

Homo: A Principled Approach

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Abstract

This thesis introduces a productive metatheoretical framework for empirical and philosophical investigation into the characteristic (phenotypical) dynamics of *Homo* called Variational Sociogenesis. This account is based on the Free Energy Principle (FEP) and its recent extensions. The FEP is a principled information-theoretic formulation of biological systems' existence. The principle states that organisms exist in virtue of minimizing their variational free energy. This means that organisms minimize their informational uncertainty in – or, equivalently, maximize their (Bayesian) generative model evidence for – the hidden causes of their sensory dynamics. Variational free energy is minimized through action and perception, at all spatiotemporal scales, in a self-evidencing process known as 'active inference.' Variational Sociogenesis applies the variational formulation to empirical and theoretical work investigating human uniqueness. Specifically, Variational Sociogenesis provides a novel metatheoretical framework for investigating shared intentionality as it manifests in *Homo* by accounting for uniquely human forms of communication and collaboration through a variational lens. The most comprehensive empirical account of shared intentionality in humans is the Shared Intentionality Hypothesis (SIH). The SIH posits that *Homo* is biologically predisposed (motivated) to 'cooperatively' share mental states with conspecifics, and has evolved specialized skills to do so. Variational Sociogenesis casts the predisposed motivation to share suggested by the SIH as an expectation for statistical attunement to conspecifics. Specifically, it is suggested that human action and perception is (phenotypically) geared towards maximizing the likelihood that sensory evidence characteristic of sharing is experienced. I fill out the multiscale implications of this proposal by replying to Tinbergen's four research questions. Variational Sociogenesis is explanatorily flush with the emerging variational (pragmatic) paradigm in cognitive science.

1.0. Introduction

“Thinking would seem to be a solitary activity. And so it is for other animal species. But for humans, thinking is like a jazz musician improvising novel riff in the privacy of his own room. It is a solitary activity all right, but on an instrument made by others for that general purpose, after years of playing with it and learning from other practitioners, in a musical genre with a rich history of legendary riffs, for an imagined audience of jazz aficionados. Human thinking is individual improvisation enmeshed in a sociocultural matrix,” Tomasello (2014, p. 1).

The present thesis synthesizes a range of evidence to introduce ‘Variational Sociogenesis.’ This is an account of the phenotypical dynamics of *Homo* in terms of a spatiotemporally deep information geometry constrained by the known laws of physics (Sengupta et al., 2016). The philosophical and, more recently, empirical (Tomasello et al., 2005) notion of ‘shared intentionality’ – that is, the idea that mental states can be shared by conspecifics (e.g., Gilbert, 1989; Tuomela, 2013; Bratman, 1992) – is presupposed by Variational Sociogenesis as fundamental and definitively basic to *Homo*. The dynamics characteristic of sharing can be usefully cast into a recursive (hierarchical) organization encompassing a nonlinearly scaled spatiotemporal grain of analysis (Ramstead et al., 2017; 2018). Thus, in line with recent work (e.g., Badcock, 2012; Badcock et al., 2017), the explanatory framework provisioned by Variational Sociogenesis is pitched at the four spatiotemporally nested scales of function, phylogeny, ontogeny, and mechanism (Tinbergen, 1963).

The formal core of Variational Sociogenesis is founded in recent work towards a variational formulation of mind and biological existence (Friston, 2010; 2012a; 2013a; 2015; Badcock, 2012; Friston and Stephan, 2007; Bruineberg and Rietveld, 2014; Kirchhoff and Froese, 2017; Ramstead et al., 2017; 2018; under review; Constant et al., 2018; Carhart-Harris et al., 2014; Sengupta et al., 2016). Specifically, Variational Sociogenesis is an extension of the Free-Energy Principle (FEP) of Friston (e.g., 2010; 2013a) to account for shared intentionality in *Homo*. The FEP has witnessed several recent additions (e.g., those cited above) which, taken together, have been suggested to comprise a ‘variational biology’ (Ramstead et al., 2018). The FEP is a principled information-theoretic formulation of biological self-organization. This approach to life and mind casts biological systems as embodied hierarchical generative models of their sensory dynamics (Friston, 2012a; 2013a). Biotic systems are definitively and solely in the game of maximizing the likelihood of experiencing their (Bayesian) statistical expectations, embodied in their respective phenotypes and shaped by the nested processes of evolution, learning, and perception (Ramstead et al., 2017; e.g., Badcock et al., 2017). The variational approach thus provisions a physics of sentient systems (Sengupta and Friston, 2017; Sengupta et al., 2016), the central premise being that in virtue of minimizing the quantity ‘variational free energy’ biological systems are such. Minimization of variational free energy entails that this class of system ‘attune’ their phenotype (their dynamics) to the dynamics of their niche (Bruineberg et al., 2016; Constant et al., 2018). Dynamical minimization of variational free energy through situated action and perception increases the likelihood of biotic systems’ continued existence (Sengupta et al., 2016). Therefore, through considering the geometry of information flow in biological systems, the free energy formulation provides a principled account of how statistically-bounded (biotic) systems minimize their thermodynamic entropy (Friston, 2012a; 2013a). Variational Sociogenesis extends these first principles of biotic self-organization to provide a novel, productive account of the dynamics characteristic of *Homo*.

1.1 Shared intentionality

Much theoretical and empirical work in the cognitive sciences has demonstrated the uniquely human centrality of sociality and lived, situated, and embodied interaction and connectedness throughout the lifespan (Reddy, 2003; Over, 2015; Feldman, 2017; Tomasello, 2014a; Baumeister and Leary, 1995; Frith and Frith, 2010; Hari et al., 2015; Jensen et al., 2014; Carhart-Harris et al., 2018). Variational Sociogenesis takes the philosophical notion of ‘we-intentionality’ (Tuomela, 2013), ‘jointness,’ or ‘sharing’ in intentional action (e.g., Gilbert, 1989; Bratman, 1992) as picking out the basic phenomenon of uniquely human experience (Searle, 1995; 2010). Shared intentionality is the interactive sharing of mental states with others such that each other’s mental states are mutually known, *together*; that is, within common ground (Tomasello and Carpenter, 2007). Common ground constrains interactants’ intentions and goals and is present in every instance of sharing (Clark, 1996). Several authors (e.g., Clark, 1996; Gardenförs, 2014; Tomasello, 2014b) have suggested several (generally) overlapping ontologies for common ground. Variational Sociogenesis borrows from Tomasello (2014b) and Garrod and Pickering (2004). The former author suggests common ground be dichotomized into a culturally-shared type (i.e., norms, conventions) and a personally-shared type (i.e., individuals’ histories of interaction with specific others; cf. Clark, 1996). This is proffered as a theoretical ontology for *what* is shared with *whom* (Bohn and Köymen, 2017), though it is important to note that the content of each respective type develops over the nested timescales of ontogeny and (cultural) phylogeny, respectively (Tomasello, 2014b; Richerson and Boyd, 2005). This observation necessitates that the *online* build-up of common ground characteristic of interaction be accounted for (Garrod and Pickering, 2004), for instance, as occurs in interactive alignment (Menenti et al., 2012).

However, clear conceptual distinctions of common ground are typically only heuristically useful abstractions, as phenomena at each spatiotemporal scale enter into and constrain the others (Falk and Bassett, 2017; Han and Ma, 2015). For example, during a communicative exchange, (fast-changing) online relevance inferences (Sperber and Wilson, 1986) drawn about the referential intention of one’s interlocutor are understandable only within cultural common ground, that is, within the (slow-changing) conventional meaning and illocutionary force of the utterance (Tomasello et al., 2007a; e.g., Liebal et al., 2013). If the interlocutors have a shared history of interaction, however, the relevance inferences drawn will be constrained further by their (‘middle-changing’) personal common ground built up across interactions throughout ontogeny (e.g., Liszkowski et al., 2007). A spatiotemporally nested common ground increases the likelihood of smooth, fluid exchanges with others by making others predictable, a key aspect of effective joint actions (Sebanz et al., 2006; 2009). This is intuitive: moving a couch (Vesper et al., 2017), playing a team sport (Araújo and Davids, 2016), or doing literally any other activity *with* another (in the sense of its being shared) is neither efficient nor effective if either individuals’ actions are unpredictable (Vesper et al., 2010).

The most comprehensive empirical account of sharing as a fundamental human uniqueness is the Shared Intentionality Hypothesis (SIH) and related theory of Tomasello (2008; 2009; 2014b) and Tomasello et al. (2005; 2007a; 2012). The SIH suggests that humans are characterized by a biologically-predisposed motivation to engage in acts of shared intentionality (Tomasello et al., 2005), and, moreover, exercise phylogenetically unique social skills to do so (Herrmann et al.,

2007). Thus, citing Tomasello et al. (2005), Carpenter (2011) suggests that shared intentionality encompasses “the *skills* and *motivation* to share goals, intentions, and other psychological states with others” (p. 107; emphasis mine). A recently proposed ‘transformative’ reading of the SIH (Kern and Moll, 2017) provides support for the present claim that the SIH supplies the most comprehensive empirical account of sharing. The transformative reading of shared intentionality construes shared intentionality as constitutive of a radically novel form of life for the species that possesses it (cf. Wittgenstein, 1955), rather than merely a novel ‘mechanism’ or module employed in specific circumstances (see discussion in Tomasello, 2014b). This outlook suggests that, in species engaging in shared intentionality, there should be, e.g., an empirically discernable causal influence on the functioning of even traditionally nonsocial phenomena attributable to the (shared) form of life instantiated by the species [1] (Kern and Moll, 2017; see also Rietveld and Kiverstein, 2014). Evidence for this claim is provisioned in the present thesis. Moreover, both the variational formulation and the SIH find certain theoretical bases in cybernetic thought (Ashby, 1962). This is quite opportune, as it signals that both accounts make use of the same basic ‘control systems’ scheme for directed or ‘intentional’ behavior (Tschacher and Haken, 2007). Hence, leveraging the insights of the SIH is attractive in the present context.

A “dual-level cognitive structure of simultaneous jointness and individuality” (Tomasello, 2014b, p. 48) is suggested to arise within and across joint exchanges in ontogeny (Moll and Tomasello, 2008; see also Moll and Meltzoff, 2011). This is a nested representation of individuals’ intentions, goals, and attention such that individuals possess a “bird’s-eye view” (Tomasello et al., 2005, p. 681), that is, a simultaneous view ‘from above’ – from a shared ‘we’ perspective with mutually coordinated goals underlain by meshed intentions and attention (Bratman, 1992); and ‘from below’ – from the point of view of each individual’s perspective on the same, shared locus. The dual-level representational format is argued to be basic to all manifestations of shared intentionality in humans and, hence, is intricately bound up with the notion of common ground (Tomasello, 2009; 2014b). Indeed, both the dual level structure and common ground have been proposed to follow a ‘two-step’ trajectory (Tomasello, 2014b; Tomasello et al., 2012). In the first step, it is suggested that the dual level representation and common ground are restricted to interactants’ personal histories within joint frames and, moreover, that such a representational structure manifests itself only within joint frames (Tomasello, 2014b). These developments precede a second step where, in phylogeny, cultural evolutionary processes accumulate various ‘patterned practices’ (Roepstorff, 2013) such as the communicative conventions and collective institutions that shape the space of the (rational) cultural common ground for the individuals making up a culture (Mercier and Sperber, 2012; Rand and Nowak, 2013). The representations that guide interaction among unknown, anonymous individuals then stay within the (expected) space of what ‘any reasonable person’ does, says, thinks, and so on (Tomasello, 2014b). This likely manifests in ontogeny as a gradual extension of the dual level format to encompass everything the individual does, both inside and outside joint frames. An individual’s action and thought comes to be structured by this extra ‘layer’ of cultural common ground (Rakoczy and Schmidt, 2013). In sum, dual level cognition constrains action and thought throughout ontogeny. Diverse experiences of interacting and coordinating with various others’ models of the world allows one to ‘tune in’ to the culture’s underlying common ground (Moll and Tomasello, 2008; Moll and Meltzoff, 2011).

It is suggested that Variational Sociogenesis largely agrees with ‘usage-based’ approaches to studying human psychology and its development (though not exclusively; see below). This rather general class of theory stresses the importance of domain-general learning mechanisms in shaping human cognition, such as pattern recognition, categorization, and schematization. For instance, usage-based construals of human communication stress the importance of domain-general schematization in extracting communicative form-meaning pairings (constructions) in ontogeny (Tomasello, 2003; Lieven, 2016). In phylogeny, constructions are altered during interactions between idiolects (Beckner et al., 2009), resulting in a dynamic set of constructions comprising a communicative system (Dingemanse et al., 2015; Kidd et al., 2017). Thus, the ‘cultural ratchet’ unique to human (cumulative) cultural evolution makes likely that, e.g., an interactively useful set of referential devices is developed and maintained across generations (Tennie et al., 2009). Moreover, usage-based approaches have been extended to mental state inference (Liszkowski, 2013; see also Moll and Tomasello, 2008). This is notable, as communication and mental state inference are reciprocally impacted by the nested, interwoven trajectories of common ground and the dual-level structure (Malle, 2002; Corballis, 2017; Tomasello, 2008; 2014b). Individuals communicate to coordinate perspectives on the same, shared locus (Tomasello et al., 2007a), which has the effect of enhancing the predictability of one’s own or the other’s attention, thoughts, or actions (Vesper et al., 2010; Tylén et al., 2010). Mature interlocutors are adept at tuning in to uncertainty in the exchange to guide their usage of communication (Pickering and Garrod, 2014), and this sensitivity to uncertainty within joint settings develops early in life (Tomasello et al., 2007a; Köymen et al., 2017). Indeed, cooperative communication is the primary substrate for the creation of the (uncertainty-minimizing) common knowledge between individuals that constrains their interactions (Clark, 1996; Tomasello, 2014b). It is thus sensible that such a receptivity to uncertainty within joint exchanges appears to develop so early in life (reviewed in Bohn and Köymen, 2017).

