—and therefore diffuse and relatively unarticulated—mode of construing one subject in terms of something else, where one or both domains may be only minimally understood. It moves through a process of articulating, probing, and refining the characterizations of one or both domains and plausible matches between them. Ultimately, it settles into a more regimented, systematic, and selective analogical mapping. At that point, the analogy may remain as a useful pedagogical tool. Alternatively, the interpretation of the framing term

may have morphed so as to become literally applicable in a few restricted respects, as has arguably happened with both "computation" and gravitational "waves." Or the metaphor may be discarded. Perhaps, like the metaphor of evolution as climbing a ladder of sophistication, it turns out to be misleading, because it directs attention toward features that are not as central as once thought, or imputes features that are not possessed. Or perhaps it does identify features that are both prominent and central, but has become too dominant and literalistic in its application, leading to neglect of other important features. Perhaps the metaphor of natural language as a logical calculus fits this description (Camp 2015).

13.4 Models and Frames

Much current philosophical discussion about scientific models has focused on their ontological status—in particular, on whether models are abstract structures or hypothetical, typically uninstantiated concrete entities—and in turn on whether the representational relation between model and target is one of direct instantiation or a more indirect one of similarity in relevant respects (Frigg 2010; Giere 1988; Godfrey-Smith 2006, 2009; Weisberg 2012). I have focused on the apparently distinct topic of frames. Although I can't pretend to have surveyed, let alone explained, all the phenomena and functions of models and modeling in science, it does seem that models and frames share remarkably many features and are used for many common epistemic purposes. One benefit of an investigation of frames is that it helps to integrate the use of models in science more smoothly into a broader theory of interpretation, and thereby into a theory of cognition and communication, from which we can discern commonalities and differences between the use of models and other interpretive strategies within science, and between the practice and evaluation of those strategies in science and in everyday cognition and communication.

Specifically, I have argued that frames are representational vehicles that provide an overarching interpretive principle or perspective. All frames presuppose a taxonomy, which is necessarily selective and contrastive; all frames determine *what* matters about their subject, and *how* it matters, along at least the two dimensions of prominence and centrality; and all frames are intuitive and non-propositional, in the sense of actually implementing rather than merely representing those interpretive structures.

However, within this broad genus, different species of frames function quite differently. Frames themselves can be more or less articulated, abstract, idealized, detailed, and affectively and experientially loaded. Some, such as the Lotka-Volterra equations, express highly abstract structures that literally describe a few highly idealized features of the target domain; others, such as vials of water, constitute concrete exemplifications of their target subjects. Frames can also be more or less conventionally tied to their vehicles: some vehicles, such as the Lotka-Volterra equations, constitute explicit semantic specifications of the relevant structures, but in many cases, such as computational metaphors of mind, the connection is one of implicit, pragmatic association.

Whatever the connection between the representational vehicle and framing principle, the interpreted representational vehicle generates a cognitive structure, which is then deployed as a principle for structuring one's overall understanding of the target. The ensuing connection between frame and target can be more or less direct, more or less instrumental, and more or less systematic. Some frames, such as sex-based theories of the evolution of tool use, assimilate the frame's defining feature, and all or most of its subsidiary features, directly into the target subject. Others, such as Maxwell's demon, assimilate that feature directly but only temporarily, in order to highlight or introduce subsidiary features that the target really would have if the framing feature was actually possessed. Some frames, such as Bohr's solar model, export a selective, coherent structure from one domain to another; others, such as the computer model of gene reproduction, highlight, explain, and restructure features of the target by an indirect mapping that is at least initially inchoate and potentially inconsistent.

All of these forms of framing can naturally be described as employing models. But we miss important commonalities and differences if we focus narrowly on the representational entities that underwrite them. Attending to the practices and processes of modeling and framing affords a more perspicuous analysis (Godfrey-Smith 2006; Levy 2015). And a full understanding of those practices requires attending to the cognitive structures and operations that make them natural and effective for agents with minds like ours. I have argued that although the various species of framing direct imaginative attention at different levels and bridge the gap between representation and reality in different ways, they all employ a synthetic, restructuring imagination to achieve a unified, open-ended, intuitive construal of their targets.

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