Interestingly, this conception of communication as a tool to manage uncertainty in individual perspectives has conceptual overlap with proposals that social interaction may be, in at least certain cases, ‘constitutive’ of social cognition (De Jaegher et al., 2010; see also Di Paolo and De Jaegher, 2012). Through situated, interactive communication, interactants gain a sort of ‘privileged access’ to others’ mental states since both are aligned to each other, that is, share largely overlapping dual level representations of the joint frame (Pezzulo, 2011; Carpenter and Liebal, 2011). Interactants dynamically co-regulate the predictability of themselves and others through communication at the grain deemed necessary to align each’s model of the joint frame to the other (Fogel and Garvey, 2007; Vesper et al., 2010). For instance, Duguid et al. (2014) provide evidence that children modulate the grain of their communication in accord with the level of uncertainty in a joint task, thereby allowing them to set up and coordinate individual representations within a shared frame (see also Wyman et al., 2012). Indeed, a large literature suggests that, in ontogeny, the increasingly adept usage of communication to gain such privileged access to others’ mental states manifests in predictable ways, namely, in increasing the success and flexibility of joint actions (e.g., Ashley and Tomasello, 1998; Brownell et al., 2006). The importance of the development of each phenomenon to the other can hardly be overstressed (Brownell, 2011; Tomasello and Hamman, 2012), and, indeed, there even exists much evidence suggesting a strong correlation between the development of ‘offline’ (non-interactive) mental state inference and communicative abilities (Miller, 2006; Milligan et al., 2007).

1.2. The present thesis

Variational Sociogenesis unpacks shared intentionality as it characteristically manifests in *Homo*. This is done through a discussion of how the shared form of life minimizes its free energy at each of the reciprocally-interconnected, nested scales of function (biological adaptation), phylogeny (cultural evolution), ontogeny (development), and mechanism (real time). In brief, a function level explanation of sharing in *Homo* suggests that selection pressures favored (and favor) biological structure and function characteristically effective at encoding precise expectations of attending to (sensory data phenotypically produced by) conspecifics (cf. Tomasello et al., 2005). Heuristically, this means that the (sensory) dynamics of conspecifics are highly salient and hence afford attending to for humans. Attention implicates ‘attunement’ to the (attended) sensory data (Bruineberg et al., 2016), a technical term from the variational literature indicating an embodied statistical recapitulation of experienced sensory dynamics (see below). At the scale of phylogeny, individual-level prior predictions of conspecific attunement entail nonlinearities (cf. ‘novel’ dynamics) at the spatiotemporal scale of the cultural group *per se* (Smaldino, 2014; Shuai and Gong, 2014), for instance, the path-dependent dynamics of a communicative system across generations (see below). Dynamics at the scale of ontogeny is characterized by a protracted process of attuning to one’s sensorium. In the human niche, this entails that the dynamics (characteristic) of others – and hence the dynamics (characteristic) of a culture *per se* (Searle, 1995; 2010; Ramstead et al., 2016) – are statistically recapitulated in the individual (Falk and Bassett, 2017; Kidd et al., 2017). These considerations inform a mechanistic scale of explanation. Here, recent work (Friston and Frith, 2015a,b; Pezzulo et al., 2013; Grau-Moya et al., 2013; Friston et al., 2015a; Perfors et al., 2011a) suggests that the variational approach can account for the characteristic behavioral and neural dynamics of cooperative (joint, model-attuning; Grice, 1975) communicative action, where linguistic communication is merely the signal case (Tomasello, 2014b). The degree of free energy-minimizing attunement between conspecifics tracks the emergence of a single, shared model of sensory dynamics (Friston and Frith, 2015a,b; Bolt and Loehr, 2017). Crucially, it is quite tempting to associate these dynamics with the dual level structure of the SIH, as key properties of each phenomenon are highly reminiscent of properties of the other (see section 4.0). Variational Sociogenesis thus accounts for individuals’ reciprocal entrainment into shared (generative) dynamics instantiated by various types of low dimensional patterned couplings between interactants (De Jaegher and Di Paolo, 2007; Riley et al., 2011).

This treatment is thus in line with proposals for a more ecologically valid ‘interactionist’ – or, more generally, ‘pragmatic’ – consideration of cognitive scientific phenomena and their spatiotemporally nested trajectories (Gallotti and Frith, 2013; Schilbach et al., 2013; Dumas et al., 2014; De Jaegher et al., 2010; see Engels et al., 2015). Indeed, the notion of attunement that is central to the variational approach is a fundamentally multi-body concept, though one that can be recursively decomposed to study whatever level of analysis one’s research question requires (Ramstead et al., 2017; 2018). Finally, it is crucial to note that though Variational Sociogenesis extensively leverages insights from empirical work into shared intentionality, the present explication is largely restricted to the relationship between the motivation and skills for sharing and uniquely-human communication and collaboration. This is to the exclusion of intricately-related work investigating, e.g., the development of uniquely human forms of altruism and

egalitarianism in children (Warneken, 2016; McAuliffe et al., 2017), phenomena quite directly implicated by the SIH (see Tomasello, 2009).

With the above considerations in place, the structure of this thesis is as follows: Next, a non-mathematical introduction to the variational approach is provided. Third, Variational Sociogenesis is outlined. This is a spatiotemporally nested (multiscale) account of the human phenotype, explicated through several brief reviews of empirical work investigating how shared intentionality manifests itself at each scale of analysis. (Due to space, a fully comprehensive account at each scale clearly cannot be provided.) Fourth, a conclusive summary is given alongside suggested future directions.

2. Variational biology

2.1 Generative models and the Markov blanket formalism

The variational formulation of biotic self-organization is founded in the Free Energy Principle (Friston, 2010; 2012a; 2013a; 2015), an information-theoretic account of the dynamics characteristic of biological systems. This principled formulation seeks to explain how biological systems maintain their form while embedded within a dynamic environment, that is, how they maintain their precarious nonequilibrium steady-state by actively avoiding thermodynamic erosion (Friston and Stephan, 2007). The formulation suggests that biological systems appear to instantiate a hierarchical generative model of their niche (Friston, 2008; 2010). Organisms are *solely* in the business of minimizing the information-theoretic quantity ‘variational free energy,’ a measure fundamental to the generative model they embody (Friston, 2012a; 2013a). Under simplifying assumptions, variational free energy is equivalent to the Bayesian model evidence for an embodied model of sensory dynamics (Hinton, 2007).

A generative model recapitulates (learns) the underlying statistical structure (hidden causes) of training (sensory) data so as to generate that data itself. In short, generative models mirror the statistical structure of their sensory data, thereby allowing them to generate predictions of sensory data with the same statistical structure (see Pickering and Clark, 2014). Generating sensory data that recapitulates experienced sensory data implicates a ‘contextualization’ of the dynamics of lower layers of the generative hierarchy with learned data. Learning in a generative model occurs in functionally hierarchical, ‘stacked’ layers of increasing abstraction and spatiotemporal depth (Perfors et al., 2011a; Friston et al., 2017a). ‘Deep’ spatiotemporality in the dynamics of a generative model means that high layers exhibit slow dynamics that constrain the fast dynamics unfolding at lower layers. Low level predictive dynamics cycle through several iterations within a single predictive cycle at high levels [2]. Heuristically, this means that slow-changing higher layers simply require greater amounts of unexplained sensory data to alter their dynamics than do fast-changing lower layers (Kiebel et al., 2008; 2009). Crucially, however, there exist mechanisms that enable quick learning of higher, contextualizing dynamics, chiefly the expected precision of sensory data (Feldman and Friston, 2010; see also Perfors et al., 2011a). Learned or ‘empirical’ prior predictions are thus optimized via bottom-up sensory input – an error signal – to impact on high-level predictions (Friston and Feldman, 2010; Friston et al., 2014a). Moreover, high level predictions oftentimes comprise ‘full’ priors with dynamics directly modulated by natural selection (Friston, 2013b; Campbell, 2016). Interestingly, under

simplifying assumptions bottom-up error signals in the variational approach are formally equivalent to ‘prediction error’ in predictive coding (Clark, 2013; den Ouden et al., 2012). The variational approach thus furnishes a principled basis for ‘Bayesian brain’ accounts of global brain function (Friston, 2010; 2012b). Bayesian model (natural) selection is thus a corollary of the variational approach (Campbell, 2016; Ramstead et al., 2017) and can be used to computationally model natural selection (cf. Bruineberg and Hesp, 2017).

The probability density function encoding the predictions of the generative model is known as a ‘variational density’ (Friston and Stephan, 2007). A variational density is an ‘approximating’ probability density insofar as its sufficient statistics (in our case, its mean and variance) are optimized through exposure to sensory data. ‘Optimized’ here means that prior predictions of the density approximate posterior expectations over the statistical structure of sensory data. Subsequent prior predictions encoded in the variational density thus increasingly (statistically) recapitulate sensory data (note that this does not entail any sort of representational ‘accuracy’ in the model; see discussion in Bruineberg, 2017). When error signals are minimized, the variational density is formally ‘attuned’ to the generating (sensory) density, i.e., the organism’s dynamics are attuned to external dynamics (Bruineberg et al., 2016).

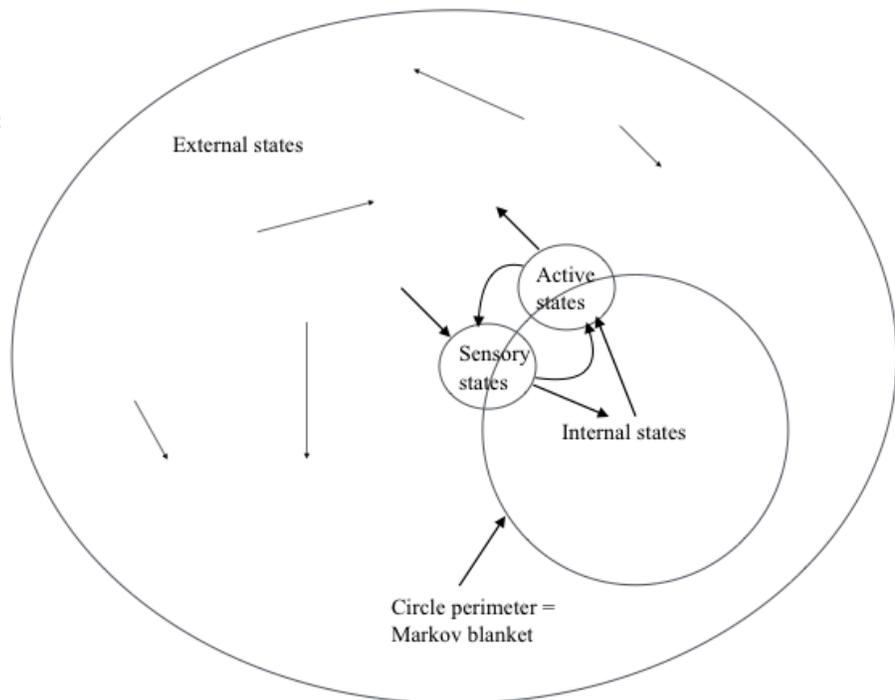
As Clark (2013) writes,

“The free energy principle...states that ‘all the quantities that can change; i.e., that are part of the system, will change to minimize free energy (Friston and Stephan, 2007, p. 427). Notice that, thus formulated, this is a claim about all elements of systemic organization (from gross morphology to the entire organization of the brain) and not just about cortical information processing [e.g., Friston, 2005],” (pp. 6-7).

What formally counts as “part of the [generative] system” (Clark, 2013, p. 6), that is, as part of the organism, is defined by the Markov blanket formalism (Pearl, 1988; Friston, 2013a). A Markov blanket statistically bounds a set of nodes (states) within some fluctuating energy map (environment; Figure 1.). Specifically, the blanket divides a random chaotic dynamical system into a set of ‘internal’ states embedded within a set of ‘external’ states (Friston, 2012a; Clark, 2017). The blanket itself is divided into ‘sensory’ and ‘active’ states, which are associated with sensory epithelia and motor effectors, respectively (see Friston, 2013a). The organism *per se* is comprised of the union of sensory, active, and internal states; and the environment is comprised of the set of external states. Information flow through the blanket is constrained by conditional dependencies between pairs of states (see Figure 1). Specifically, external states send information to (i.e., influence) sensory states; sensory states influence internal and active states; internal states influence active states; and active states influence sensory states and external states (Friston, 2012a; 2013a; see Figure 1). Since internal states can only ‘see’ through the Markov blanket, they have indirect access to the dynamics of external states (Hohwy, 2013). The dynamics of external states are thus technically ‘hidden’ behind the Markov blanket (Clark, 2017; Gallagher and Allen, 2016). Therefore, internal states (encoding the variational density) must approximate the dynamics of external states through the dynamics of sensory states (Friston, 2012a; 2013a). As described below, internal states’ recapitulation of the dynamics of external states means that the generative model (organism) is a control system for (active) inference (Friston, 2012a), that is, a control system for active evidence gathering for its embodied model of its niche (Friston et al., 2017b; cf. Tomasello et al., 2005). This insight makes clear how free energy minimization extends the Good Regulator Theorem of cybernetics,

Figure 1.

The Markov blanket formalism. Conditional dependencies define the various components of the Markov blanket (active and sensory states) and the internal and external states it divides. Specifically, external states influence sensory states; sensory states influence active and internal states; internal states influence active states; active states influence sensory states and external states (see the main text). This induces a basic, all-pervasive energetic circular causality which the variational approach posits is a scale-free property of biological self-organization. The arrows in the external embedding represent the dynamics of the environment and contain a small amount of random fluctuations (noise) with respect to the predictions encoded by internal states. This renders the internal model statistical in nature. The model leverages active inference to statistically recapitulate the dynamics of its embedding so as to preserve its internal states.



which states that “every good regulator of a system must [entail] a model of that system,” (Conant and Ashby, 1970, p. 89; for instance, Pezzulo et al., 2015a).

2.2 Variational free energy, surprisal, and attunement

Information-theoretic variational free energy and its minimization is *the single most important* quantity and phenomenon (respectively) to consider in the variational approach. Free energy upper-bounds the (information-theoretic) entropy of the Markov blanket (see Lemma 1 of Friston, 2012a). The entropy of the blanket is equivalent to the long-term average of ‘surprisal.’ Surprisal is also known as ‘self-information’ and is the negative log probability of experiencing some sensory state. Relatively ‘surprisal-ing’ (Clark, 2013) states are relatively unexpected and therefore undesirable. Minimizing surprisal is imperative to the organism’s continued existence (Friston 2012a; 2013a). Although surprisal is an intractable quantity and hence is not used by to the organism (Friston, 2010; Bruineberg et al., 2016), because free energy upper-bounds entropy, the proximal imperative to minimize surprisal becomes the distal imperative to minimize the entropy of sensory states, that is, to minimize variational free energy (on average and over time). This relation is clearest in one of the three (Friston, 2010) formal definitions of free energy, namely, the sum of surprisal and the Kullback-Leibler (KL) divergence between the internal and external states (Friston, 2010). By minimizing variational free energy, the organism implicitly minimizes surprisal by minimizing the KL divergence – that is, by embodying the statistics over external states. Bruineberg and Rietveld (2014) and Bruineberg et al. (2016) describe this dynamic process of minimizing the KL divergence as formally ‘attuning’ the internal and

external states to one another. Technically, attunement is a product of the process of ‘generalized synchronization’ between coupled chaotic dynamical systems (Friston, 2013a; see Bruineberg et al., 2016). Minimizing the KL divergence through generalized synchronization leads to an increase in the mutual information of the states of two coupled systems, that is, to attunement of the two systems (see Hasson and Frith, 2016). Hence, prediction of the dynamics of one system given the dynamics of another can be quite accurate, as each literally embodies the (statistics describing) the other. Minimizing the KL divergence (i.e., maximizing the mutual information) between the statistics of internal and external states means that the variational approach subsumes KL- or infomax formulations of control (Friston et al., 2015b; see Butko and Movellan, 2010). Mutual information is thus the quantity that formally defines attunement and is, by definition, irreducible to any one system (cf. Fogel and Garvey, 2007). Since minimizing the KL divergence entails minimizing free energy (Bruineberg et al., 2016), free energy is a measure of the graded ‘dis-attunedness’ of two informationally-coupled systems (Bruineberg and Rietveld, 2014).

The second definition of free energy is the complexity minus the accuracy of the generative model [3] (Friston, 2010). While the organism is in the game of optimizing the statistics of its variational density so as to maximize the accuracy of the generative model’s output, it must also optimize (minimize) the complexity of the parameters of the model encoding those predictions (e.g., synaptic connections and weights). This is intuitive: complex models are thermodynamically costlier to maintain and hence undesirable (Sengupta et al., 2013). We can heuristically cast this in terms of Occam’s razor and the simplicity of explanations or hypotheses for sensory input (Gregory, 1980; Friston et al., 2012a). The simplest explanation possessing a high posterior likelihood tends to be the most useful (adaptive) one, that is, the one that minimizes variational free energy (see Hohwy, 2013). Moreover, this definition provides a principled grounding for observed model-optimizing phenomena (Friston, 2010) such as, e.g., Hebbian learning (Hebb, 1949) and synaptic renormalization (Wenger et al., 2017). The definition of free energy introduced in this paragraph proves quite useful in section 3.2, where the ratcheted or ‘iterative’ optimization of human communicative systems across phylogeny is discussed (Tamariz and Kirby, 2016).

In attuning its dynamics through action and perception, biological systems converge towards a low-entropy subset of attracting (phenotypical) states (Friston and Stephan, 2007). Sensory dynamics consistent with the set of attracting states are (statistically) expected; and data outside the attracting set are unexpected, hence possessing a high free energy and motivating active avoidance (Sengupta et al., 2016). For instance, humans maintain an internal body temperature of roughly 98 degrees Fahrenheit, and, when outside this set range, interoceptive allostatic mechanisms (e.g., fevers, striated muscle contractions, immune system mobilization, etc.) make likely that our bodies regain the expected, (statistically) unsurprising sensory experience (Seth, 2013; Pezzulo et al., 2015a). The frequent state visitation and re-visitation necessitated by minimizing free energy is described as ‘ergodic.’ Ergodicity roughly means that the average value of a random variable over a short time span closely approximates its value when observed over a long time span. This means that organisms tend to maintain their dynamics around homeostatic set points or zones, and engage in allostatic behavior to efficiently regain homeostasis when experiencing sensory dynamics outside this expected range (Sengupta et al., 2016; e.g., Kleckner et al., 2017). Ergodicity is maintained through self-organized intentional

behavior (Tschacher and Haken, 2007), that is, through free energy minimizing action policies (see below). The characteristic dynamics for a given biological system entailed by its maintaining a low entropy over its experienced sensory states is its phenotype (Friston, 2012a; Ramstead et al., 2017). The phenotype is thus an embodied, dynamical, and transient instantiation of (Bayesian) expectations (selected for through dynamics perched at nested spatiotemporal scales; Badcock, 2012; Ramstead et al., 2017).

2.3 Active inference, expected precision, salience, and affordances

As noted above, since biological systems are embedded within a fluctuating environment, these systems must act (manipulate their active states) to maintain their characteristic probability distribution over (sensory) states – their respective phenotypes. In lieu of this, biological systems risk deleterious phase transitions, the most extreme case being death (i.e., a return to equilibrium with their environment; Friston and Stephan, 2007). Thus, biotic systems must predict the future states of their active states such that predictions of the dynamics of active states minimize free energy. Since active states influence sensory states, predictions of the dynamics of active states minimize the expected free energy of both active *and* sensory states. Action and perception work together to minimize free energy in a process called ‘active inference’ (Adams et al., 2013; Friston et al., 2015b; 2017b). Thus, in active inference, predictions of active states induce a discrepancy (prediction error) in experienced and expected active states that drive the dynamics of active states (Friston, 2011). Free energy is minimized by behaving in the expected way, that is, by acting (Friston, 2011). At an ontogenetic scale, this entails from the very beginning a generative model of (the sensory effects of) action policies (Kelso, 2016).

Active inference entails that organisms preferably orient and attend to external states possessing a high ‘expected precision’ (Feldman and Friston, 2010; Friston et al., 2012a). The expected precision of sensory data is the expected inverse variance, or expected negative entropy, of the possible causes (statistics) generating sensory data. Since entropy is upper bounded by free energy, maximizing the expected precision of attended sensory samples means that precise, low-entropy (certain) sensory predictions guide attention and action (Friston et al., 2012a; 2015b; 2017b). Possessing a low expected free energy is thus (heuristically) equivalent to possessing a high expected precision. The expected free energy of sense data is that data’s ‘saliency,’ which is defined as the expected free energy of active and sensory states were an action policy selected that causes the system to orient and attend to that sensory data (Parr and Friston, 2017). What this means is that certain (counterfactual) active states are expected to minimize variational free energy by varying amounts. The set of sequential active states which has the most precise (free energy-minimizing) expectations associated with it is, in control systems terminology, the ‘action policy’ or ‘intention’ that guides the system (Friston et al., 2015b; 2017b; cf. Tomasello et al., 2005). The dynamics of attention in active inference are thereby quasi-‘normative’: data with the highest expected precision *should* be attended to, *given that* the organism minimizes its free energy (Kirchhoff and Froese, 2017). Attention *per se* is suggested by the variational formulation to be a mechanism allowing for the ‘singling out’ precise sense data for gain-enhancement (Feldman and Friston, 2010; Sengupta et al., 2016), which means that attended-to sense data are leveraged to provide ‘precision-weighted’ updates to high levels of the generative model (e.g., Moran et al., 2013). Attention directed towards precise stimuli is thus a process of neuromodulatory ‘gating’ or ‘gain control’ of prediction error (Yu and Dayan, 2005; Park and

Friston, 2013), likely implemented by midbrain dopaminergic and cholinergic efferents to the cortex (Friston et al., 2014a; 2014b). These processes balance the influence of embodied, top-down prior expectations relative to bottom-up error signals (Clark, 2013; Powers III et al., 2016). In instances where the precision of low level sensory states is expected to be high relative to high level predictions encoded in internal states, sensory data ascends the generative hierarchy to impact high level predictions (Yildiz et al., 2013).

In their variational treatment of affordances [4], Bruineberg and Rietveld (2014) situate action-perception cycles within ‘landscapes’ and ‘fields’ of affordances (see also Rietveld and Kiverstein, 2014). Ramstead et al. (2016) define a ‘landscape of affordances’ as “the total ensemble of available affordances for a population in a given environment [and] corresponds to what evolutionary theorists...call a ‘niche’,” (p. 3; see Bruineberg and Rietveld, 2014). We can usefully construe affordances shaped through niche construction as constituting a precise set of third-order prior expectations ‘offloaded’ onto the environment (Constant et al., 2018). Specifically, in addition to the first-order priors encoded in cortex and second-order priors encoded in midbrain – sensory predictions and the expected precision of those predictions, respectively (Friston et al., 2014a) – affordances constitute ‘third order’ prior expectations offloaded by the organism onto the niche itself (see also Ramstead et al., under review). A landscape of precise affordances is a corollary of active inference (Constant et al., 2018): action minimizes free energy, which entails that organisms shape their respective niche in such a way that it discloses itself at any given time as a precise, low entropy ‘field of affordances’ (Bruineberg and Rietveld, 2014). Affordances themselves are cast as expected free energy gradients that intentions or action policies dissipate (Bruineberg and Rietveld, 2014; Tschacher and Haken, 2007). Indeed, the exact same self-organizing active inference dynamics are at work in chemical signaling gradients in cellular morphogenesis (Friston et al., 2015a) as are at work in the human niche (Ramstead et al., 2016; 2017). Affordances characterized by the most precise (strongest) gradient are ‘solicitations’ – affordances that solicit the self-organization of intentions to dissipate the gradient (Bruineberg and Rietveld, 2014; see also Cisek, 2007). Formulating intentions to effectively dissipate affordance gradients means that the biological system formally exhibits a gradient descent on, or stepwise minimization of, free energy (Friston, 2012a). A gradient descent on free energy is instantiated by cyclic evidence-gathering transients – ‘rolling cycles of action-perception’ that continually dissipate and reshape the field of affordances (Ramstead et al., 2016). The particular affordances that are soliciting at a given time is a function of the complex, path-dependent history of the organism in conjunction with its form of life and immediate needs, disposition, and bodily states (Bruineberg and Rietveld, 2014; for instance, Pezzulo et al., 2015a).

Clearly, the landscape of affordances for *Homo* is unique, as it not only instantiates a species general form of (shared) life (Kern and Moll, 2017; Tomasello et al., 2005), but also numerous, cumulative, culture specific forms of life (Winch, 1964; Richerson and Boyd, 2005). Ramstead et al. (2016) suggest that cultures constitute local free energy basins – ‘local ontologies’ that can be formally parameterized in terms of the dynamics of phenomena at that scale of analysis [5] (see also Ramstead et al., 2017; 2018). As suggested below, furnished by this is what we may call a (formal, statistical) cultural attractor exhibiting characteristic (culture-specific) dynamics and towards which the members comprising that ontology tend towards (e.g., Beckner et al., 2009). Within this context, the general functional role of numerous phenotypical traits unique to

Homo – e.g., so-called cultural learning (Tomasello, 2016) that manifests in species-unique traits like joint attention (Carpenter et al., 1998), teaching (Burdett et al., 2017), collaborative problem solving (Vygotsky, 1978), and engagement in ritual (Watson-Jones and Legare, 2016) – is rather straightforward. Each phenomenon functions to attune individual-level dynamics to the cultural attractor (Veissière, 2017; Ramstead et al., 2016). Since the local ontology is constituted solely by others' expectations (Searle, 1995; Ramstead et al., 2016), attuning to the cultural attractor is (largely [6]) just attuning to others' expectations of how being in time and space should unfold. This suggestion entails that dynamics at the local level shape and constrain the path-dependent trajectory taken by a given cultural attractor (see below).

2.4 A multiscale ontology for the biosphere: Variational Neuroethology

Variational Neuroethology (VNE) extends the variational approach to provision a spatiotemporally deep metatheoretical ontology for the biosphere, as well as a research heuristic for the biological sciences (Ramstead et al., 2017; 2018). VNE casts Markov blankets as fractally recursive, a nesting property following from attunement of the internal states of Markov blankets at a given scale (Ramstead et al., 2017; 2018). The product of this is so-called 'deep evolution,' or the genesis of novel levels or units of selectable structure (Watson and Szathmáry, 2016; see also Szathmáry, 2015). Indeed, though such structure mechanistically instantiates itself in the human niche through a combination of imitative and innovative copying tendencies (Legare and Nielsen, 2015) that lead to cumulative cultural evolution (Creanza et al., 2017) and consequent cultural group selection (Richerson and Boyd, 2005), the variational approach suggests that the emergence of selectable hierarchy in biological self-organization is a rather ubiquitous phenomenon [7] (see Corominas-Murtra et al., 2013). For instance, hierarchically organized structure and dynamics are instantiated by, e.g., the nervous system (Huntenburg et al., 2018; Buckner and Krienen, 2013); the evolution of taxa (Bejan and Lorente, 2011); action (Csibra, 2008; Botvinick, 2008); language (Eveaert et al., 2015); mental state inference (Koster-Hale and Saxe, 2013; Chambon et al., 2017); and group-scale organization (Anderson and Brown, 2010). Importantly, it is stressed that – though hierarchical free energy minimization is the defining feature of biological existence (Friston, 2012a; 2013a; Ramstead et al., 2017 – the phenomena minimizing free energy, namely, the structure and dynamics of specific biological phenomena are exceptionally variable within and between levels of analysis (Allen and Friston, 2016; Sengupta et al., 2016).

By attuning states, what were the random fluctuations of the (generative) dynamics at the level above now constitute the dynamics of prediction – a higher, contextualizing level of Markov blanket organization (Ramstead et al., 2017). The biosphere is characterized by a (restricted) power scaling law as one ascends spatiotemporal scales (Avnir et al., 1998). Thus, *exactly* as with internal dynamics, external dynamics tend to be characterized by several cycles of predictive dynamics (at the scale of, e.g., ontogeny) constituting a single cycle at a higher level (at the scale of, e.g., phylogeny). This entails that the same generative dynamics employed in attuning organisms and non-biological aspects of the niche (Constant et al., 2018) is leveraged to attune dynamics between organisms (Friston and Frith, 2015a,b; Dindo et al., 2014), namely, the reciprocal interplay of the active states of one system and the sensory states of another (Fogel and Garvey, 2007; Renzi et al., 2017). The importance of this for Variational Sociogenesis

cannot be overstated: Variational Sociogenesis suggests how the simple expectation of attuning to others gives rise to the functional hierarchy and dynamics phenotypical of *Homo*.

3.0 Variational Sociogenesis

“We happen to observe behavior more readily than survival, and that is why we start at what really is an arbitrary point in the flow of events. If we would agree to take survival as the starting point of our inquiry, our problem would just be that of causation; we would ask: “How does the animal – an unstable, ‘improbable’ system – manage to survive?” Tinbergen, (1963, p. 418).

This section presents Variational Sociogenesis (Figure 2). This is a variational treatment of the characteristic dynamics of humans through an investigation of shared intentionality as it manifests in humans. This account is organized by Tinbergen’s (1963) four research questions and their associated spatiotemporal domain (Badcock, 2012; Ramstead et al., 2017), though cross-scale interactions are discussed to highlight the circular dynamics characterizing each scale of analysis within the variational approach (Friston, 2013a; Sengupta and Friston, 2017). Indeed, this explication presents phenomena at the spatiotemporal scale of ontogeny and mechanism within one subsection for explanatory clarity. Variational Sociogenesis assumes the same restricted power-scaling law typical of the variational formulation (Ramstead et al., 2017). Explanation at the scale of function accounts for dynamics characteristic of biological evolution; at the scale of phylogeny, cultural evolution; at the scale of ontogeny, development; and at the scale of mechanism, online or ‘real-time’ dynamics.

3.1. Function

This section presents a variational approach to evidence at the explanatory scale of function suggesting that *Homo* underwent some degree of biological evolution through natural selection for a predisposition to engage in shared intentionality (Tomasello et al., 2005). Importantly, when discussing neural dynamics, the brain’s mentalizing network (Koster-Hale and Saxe, 2013; Mahy et al., 2014) is the primary focus of discussion; and therein primarily paralimbic structures such as (anterior) cingulate cortex (ACC). This is intended merely to aid explanation: cingulate cortex (and much less simply its anterior portions) are quite clearly not assumed to be exhaustive of the relevant neural regions and dynamics for the topics in this thesis (e.g., Grossmann, 2015; Mundy and Newell, 2007). For the purposes of the present section, it is simply stressed that the neurobiological architecture put forward here has as evidence theoretical (e.g., Friston et al., 2012b; 2014a) and experimental (e.g., Moran et al., 2013; 2014) treatments in the variational approach. Specifically, Friston (2013b) suggests that areas of paralimbic cortex occupy the highest levels of the generative hierarchy. There is much evidence suggesting that, more specifically, cingulate cortex is a high level ‘hub’ node of the brain (Bullmore and Sporns, 2009), with widespread efferents throughout cortex (van den Heuvel and Sporns, 2013) and subcortical areas (Etkin et al., 2011; Allman et al., 2001). The dynamics of paralimbic regions are suggested by Friston (2013b) to encode ‘full priors’ – high level precise prior expectations selected for in evolution or learned very early in ontogeny (oftentimes making them appear ‘innate’; see discussions of ‘overhypotheses’ in Kemp et al., 2007; Goodman et al., 2009). Generally speaking, the dynamics of cingulate cortex are thus thought to play a ‘contextualizing’ role in (the neurodynamics underlying) human cognition and action (van den Heuvel and Sporns, 2013; Carhart-Harris et al., 2014). We can illustrate this by considering the neural dynamics

characteristic of the declarative (sharing) pointing gesture (Tomasello, 2008). In adults, it was recently found that dorsal ACC activity uniquely positively correlates with cooperative pointing for conspecifics (Brunetti et al., 2014; notably, see also Haroush and Williams, 2015). Interestingly, ACC may integrate predictions in both ‘self’ and other’ frames of reference to influence the decision to cooperatively point (Apps et al., 2016; see also Lavin et al., 2013). This suggests that pointing may be a cooperatively-motivated ‘option’ – an extended sequence of behavior that aids in learning (Holroyd and Yeung, 2012) and which is selected on the basis of its (expected) free energy-minimizing efficacy (Friston et al., 2015b). Indeed, infant pointing has been demonstrated to be associated with enhanced learning of (intended) object labels (Begus et al., 2014). Thus, conspecifics who are (expected to) produce precise sensory data characteristic of sharing (i.e., who embody precise affordance gradients for sharing) are selectively attended to (Begus et al., 2016; Marno et al., 2016), and, indeed, may selectively inhibit or maintain pointing behavior (cf. joint action) across interactions (Liszkowski et al., 2004; see section 3.3).

Interestingly, this neurobiological architecture and its putative place in the generative hierarchy are potentially informative regarding the ‘emotional reactivity’ or ‘self-domestication’ hypothesis of Hare and Tomasello (2005). The authors hypothesize that early selection in *Homo* favored evolutionarily novel prior expectations in (para)limbic regions, likely in response to altered feeding ecologies (niche dynamics). Selection on these regions is hypothesized to have favored models with dynamics encoding increased trust, tolerance, and reduced aggressiveness towards conspecifics in feeding contexts (Hare and Wrangham, 2017). It is suggested by Variational Sociogenesis that selection for novel high level paralimbic dynamics consequently “set the tone” (Friston, 2013b, p. 41; i.e., the precision) for internal dynamics contextualized by backwards efferents from, e.g., cingulate cortex. Top-down (anterior) cingulate dynamics been found to exert context-sensitive control over action policy selection (e.g., Brunetti et al., 2014; see Holroyd and Yeung, 2012) and the deployment of the mentalizing network (Chambon et al., 2017). A prediction of this account is that emotion and temperament should relate to behavioral measures of theory of mind in ontogeny. Indeed, Wellman et al. (2011) recently describe novel evidence that suggests “temperament aids theory-of-mind achievement within human development,” (Wellman et al., 2011, p. 324). Specifically, the authors found in 3- to 5-year-olds that certain temperament traits – a lack of aggression, shy-withdrawn personality type, and social-perceptual sensitivity – correlated significantly with theory of mind achievement two years later (see also Lane et al., 2013). Moreover, other behavioral evidence suggests that basic temperamental traits and motivations constrain and guide the human phenotype from remarkably early in life (Reddy, 2003; Over, 2015; Jensen et al., 2014). This, too, is suggestive of deep phylogenetic roots for basic human motivations when in the context of others (Over, 2015; Hare and Wrangham, 2017). When sensory evidence inconsistent with these evolutionarily-deep, high level priors is not experienced, we should expect to see robust (precise) forms of allostatic control (see also section 3.3). An example here is the increased fidelity in the copying behavior of children in response to experiencing ostracism (Over and Carpenter, 2008). Children appear to selectively enhance the precision afforded to conspecific-produced sensory data in response to ostracizing cues so as to re-align or re-attune their dynamics with the other (Over, 2015). Moreover, other forms of social sensory disattunement, such as that suggested by Badcock et al. (2017), likely drive allostatic behavior. In this instance, Badcock et al. (2017) suggest that the increased sensory precision attributed to conspecific-produced sense data characteristic of individuals with depression is a response to a perceived inability to adaptively leverage prior

predictions in social contexts (see also Carhart-Harris et al., 2014). Since attributing high precision to external states requires the attenuation of internal state precision (Brown et al., 2013; Yildiz et al., 2013), depressed individuals forego action. This suggests that depression is a maladaptive manifestation of the (typically) adaptive gathering of sensory evidence to alter one's model with respect to sensory data produced by conspecifics (Badcock et al., 2017).

The temperamental evolution discussed above has been suggested (Tomasello, 2014b; Tomasello et al., 2012) to provide something of a cooperative base for subsequent selection favoring the unique social 'skills' characteristic of *Homo* (e.g., Herrmann et al., 2007). To this end, several authors have proposed (e.g., Skyrms, 2001; McLoone and Smead, 2014; Tomasello et al., 2012) that the game theoretic Stag Hunt is useful for modeling and empirically examining selection pressures subsequent to those discussed above (i.e., Hare and Tomasello, 2005). The Stag Hunt is a game theoretic scenario characterized by two evolutionarily stable payoff structures, namely, cooperation or defection (Skyrms, 2001). Two individuals have the choice of individually defecting to pursue a low payoff, low risk, 'hare' or cooperating to capture a high payoff, high risk 'stag.' Crucially, the stag can only be captured with the other, and the other's mental (motivational) state is unknown. Moreover, if both commit to hunting stag, but one individual defects during the hunt, then it is certain that neither receives the stag nor the hare (Skyrms, 2001). Obtaining the high-risk, high-reward stag is consequently a problem of effectively managing ambiguity in the goals and intentions underlying the other's actions so as to successfully coordinate with them (Tomasello, 2014b). It is suggested by Tomasello (2014b) and Tomasello et al. (2012) that humans have evolved unique skills (underlain by the motivation to employ those skills cooperatively) to solve this problem (see Duguid et al., 2014). Specifically, these authors suggest that humans cooperatively communicate to jointly 'mesh' or coordinate – "to some hierarchical depth" (Tomasello et al., 2005, p. 680) – individuals' respective intentions and goals outlined in the introduction [8] (see also Pezzulo, 2011). Below is discussed evidence suggesting the dynamics characteristic of individuals during stag hunt scenarios (e.g., Duguid et al., 2014) are predicted (and computationally modeled) by Variational Sociogenesis.

Due to reciprocal (cooperative) coupling with conspecifics throughout ontogeny (Moll and Tomasello, 2008), Variational Sociogenesis suggests that certain embodied aspects of the generative of conspecifics (and oneself) should be selected for in evolution to minimize one's own (and others') free energy. Interestingly, Tomasello et al. (2007b) have offered the 'cooperative eye hypothesis' (see also Grossmann, 2017). The authors propose that the uniquely human, large white sclera surrounding the eye's iris was favored in evolution, likely to facilitate gaze following and intention inference in early (and later) *Homo*. Moreover, in addition to selection on morphological characteristics of the generative model, numerous authors have posited model selection favoring various cognitive biases and stances for the social world (e.g., Csibra and Gergely, 2011; Richerson and Boyd, 2005; Sperber et al., 2010; see Tomasello et al., 2012). There is no obvious reason to suggest that other such priors could not be captured by the present framework (see Dindo et al., 2014, for one interesting example), though space limits consideration of them here. It is worthwhile to note that Variational Sociogenesis suggests that at least certain proposals (e.g., Haun and Over, 2013; Marno et al., 2016) may be better considered by placing larger emphasis on the circular interaction of dynamics at nested scales (see below).

In sum, Variational Sociogenesis proposes that model selection in *Homo* favored (and favors) models that characteristically encoded precise expectations of sensory data phenotypically produced by conspecifics [9]. Put another way, selection pressures favoring models characteristically effective at minimizing free energy, in the present setting, entails selection for models (characteristically effective at encoding) dynamics that minimize sensory uncertainty with respect to conspecifics. Thus, evidence-gathering cycles of active inference directed towards conspecifics (i.e., entering into and maintaining shared representational frames) tends to be highly salient (motivating) for humans. It is suggested here that this just *is* what cooperative communication is, namely, intentionally produced cycles of active evidence-gathering with respect to conspecifics (see also Tomasello 2008; 2014b). Indeed: this, regardless of the type (prelinguistic or linguistic), degree of surface complexity (e.g., pointing or syntax), or physical form (e.g., spoken or written) that communication takes (Clark, 2006; Fusaroli et al., 2014). Cooperative communication is a (contextually) salient action that is *intended to attune* – increase the mutual information of – the internal states of interactants, hence minimizing their (individual and shared) free energies (Friston and Frith, 2015a,b; Pezzulo et al., 2013). A consequence of this is a feedforward process such that entering into and maintaining subsequent joint frames becomes an increasingly precise affordance, that is, becomes increasingly soliciting since mutually known prior predictions (common ground) can be leveraged to make likely predictable sensory exchanges [10]. Moreover, Variational Sociogenesis suggests that uniquely human forms of cooperative communication and collaboration emerge alongside precise expectations for engaging in shared intentionality (Tomasello, 2014b; see below). This is because – just as individuals attune to the generative model underlying the nonsocial world by acting in it (Friston et al., 2015b; 2017b) – individuals attune to the generative model(s) underlying the social world by acting with it (Friston and Frith, 2015a,b; Moll and Tomasello, 2008). These considerations at the scale of function enable a principled account of the phenotypical dynamics of humans at the nested scales below.

3.2 Phylogeny

In this subsection evidence is presented suggesting that the complex dynamics characteristic of human communicative systems *per se* (Beckner et al., 2009) optimize a variational free energy bound over sensory evidence. Specifically, since one definition of free energy is complexity minus accuracy (Friston, 2010), evidence is presented that communicative systems (i) tend to minimize their complexity with respect to accuracy. Then, evidence is presented that (ii) communicative systems appear to maximize their accuracy with respect to complexity. Finally, these dynamics are (iii) concretely illustrated with an example. In this subsection, the blanket term ‘communicative system’ or some obvious derivative is used in place of ‘language,’ ‘linguistic’ and so on to stress adaptive dynamics in the cultural evolution of human communication. With this in mind, we associate the complexity of a communicative system with its informational (Kolmogorov) complexity (cf. Seoane and Solé, 2018). Formally, this allows us to formulate a solution to the Kolmogorov forward (Fokker-Planck) equation, hence furnishing a free energy minimizing ergodic distribution over sense data (Friston, 2012a; 2013a). This means that as a communicative system grows in internal interconnectivity between nodes – that is, as either (i) more speakers are added to a communicative system (Lupyan and Dale, 2010; Fay and Ellison, 2013); or as (ii) a static population increases in internal connectivity (Reali et al., 2018) – dynamics such as chaos (Sanders et al., 2018), critical slowing (Gandhi et al., 1998), and

parameter reduction (Riley et al., 2011) should nonlinearly manifest (Shuai and Gong, 2014). Heuristically, an ergodic distribution over the sensory states of a communicative system *per se* suggests an intergenerational ‘decoupling’ of the high level dynamics of communicative systems from the low level (fast) dynamics that constitute them (see Shuai and Gong, 2014). Intuitively, complexity minimization tends to increase communicative systems’ learnability (Kirby et al., 2015), consequently facilitating their intergenerational transmission.

‘Iterated learning’ studies suggest communicative systems minimize their complexity. Iterated learning is the learning of information from another, who in turn learned that information from another, and so on (Scott-Phillips and Kirby, 2010). This is often investigated within the context of ‘transmission’ or ‘diffusion chain’ paradigms (reviewed in Tamariz and Kirby, 2016; Kirby et al., 2014), which seek to experimentally approximate the ratcheted phenomena characteristic of the scale of human cultural evolution (Tennie et al., 2009). Individuals are placed within ‘transmission chains’ where information – e.g., how to use a tool (Flynn and Whiten, 2008) or some piece of communication (Tamariz and Kirby, 2016) – is initially provided to one end of the chain. The information is communicated from one link to the next and the evolution of the variable is examined across the chain. For example, Smith and Wonnacott (2010) leverage this paradigm to provide evidence that intergenerational transmission of communication tends the system towards a minimization of its complexity. Specifically, the authors provided an initial subject with communicative data containing two randomly placed (nominalized) plural markers. Each individual marker thus possessed maximal complexity in its distribution across nominal forms, i.e., the two plural markers were equally likely to attach to a given noun. It was found that only in chains of learners – and not when presented to an individual learner – did each plural marker minimize its distributional complexity (by becoming grammaticalized to specific nominal forms). This highlights the intergenerational (nonlinear) amplification of individuals’ (weak) inductive biases typical of diffusion chains (Reali and Griffiths, 2009; Tamariz et al., 2014). Moreover, concluded by the authors was that their findings provided evidence of complexity minimization in a communicative system. However, the authors did not investigate accuracy (defined below) and, indeed, did not situate transmission episodes within a joint task. This latter point is important: degenerate communicative systems possessing low complexity but low accuracy have been shown to evolve in the laboratory in the absence of transmission situated within some joint task (e.g., Kirby et al., 2008). Thus, Kirby et al. (2015) provide computational and experimental evidence that – by implementing transmission within a joint task (cf. by modulating the motivation for transmitting information; Tomasello et al., 2005) – communicative systems optimize both their learnability (complexity) as well as their expressivity (accuracy). The above findings, as well as much other work, are reviewed in Tamariz and Kirby (2016) and Kirby et al. (2014). Both reviews suggest that macroscopic organization in human communication systems can be understood as a ratcheted, dynamic product of relatively weak (complexity minimizing; Friston, 2010) biases in individual learners. Though space limits me from further considerations, these results are in line with the suggestions of Variational Sociogenesis.

The active state dynamics characteristic of human communication is tightly bound with the set of communicative constructions encoded by those systems (Goldberg, 2003; Tomasello, 2003). Since constructions form the most basic aspect of the (cultural) common ground of interlocutors (Searle, 1995), in the remainder of the present thesis ‘cultural common ground’ is heuristically

associated with the set of constructions embodied in a cooperative communication system (cf. Tomasello, 2014b). Cultural common ground is thus the set of affordance gradients the ‘high level’ communicative system affords for ‘low level’ individuals attuned to its dynamics and is hence a third-order prior unique to *Homo* (Constant et al, 2018). Specifically, (the active state dynamics producing) constructions are just affordance gradients whose precision varies by context and at nested spatiotemporal scales. Cultural common ground just is the dynamical action-driving expectations of a (culturally shared) sensorium (Veissière, 2017; Ramstead et al., 2016). These considerations furnish the suggestion that human communicative systems should tend towards a maximization of their communicative accuracy at the spatiotemporal scale of cultural evolution. Specifically, accuracy maximization suggests an increase in a communicative system’s expressivity (Tamariz and Kirby, 2016), that is, the likelihood that it enables attuned low level systems (speakers) to comprehensibly talk about the things in their world. Clearly, one could have an arbitrarily accurate communicative system, but this would likely decrease the learnability of the communicative system owing to a lack of underlying statistical regularities structuring the sensory input (Kirby et al., 2015). Thus, Variational Sociogenesis suggests that accuracy is maximized with respect to complexity (Friston, 2010).

Evidence suggests that communicative systems maximize their accuracy (with respect to complexity). Since arbitrariness greatly increases the design space of a communicative system (Hockett, 1960; Seoane and Solé, 2018), the expressivity of a communicative system can be increased through encoding arbitrary constructions (Dingemanse et al., 2015). Variational Sociogenesis thus suggests an increase in the arbitrariness of the dynamics of communicative systems. Indeed, other authors have already posited a communicative “drift to the arbitrary” (Tomasello, 2008, p. 219) in the set of constructions comprising human communicative systems. Specifically, it has been suggested by several authors that communication in humans began with cooperatively-motivated pointing gestures (Corballis, 2017; Tomasello, 2008; Fay et al., 2013; Tomasello et al., 2012). Pointing as the primary means of cooperatively communicating with others may have been facilitated by iconic gestures such as pantomime and other iconic gesturing (Tomasello, 2008; Perniss and Vigliocco, 2014) that appeared simultaneously, or very nearly so, with the pointing gesture (see Bohn et al., 2016). In line with Variational Sociogenesis, the subsequent trajectory of communication in *Homo* is suggested by theory, computation, and experiment to have traced a path from iconic constructions through to – in many (perhaps most) instances – fully arbitrary conventions (reviewed in Tomasello, 2008; 2014b; Tamariz and Kirby, 2016; Perniss and Vigliocco, 2014; Dingemanse et al., 2015). Immediately, however, two important nuances should be stressed given this very general trajectory. Firstly, the exact degree of arbitrariness varies within and across communicative systems as a function of several factors (see Dingemanse et al., 2015). Thus, arbitrariness, iconicity, and systematicity (regularities within a given communicative system) likely co-exist with one another within, e.g., the vocabulary structure of a communicative system (Dingemanse et al., 2015). Variational Sociogenesis suggests that the dynamics of even relatively fine-grained phenomena such as word structure exist in virtue of their optimizing the likelihood of reciprocal attunement between low and high level dynamics (recall Clark’s, 2013, definition above). This means that word structure is dynamically optimized across phylogeny to optimize its use by adults and its uptake by children (Tamariz and Kirby, 2016; Dingemanse et al., 2015). Secondly, as discussed above it appears integral to the cultural evolution of (shared) accuracy in communicative systems that communication be situated within some shared problem-solving situation (e.g., a Stag Hunt;

Santos et al., 2011). Indeed, Variational Sociogenesis suggests just this, as individuals' communicative (active state) dynamics are modulated by (contextualized) affordance gradients (Friston et al., 2015b; 2017b).

The above review motivates a novel take on what is perhaps one of the most noteworthy features of human communicative systems: recursive or hierarchical structure (Everaert et al., 2015). Though the variational formalism itself already implies pervasive hierarchy in biological systems (Ramstead et al., 2017), we can synthesize independent (corroboratory) results with the suggestions of the variational approach to strengthen the present proposal. Specifically, it is noted that free energy minimization maximizes the thermodynamic work of biological systems (Sengupta et al., 2013; 2016). We thus link Variational Sociogenesis with the insights of Bejan and Lorente (2011), who show that hierarchical structure in flow (i.e., biotic or abiotic) systems is the thermodynamically most efficient means to access the energetic currents that feed their growth (cf. Ramstead et al., 2017; 2018). A maximization of the work of biological systems – manifest in their hierarchical growth – thus suggests a minimization of their free energy [11]. Group scale phenomena such as hierarchically structured constructions synergistically self-organize via repeated (fast) informational couplings occurring at the ontogenetic scale (Beckner et al., 2009; Riley et al., 2011). Cumulative growth in the constructions comprising communicative systems likely facilitated (and was facilitated by) collaborative joint actions in ontogeny (Tomasello, 2014b; see also Angus and Newton, 2015). This is because cooperative communicative systems both imply and enable precise (niche constructed and biologically selected) expectations for sharing mental states (Ramstead et al., 2016; Constant et al., 2018). Indeed, this circularity is the main crux of Variational Sociogenesis (Sengupta and Friston, 2017): expectations of sharing generative models with conspecifics entail (expectations for) the cooperative communication that brings about (sensory evidence for) sharing in the first place (see section 3.3). Because sharing is a contextualizing full prior for *Homo* (see above), successful joint actions increase the precision of the posterior expectation over sensory data consistent with sharing. This, in turn, drives salience mappings (i.e., the precision of affordance gradients) in subsequent contexts affording sharing with conspecifics, which, in turn, drives the free energy minimizing dynamics characterizing communicative systems *per se* discussed above. Circularly, this is because intentional communication is the means by which individuals gather sensory evidence for a shared generative model (Clark, 1996; Tomasello, 2014b). A cultural evolutionary dynamics is suggested by this, namely, that successive generations of *Homo* (or links in a transmission chain) may be characterized by step-wise (nonlinear) increases in attunement at the local scale owing to increasingly sophisticated (communicative) dynamics at the scale above (Angus and Newton, 2015; Shuai and Gong, 2014).

The above considerations suggest two things. Specifically, Variational Sociogenesis suggests both idiosyncrasies and similarities across cultural Markov blankets. That is, there exists the distinct possibility of global free energy minima – attractor dynamics characteristic of all cultural Markov blankets such as, e.g., some manifestation of hierarchical structure (Corominas-Murtra et al., 2013). We can usefully characterize this dynamics as full priors over the sensory dynamics of communicative systems (see Griffiths and Kalish, 2005; 2007). Nested within this dynamics is, nonetheless, an exceptionally large (but bounded) design space within which fast dynamics may (idiosyncratically) evolve (Seoane and Solé, 2018). For instance, Perfors and Navarro (2014) leverage an iterated learning approach to experimentally demonstrate that the

contextually situated nature of human communication impacts the meanings encoded by a communicative system. Clearly, semantic change is implicated in the intergenerational increase in the accuracy of communicative systems highlighted above (Tamariz and Kirby, 2016). Hence, cultural common ground – in the present setting, phenomena such as, e.g., a group’s concepts and categories (Gelman and Roberts, 2017) and the semantic shifts operating on those categories (Perc, 2012; see Youn et al., 2016) – may thus reflect (relatively) fast idiosyncratic dynamics operating within a (relatively) slow global regime characterized by a tendency towards hierarchical organization. This suggests the possibility of an intrascale spatiotemporal partitioning in the cultural evolutionary dynamics of human communicative systems *per se*. For instance, a graded distinction in the spatiotemporal scale characteristic of semantic shifts (Perc, 2012) and that characteristic of hierarchical growth (Tomasello, 2008). Indeed, such an intrascale decomposition is reminiscent of the deep (neural) dynamics of an individual (see above). Indeed, this may be just to say that the (spatiotemporally deep) dynamics characteristic of communicative systems maximize their mutual information with the (spatiotemporally deep) brains from which they find their origins (cf. Christiansen and Chater, 2008). In this way, cultural Markov blankets come to be characterized by their own (boundedly) idiosyncratic (cultural) attractor dynamics while nonetheless remaining learnable and usable at the spatiotemporal scales of ontogeny and mechanism (see below).

In summary, these considerations are in line with Variational Sociogenesis: human communicative systems *per se* appear to minimize their free energy. Their evolution depends on being transmitted within joint, situated settings at the local scale. Induced by this is a deep, inherently circular causality in the characteristic dynamics of human communicative systems, and human culture more generally (Han and Ma, 2015; Falk and Bassett, 2017). These systems manifest as a novel unit of selectable organism characterized by its own cultural attractor (Markov blanket) dynamics (Szathmáry, 2015; Ramstead et al., 2017). This blanket constitutes the contextualizing cultural common ground shared (constituted) by interactants (Tomasello, 2014b; Searle, 1995). Hence, the cultural blanket is (reciprocally) attuned to throughout ontogeny (Beckner et al., 2009; Kidd et al., 2017). *In virtue of this*, the blanket constrains (shapes) interaction with others (predicted to be) attuned to that same blanket. In this way, attunement to the cultural attractor tends to minimize the free energy of individuals attuned to those dynamics. Though global optima such as, e.g., hierarchical structure (Corominas-Murtra et al., 2013) likely exist, the design space within which fine-grained dynamics at this scale of analysis may evolve is nonetheless staggering in scope (Seoane and Solé, 2018). This allows for the evolution of (bounded) idiosyncrasies in the, e.g., the semantics encoded in communicative systems (Perfors and Navarro, 2014; Youn et al., 2016). Finally, given that I’ve focused on information dynamics in the cultural niche, the considerations in this subsection may have wider generality. Indeed, the dynamics of the cultural Markov blanket formalizes – at least in principle – phenomena not presently considered explicitly, such as the norms and rationality of a culture (see also Veissière, 2017; Ramstead et al., 2016). This claim of wider generality to cultural dynamics can be empirically examined through studies in ‘cliodynamics’ (Turchin, 2008). This is an emerging field which proposes to quantitatively study complex cultural (historical) phenomena and seeks to supplement existing work in the cultural evolutionary accounts of historical data (e.g., van Schaik and Carel, 2016). Studies in this field have already indicated similar bifurcating (hierarchical growth) dynamics to those suggested above, as in the evolution of the properties of popular music genres across decades (Mauch et al., 2015). Moreover, related

work has indicated interesting coupled culture-subculture dynamics (Bunce and McElreath, 2018), a fundamental aspect of the variational approach (Friston, 2013a; Sengupta and Friston, 2017). Indeed, Variational Sociogenesis may be particularly useful in studying these phenomena, as the framework provides an integrative account with dynamics at other scales of analysis (see also Hari et al., 2016).

3.3. Ontogeny and mechanism

This section casts the ontogenetic and mechanistic scales of cooperative communication and collaboration as (individual) active inference recursively situated within a (joint) coupled dynamical systems framework (cf. Tomasello, 2014b; Tomasello et al., 2005). This framework allows for productive consideration of the developmental trajectory of communicatively (informationally) co-regulated couplings (Renzi et al., 2017). Co-regulated couplings (joint interactions) “self-organiz[e]...in such a way that [individuals] temporarily lose their “individual” identities, thereby forming cooperative units, or coordinative structures, that have unique properties that transcend the individual components [e.g., Riley et al., 2011],” (Fogel and Garvey, 2007, p. 252). In joint frames, individuals attune to each other through cooperative communication (Grice, 1975; Tomasello, 2014b; Tylén et al., 2010). Attunement, formally defined by the mutual information between two interactants (see above), is a statistical notion. Hence, ‘jointness’ here is not an ‘all-or-nothing’ phenomenon, but is, rather, a graded ‘more-or-less’ (Pacherie, 2012; Bolt and Loehr, 2017). Through cooperative communication, individuals transiently lose their individuality to some degree, formally defined in such contexts by the mutual information characterizing the two individuals during a joint exchange (Hasson and Frith, 2016; Friston and Frith, 2015a,b). The key effect of interactive attunement is a greatly facilitated capacity for joint action (Tomasello, 2014b; Vesper et al., 2010), as individuals have jointly attuned their generative models of sensory data (Pezzulo, 2011), that is, their predictive models of cultural affordances (Ramstead et al., 2016; e.g., Bach et al., 2014; Maranesi et al., 2014). Indeed, human cooperative communication is phenotypically defined by its ability to engender this higher level of organization (Tomasello, 2014b; Szathmáry, 2015). Model averaging across diverse joint frames in ontogeny (Moll and Tomasello, 2008) Bayes-optimally attunes individuals to their cultural embedding (Moran et al., 2014; Karmali et al., 2018). In the present context, model averaging entails individuals’ attunement to the Markov blanket characterizing their communication system (Kidd et al., 2017). It is interesting to consider this as a developmental trajectory through a ‘semantic continuum’ (Gardenförs, 2014) that leads individuals to embody increasingly adept constructions and pragmatic co-regulatory skills for attuning states some way down the hierarchy. The dynamical ‘end point’ of this continuum is attunement to one’s wider communicatory (linguistic) embedding (Kidd et al., 2017), which allows for the skilled creation and maintenance of transient, task-dependent (free energy-minimizing) collaborative couplings with the entirety of one’s cultural group (Tomasello, 2014b). With the above in place, I first more concisely outline the underlying variational (neuro)computational dynamics by discussing Variational Sociogenesis in relation to recent computational modeling of development (Tenenbaum et al., 2011; Perfors et al., 2011a). This allows me to situate the following with some form of (computationally-tractable, experimentally-testable) common ground. Then, I sketch out an (admittedly) rough developmental trajectory, using existing developmental research to make my case chronologically across the lifespan.

As noted above, attention adaptively serves biotic self-organization by enhancing the precision of sensory data (Feldman and Friston, 2010; Sengupta et al., 2016). Gain enhancement enables sense data to ascend cortical hierarchies to impact on high-level neurodynamics that inform sensory predictions at lower layers of the hierarchy (e.g., Kanai et al., 2016). Since precision is the (inverse) variance of the causes underlying sensory data (Feldman and Friston, 2010), we can link up the variational formalism – and, in particular, precision (see Friston, 2009) – with work in mainstream developmental science employing the same (hierarchical Bayesian) computational architecture. Perfors et al. (2011a) and Tenenbaum et al. (2011) review the potential utility for such models to computationally replicate empirical observations of a diverse array of social and nonsocial phenomena in ontogeny, in particular the early learning of abstract syntactic and semantic knowledge (e.g., Bannard et al., 2009; Perfors et al., 2011b; Thaker et al., 2017; see appendix A.2 in Perfors et al., 2011a). Moreover, work in the variational approach has shown promise for related models in replicating human performance in online recognition of speech input (Kiebel et al., 2008; 2009; Yildiz et al., 2013), as well as reading comprehension (Friston et al., 2017a) and conversational alignment (Friston and Frith, 2015a,b). In describing their work, Tenenbaum, Perfors, and colleagues note what they term the ‘blessing of abstraction’ (see Gershman, 2017), namely, the ability for hierarchical Bayesian (generative) models to, in some instances, learn high level (abstract) features of sensory data faster than low level (concrete) features. This is suggested to be due to (i) relatively larger sample spaces for abstract hypotheses enabling a wider array of low-level data to be relevant for creating these (abstract) hypotheses; and (ii) relatively fewer hypotheses as one ascends levels (hence abstraction; see Perfors et al., 2011a). An important neurocomputational observation here is that all backwards connections providing top-down predictions are complemented by bottom-up sensory error signals in the brain (Bastos et al., 2012) whose strength is modulated by attention (Feldman and Friston, 2010). This keeps predictions anchored to sensory data and accommodates (modulates) diverse forms of top-down and bottom-up learning [12] (Friston, 2010; Clark, 2013). These considerations allow us to supplement the considerations of existing developmental work by Tenenbaum, Perfors, and colleagues, as well as related proposals for hierarchical predictive processing approaches to development (e.g., Fabry, 2017; Joiner et al., 2017). Specifically, Variational Sociogenesis complements these accounts by suggesting a principled, neurobiologically-plausible active inference (cf. dynamical systems; Smith and Thelen, 2003) framework for considering how human infants and children (and adults) *act* to optimize their (attention to) sensory input to optimize learning of cultural affordances (Byrge et al., 2014; Pezzulo et al., 2015b). Importantly, I use ‘optimize’ here with technical reference to boundedly rational decision making schemes (Gershman et al., 2015), where actors leverage embodied computational mechanisms that are bounded by maturity and thermodynamic constraints to do (Bayes-optimal) inference on sensory data (see Sengupta et al., 2013). Indeed, that (boundedly rational) Bayes-optimal inference appears to be performed by biological systems is a corollary of the variational approach (Friston, 2013a). Hence, infants and children, just as adults, are engaging in (boundedly) optimal action-perception cycles given their (developing) embodied generative architecture (Chiel and Beer, 1997).

Variational Sociogenesis thus suggests a principled and “amazing set of necessary cognitive skills – namely, the statistical learning of concrete and abstract auditory [cf. sensorimotor] patterns – that are ready to be put to use in constructing the grammatical dimensions of language” (Tomasello, 2003, p. 30). While there is debate (Reddy, 2003; Mundy and Newell,

2007), the best behavioral evidence currently available suggests that the expectation for sharing emerges in all cultures around nine to twelve months of age with the onset of the cooperative pointing gesture [13] (Lieven and Stoll, 2013; Tomasello et al., 2007a; Matthews et al., 2012). One key example of sensory evidence consistent with sharing is infants' own production, and noticing of adults', so-called 'look-backs' between the item of interest and their interactant (Tomasello et al., 2007a; cf. nonhuman great apes; Carpenter and Call, 2013). Variational Sociogenesis suggests that when sensory evidence inconsistent with this prediction is experienced, infants should engage allostatic feedback loops and exhibit subsequent learning when error signals continue despite allostatic control (cf. section 3.1). Interestingly, Liszkowski et al. (2004) found that, with trials, 12-month-old infants pointed more often for uncooperative adults who didn't provide look-backs. Moreover, infants in this study pointed less on successive trials when repeatedly interacting with an uncooperative adult. When adults cooperated by providing look-backs, however, Liszkowski et al. (2004) found that these had to be accompanied by (attuned) emotive sharing between the infant and adult for the infant to appear satisfied, suggesting another important piece of sensory data which infants may use to gauge the sharedness of an interaction (see also Reddy, 2003). These results suggest that infants were attempting to quickly 'error correct' via a fast increase in pointing behavior when experiencing sensory data inconsistent with their top-down prediction for sharing. Infants then learned across trials which adults (don't) embody precise gradients for eliciting sensory evidence consistent with sharing, hence resulting in minimized action directed towards those adults. This suggests the presence of nested attunement dynamics operating at two spatiotemporal scales (perceptual inference and learning) that mutually influence the other (Ramstead et al., 2017), something which future developmental work employing complementary methods (e.g., Siegler and Crowley, 1991) may look to explore in greater depth. Moreover, other sensory data likely play (age- and context-dependent) roles in individuals' phenomenal identification of sharing, for instance, the presence of various ostensive cues demonstrating communicative intent (Tomasello et al., 2007a), such as eye contact or infant-directed speech (Csibra, 2010); and spatiotemporally contingent dynamics (Levinson, 2016). Contingency (turn-taking) is an ontogenetically early emerging (Gratier et al., 2015) feature of bidirectionally coupled dynamical systems (Friston and Frith, 2015a,b) that appears to have old phylogenetic roots (Levinson, 2016). Butko and Movellan (2010) recently demonstrated that – by using precise information *per se* as the value signal (i.e., infomax control) – they could computationally replicate 10k-month-old infants' empirically-observed behavior during interaction with a contingently-acting robot (Movellan and Watson, 1987). Indeed, using similar infomax computational simulations of coupled dynamics, Friston and Frith (2015a,b) suggest that contingent behavior may just be an (optimal) novel phenomenon that emerges when informationally-coupled generative models are motivated (i.e., expect to) maximize their information with respect to one another.

It is pertinent to note that precision is related, *but by no means equal*, to familiarity (Friston et al., 2012c; Schwartenbeck et al., 2013). Hence, relatively imprecise sensory data that diminish shared sensory expectations (and hence shared action) are quite diverse in nature: they can be familiar or unfamiliar, e.g., languages or accents (reviewed in Cohen, 2012); incorrect adult informants (Harris and Corriveau, 2011; Harris et al., 2017); or different shirt colors (Dunham et al., 2011; McClung et al., 2017; see also footnote ten). On the other hand, overly familiar sensory data can be dispreferred as well (Friston et al., 2012c), perhaps especially in early development (Kidd et al., 2012). This is because individuals (including infants) preferably dissipate affordance

gradients that are ‘just right’ in their (model-relative) complexity [14] (Friston et al., 2017c), leading to context-sensitive attunement to niche dynamics across ontogeny [15] (e.g., Frankenhuys et al., 2016). Since Variational Sociogenesis predicts an *a priori* high precision for sensory evidence consistent with sharing, phenotypical shared frames beginning around 9-12 months should be associated with enhanced learning throughout the lifespan (Hasson et al., 2012). Importantly, however, joint contexts may be particularly important at certain stages of human life history (see Gopnik et al., 2017), particularly in early development (Tomasello et al., 2005). Indeed, Moll et al. (2007) found that engaging in joint interaction appears necessary for 14-month-old infants to perceive some referent as within common ground (see also Moll and Meltzoff, 2011). Specifically, the authors found that shared interactions with an adult directed towards a set of toys – and not simply third-person observation of the adult with the toys – was necessary for 14-month-old infants to disambiguate the adult’s request for a specific toy. Variational Sociogenesis suggests that this is due to the high precision of (gain-enhanced) sensory data in such contexts. Moreover, since (expected) precision drives salience mappings and hence action, infant pointing should be associated with enhanced learning of, e.g., the label of an intended referent. Evidence for this comes from Begus et al. (2014), who found that 16-month-old infants exhibit enhanced learning (fast mapping) of the labels provided by their caregivers to the objects they pointed to. Similarly, Lucca and Wilbourn (2016) found that 18-month-olds (but, interestingly, not 12-month-olds) fast-mapped the labels provided by caregivers specifically when caregivers labeled the intended (expected, precise, shared) referent. Infants no longer fast-mapped when adults labeled an incorrect, unintended object. For their part, caregivers in at least one culture preferably provide labels to the (intended) referent of infant points over verbalizations (Wu and Gros-Louis, 2015). These findings suggest the importance of triadic joint attention to the other and an outside entity for learning cultural affordances (common ground) such as form-meaning pairings (Tomasello, 2003; Vouloumanos and Curtin, 2014; Renzi et al., 2017). The necessity of jointly coupled dynamics for learning may, nonetheless, alter with age (see Moll et al., 2007; Gopnik et al., 2017). This likely enables the learning of (shared) affordances on a more individualistic (observational) basis later in ontogeny (Joiner et al., 2017).

Though the limited repertoire of means for young infants to actively co-regulate interactants (Carpenter, 2009) is clearly present in, e.g., Liszkowski et al. (2004), we can illustrate co-regulatory dynamics more clearly by considering its ontogenetic trajectory. Brownell (2011) highlights that joint action is characterized by a movement from primarily asymmetric, adult-guided exchanges early in the second year; to more symmetrically co-regulated exchanges with adults typically around late in the second year (possibly enabling children’s interaction with peers early in the third year; Tomasello and Hamann, 2012). For instance, Aureli and Presaghi (2010) found that ‘unilateral’ mother-infant dynamics prevailed early in the second year, with mothers actively directing and shaping their infant’s attention and action towards some shared locus during at-home play sessions (see Smith et al., 2018). Over the course of the second year, ‘symmetric’ interactions gradually became the predominant form of joint action, with mother and infant taking a more equal role in shaping each’s action and attention. Moreover, those dyads which spent relatively more time in symmetrical interactions also spent relatively more time communicating linguistically to co-regulate perspectives. These findings are captured by Variational Sociogenesis: the capacity for joint co-regulation is suggested to develop gradually throughout ontogeny as individuals (gradually) attune their generative dynamics to the generative dynamics causing others’ active dynamics. Adults, and in particular mothers (Hrdy,

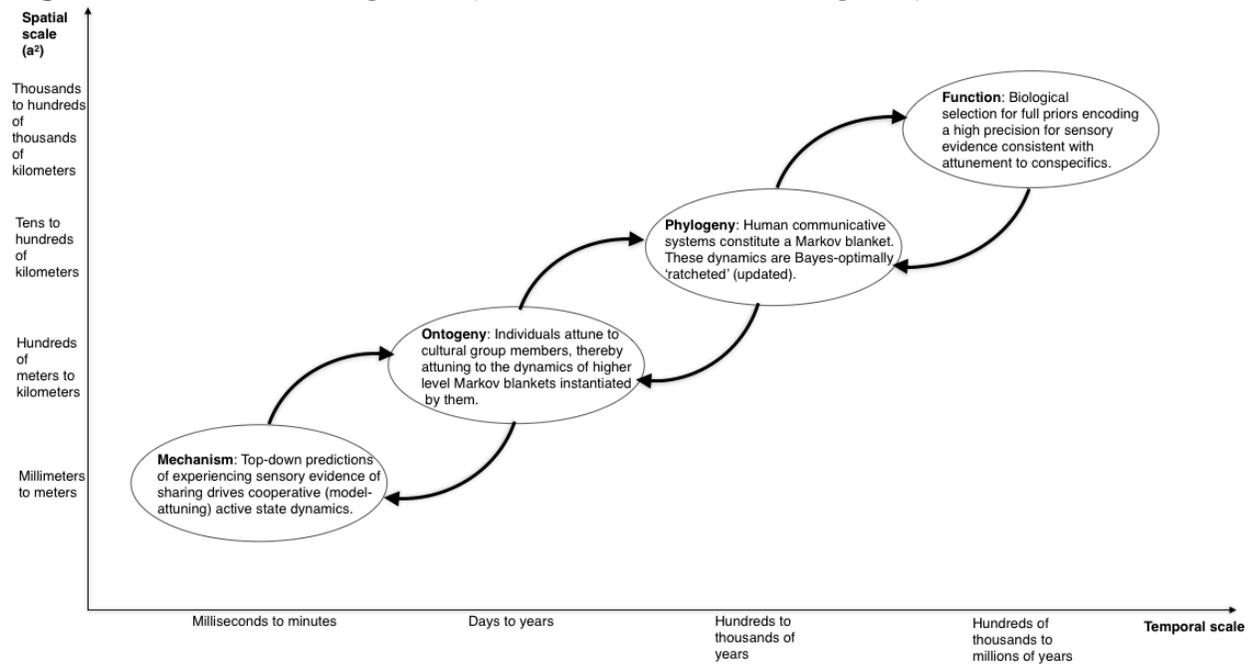
2011; see also Feldman, 2015), actively shape the dynamics of the infant environment – such as through ‘unilateral’ joint engagement (Aurelia and Presaghi, 2010) – such that infants are efficiently ‘pulled in’ to their statistical embedding within and across interactions (Constant et al., 2018). In virtue of this, infants and children gradually embody these dynamics, enabling them to adeptly (jointly) predict the dynamics of their interaction partners with respect to the cultural affordances on offer (Bohn and Köymen, 2017; Rakoczy and Schmidt, 2013). For instance, Ashley and Tomasello (1998; relatedly, see Brownell et al., 2006) found an ontogenetic trend in preschool children’s ability to coordinate with another to solve a joint task. Specifically, preschool dyads’ ability to reverse complementary roles to complete a complex joint task correlated with their usage of pointed linguistic directives to help the other with their role within the task (though the authors note that simple motor development also likely played a role; see Meyer et al., 2010). Variational Sociogenesis suggests that the gradually developing ability to leverage apt, pointed communication enabled children to successfully form and manage shared representations of the joint task (Pezzulo, 2011; Tomasello, 2014b). Attunement to the other enables the skilled deployment of communication to (co-) regulate the dynamics of the other (Pezzulo and Dindo, 2013; Tylén et al., 2010), since one literally embodies a statistical recapitulation of the other. Hence, implicit in the notion of attuned generative dynamics is a (gradually developing) ability for role-reversal (Tomasello et al., 2005) and ‘socially-recursive’ (Tomasello, 2014b) forward modeling of the, e.g., relevance and rationality of one’s communicative message (Pickering and Garrod, 2014).

For instance, Duguid et al. (2014) found that children’s communication within a Stag Hunt scenario tracked the unpredictability of the other during the interaction. In particular, the authors found that children (but not chimpanzees; see also Bullinger, 2011) preferably formed joint couplings with each other regardless of the risk (uncertainty) involved in capturing a stag. In particular, children were found to manage varying amounts of uncertainty by leveraging pointed, specific communication, as well as communicating more in general. While the communicative signals necessary for children to establish a joint coupling in Stag Hunt scenarios may be quite minimal (e.g., merely a smile and eye contact; Wyman et al., 2012), individuals’ communicative dynamics are nonetheless quite flexible. Specifically, a notable feature of human communication is that it can be intentionally modulated as a function of (perceived) uncertainty so as to minimize that uncertainty (Sebanz et al., 2006; Vesper et al., 2010). First, consider Grau-Moya et al. (2013), who leveraged computational and experimental work to demonstrate that human behavior in Stag Hunt scenarios is sensitive to the amount of information (certainty) they have about the motivation of a virtual player. Specifically, the authors found that individuals modified their cooperative behavior (to engage a stag ‘together’) in accord with their model certainty about the generative dynamics (motivation) causing the (predicted) behavior of the virtual partner. Though individuals’ decisions whether or not to jointly pursue a stag with the virtual partner in Grau-Moya et al. (2013) could be computationally replicated as minimizing the variational free energy of the individual, since the interactions involved a virtual partner the authors could not investigate whether individuals’ communicative dynamics could be modeled as minimizing free energy. Thus, in putting forth their ‘joint action optimization framework,’ Pezzulo et al. (2013) show that human communication within joint interactions minimizes the free energy of individuals (and hence dyads). Specifically, the authors showed that the decision to leverage communication – and, if so, at what grain – optimized a tradeoff between minimizing model complexity (cost of action) and maximizing model accuracy (certainty; see related

discussion in Rabinovich et al., 2012). The authors concluded that this attunement dynamics “emerges naturally from the objective of optimizing a joint goal,” (p. 9), and, indeed, Friston and Frith (2015a,b) leverage the variational approach to provide corroboratory results. The authors found that informationally coupling two generative models that are motivated to predict the other appears to entail reciprocal attunement of each’s dynamics. Notably, this dynamics appeared to manifest phenomena reminiscent of interactive alignment in human communication (Menenti et al., 2012). These results are captured by Variational Sociogenesis, which forefronts the centrality of tight attunement (a high mutual information) with conspecifics through cooperative communication. Interestingly, Hasson and Frith (2016) suggest the potentially wide utility of mutual information for quantifying the similarity of interbrain neural dynamics observed during neuroimaging studies of transient informational coupling. For instance, reliable transformations from a speaker’s brain to a listener’s brain (a high mutual information) has been shown to strongly predict the meaningfulness of the speech stream to the listener (Stephens et al., 2010; Liu et al., 2017; see also Schmälzle et al., 2015). Indeed, reliably co-varying inter-brain dynamics during communication scales with the subsequent capacity for listeners to leverage that information to constrain their common ground with the speaker (Zadbood et al., 2017; see also Dikker et al., 2017). These results speak to related empirical (Bolt and Loehr, 2017) and philosophical (Pacherie, 2012) findings suggesting that the phenomenal ‘jointness’ of a given interaction gradually scales with the predictability of the other within the joint setting (cf. Sebanz et al., 2009).

The results reviewed in this subsection speak directly to the key claim of Variational Sociogenesis: the motivation to share manifests in action geared towards maximizing one’s certainty that sensory data consistent with sharing is experienced. Hence, individuals act to minimize their own uncertainty with respect to (the model dynamics underlying) another’s action through communicating (Tomasello, 2014b; Carpenter and Liebal, 2011). This greatly enhances the predictability of the other (Liszkowski, 2013; Vesper et al., 2010), since both individuals possess attuned (joint) generative models of sensory data (Pezzulo, 2011; De Jaegher et al., 2010). Consequently, effective (free energy-minimizing) joint action is greatly facilitated (Tomasello, 2014b). It is crucial to note that attunement to the shared world can *only* begin through diverse, recurring experiences of setting up and managing joint frames (Moll and Tomasello, 2008; Moll and Meltzoff, 2011). This shared base later enables individuals to learn a shared world through more observational forms of learning (Joiner et al., 2017), though learning in shared frames likely continues to be a key form of learning throughout life (Hasson et al., 2012). Individuals embody increasingly attuned generative models to those structuring their cultural group, thus enabling increasingly sophisticated, effective joint co-regulation with the entirety of one’s cultural group (Bohn and Köymen, 2017; Rakoczy and Schmidt, 2013). Conceptually, it is quite tempting to consider this ontogenetic trajectory as constituting a ‘semantic continuum’ (Gardenförs, 2014) that allows for increasingly privileged access to the mental states of interactants (De Jaegher et al., 2010). In any case, gradual attunement to the cultural Markov blanket allows individuals to leverage their own free energy-minimizing, socially-sculpted predictions to, e.g., meet a friend at culturally salient locations when no prior meeting point has been specified (Goldvicht-Bacon and Diesendruck, 2016). Indeed, cultural Markov blankets themselves constitute precise, constructed designer environments – landscapes of affordances – that further aid in prediction of the dynamics of others (Clark, 2016; Constant et al., 2018). This suggests a basic circular causality in the dynamics occurring at an ontogenetic

Figure 2. Variational Sociogenesis (cf. Ramstead et al., 2017, Figure 2).



scale of analysis (Witherington, 2007; Han and Ma, 2015). In particular, is interesting to speculate that reciprocal attunement to the Markov blanket characterizing one's communicative system influences humans' information-processing abilities. To be more specific, in virtue of attuning to the communicative system in early development individuals statistically recapitulate its network structure and dynamics (Falk and Bassett, 2017; e.g., Schmäzle et al., 2017). This has been shown to manifest in statistically significant differences in neural dynamics between cultures (Han, 2015). However, it is possible that these surface differences reflect Bayes-optimal model averaging across interactions in the lifespan (Moran et al., 2014; Karmali et al., 2018). This may influence humans' neural dynamics in universal ways. For instance, coordinating with numerous others' models of the world (Moll and Tomasello, 2008) may influence individuals' development of slightly sub-critical (ordered but flexible) information-processing dynamics (Carhart-Harris et al., 2014).

4.0. Summary and conclusion

This thesis has provisioned a physics for the human phenotype by considering the information dynamics of sharing as manifest in *Homo*. Figure 2 provides a graphical summary of the spatiotemporally nested explanatory framework furnished by Variational Sociogenesis. The dynamics occurring at each respective scale of analysis circularly feeds into, and is fed by, each other level of analysis. At each respective scale, various phenomena (characteristically) manifest to minimize the free energy that each scale. For instance, we've considered how, in ontogeny, individuals reciprocally attune to the Markov blanket constituted by their communicative system. They do this through embodying an increasingly (statistically) average model of their sensory dynamics. Consequently, this makes likely the predictable, free energy-minimizing relations

between self and other (constitutive of a ‘we’) that biological self-organization in the human niche characteristically manifests.

In addition to reviewing much work from a variational viewpoint, throughout this thesis I’ve explicitly noted how future work may look to expand on the present account through computational, experimental, theoretical, and philosophical investigations. Indeed, part of the intrinsic appeal of the variational approach is its (proposed) capacity to provide a unified theoretical framework for computation and experiment (Allen and Friston, 2016; Ramstead et al., 2018). This provides a scientific base which is likely to be bettered through a fruitful exchange with philosophical inquiry. An immediately obvious avenue for philosophical inquiry is the relation between attunement nested (cultural) Markov blankets (Ramstead et al., 2017) and the dual level structure of human thought and action (Tomasello, 2014b). I shall merely suggest that rather stark, clear conceptual parallels between the two exist. An earlier version of the present thesis had included the beginnings of a conceptual analysis of the dual level structure in relation to Variational Sociogenesis, however the empirical review quickly took precedent; the intended scope of the present thesis, I believe, required space for sufficient empirical considerations prior to philosophical reflection. Moreover, philosophical work may look to investigate perhaps more proximal (if no less important) themes in, for instance, political philosophy and, in particular, the nature of propaganda (Chomsky, 1997; Stanley, 2015). Variational Sociogenesis provides a principled means for considering the information dynamics of highly connected hub nodes and their influence on network dynamics (relatedly, see Falk and Bassett, 2017). One last example of potentially fruitful philosophical inquiry can be found in considering whether shared intentionality has in fact evolved several times in the history of life on Earth (Szathmáry, 2015). By this, I mean shared intentionality *per se*, the phenomenon understood to (functionally) manifest in *Homo*. A prior to attune generative models with conspecifics may simply be how novel units of selectable structure are instantiated (e.g., Friston et al., 2015a). Such an analysis may fit well with recent work defending a strong life-mind continuity thesis (Kirchhoff and Froese, 2017; see also Kirchhoff, 2016). These are merely three (semi-)randomly selected examples of what, as noted above, should be a fruitful, mutually-informative (and mutually constraining) exchange between science and philosophy.

Taken together, the present thesis has submitted an admittedly ambitious project which future installments will help to flesh out. I have provided several brief reviews of the empirical (and, particularly in section 1, philosophical) evidence at each scale of analysis, with the intended aim being to show that humans, as biotic systems, minimize their free energy. They do this by actively gathering sensory evidence for sharing. The best empirical evidence currently available (Tomasello et al., 2005) suggests that this active evidence gathering begins around nine to twelve months of age with the onset of the cooperative pointing gesture. This likely is the product of selection on high level dynamics in the generative model instantiating *Homo* (Friston, 2013b; Hare and Tomasello, 2005). Local dynamics in ontogeny self-organize to produce novel phenomena constituting a higher level of Markov blanket organization. Numerous and diverse local interactions at the ontogenetic scale all but ensures (phenotypical) attunement to the cultural attractor dynamics one helps constitute. Indeed, attunement dynamics means that the whole of the spatiotemporally deep hierarchical scaling of human self-organization – as merely but one way in which biology, and, hence, physics and the universe realizes itself – is no more than an (exceptionally) improbable, ephemeral mirroring of the dynamics in which it is situated.

The whole thing, the whole of human self-organization, culture, language, and so on is but a cheap solution settled on by evolution that, at least for the most part and so far, seems to work out well enough. It all begins, Variational Sociogenesis suggests, with the simple expectation to attune dynamics with conspecifics.

Footnotes

[1] “The defining feature of the additive account is the assumption that it is possible to characterize a living individual as engaging in activities that manifest collective intentionality regardless of whether this individual instantiates a collective form of life [i.e., shared intentionality as merely a mechanism]. From this perspective, the question of whether an individual can engage in activities that manifest collective intentionality is considered neutral with respect to the question of what kind of life form this individual instantiates. By contrast, the transformative account takes the main lesson from Wittgenstein’s... *Philosophical Investigations* to be that we have to invoke humans’ collective form of life to adequately understand any given human activity, be it eating or calculating, walking, or talking [i.e., shared intentionality as an evolutionarily novel form of life],” (Kern and Moll, 2017, p. 324).

[2] For the interested reader, in this footnote I briefly outline a rather technical, abstract introduction to the dynamics suggested to implement the hierarchical generative model specified by the variational approach (Friston, 2010). For the unfamiliar but interested reader, useful introductions to the various themes discussed in this footnote can be found in Barton (1994), Boeing (2016), Rabinovich et al. (2015), and Afraimovich et al. (2012). With this in place, the notion of ‘metastability’ has been proposed to be useful for conceptualizing the transient dynamics of large scale neural ensembles (Friston, 1997; Kelso, 2012). Specifically, metastability denotes the transient, task-dependent formation and dissolution (‘soft-assembly’; Clark, 2008), of neuronal ensembles that appears to be a key feature of adaptive neural dynamics (Tognoli and Kelso, 2014). Put another way, metastability denotes the phenomenon of fluid maintenance and switching between various (metastable) states or modes that is key to adaptive brain-behavior dynamics (Kelso et al., 2013) and which appears to be disrupted in various psychopathologies (Carhart-Harris and Friston, 2010; Carhart-Harris et al., 2014). For instance, the activity of the default mode network (DMN) during cognitively demanding tasks (Raichle et al., 2001) involves the transient dissolution of the DMN concomitant to transient, task-dependent network formation in others areas of the brain (Bullmore and Sporns, 2009). This dynamics can be modeled using phase space models where a given metastable mode is exhibited as a temporally transient slowing of dynamics within the locality of an attractor (Rabinovich et al., 2015). Switching between modes can then be modeled as a dynamical transient between attractor regions. Specifically, we can model sequential switching between metastable modes using ‘stable heteroclinic channels’ (SHCs; Rabinovich et al., 2015). SHCs prescribe a sequence of unidirectional transients between attractors along a manifold topology. When neural dynamics are within the locality of a given attractor, the dynamics temporarily tend towards this attractor; and then move (unidirectionally) to the next attractor region in some topological space. Thus, sequential switching between dynamical (metastable) modes corresponds to cyclic transitions between a sequence of metastable states (constituting a limit cycle).

This dynamics is robust to noise but flexible in the face of unexpected sensory data (e.g., Rabinovich et al., 2014), hence making it an attractive candidate for modeling neural dynamics (Rabinovich et al., 2015). In particular, the variational approach suggests a hierarchical ordering of SHCs in the brain (e.g., Kiebel et al., 2008). This is because a spatiotemporal partitioning (abstraction) of the dynamics of SHCs appear to be a necessary phenomenon of feeding information into recurrent neural networks (Hinton, 2007; Perfors et al., 2011a), and, most importantly, there is much neurobiological evidence in favor of hierarchically organized dynamics in the brain (Friston, 2010). As noted in the main text, in spatiotemporally deep

neurodynamics the fast dynamics of a level of the neural hierarchy are prescribed (predicted) by the slow dynamics of the (functional) level above. Heuristically, a high level SHC goes through a single limit cycle in the time it takes for a low level SHC to cycle several times (Kiebel et al., 2008; 2009). For instance, Jensen and Colgin (2007) describe cortical ‘nestings’ of oscillatory dynamics (e.g., gamma rhythms nested within theta rhythms) that may functionally implement a wide range of phenomena, in particular when oscillatory dynamics are synchronized (Fries, 2005; Fell and Axmacher, 2011). Gain enhancement of sensory data expected to be highly precise (Feldman and Friston, 2010) causes ascending prediction error signals update the attractor topology of higher level dynamics. Neuromodulatory neurotransmitters such as dopamine (Friston et al., 2014a) and acetylcholine (Moran et al., 2013) likely variably implement gain enhancement of precise sensory data by adjusting the post-synaptic gain of ascending error signals. This leads to the fluid (metastable) switching of large scale neural ensembles between contextualized modes of behavior that necessarily induces a novel (contextualized) dynamical regime at lower levels of the hierarchy (e.g., Tajima et al., 2017). Further empirical observations that spatiotemporally decomposable neural dynamics can be used to computationally replicate include, e.g., chunking dynamics in working memory (Parr and Friston, 2017; Rabinovich et al., 2014). Indeed, this may lend explanatory power to the underlying neural dynamics of infant working memory, which has recently been demonstrated to be hierarchically organized by as early as 7 months of age (Rosenberg and Feigenson, 2013). Moreover, Kiebel and Friston (2012) note that hierarchically organized SHCs are in fact the least expensive (neurobiologically-plausible) computational implementation of recurrent neural networks, suggesting a neurobiological architecture for implementing (boundedly) optimal Bayesian inference throughout the lifespan (Gershman et al., 2015) and across species (Friston, 2013a; Ramstead et al., 2017).

[3] The third definition is accuracy minus the Kullback-Leibler divergence (Friston, 2010).

[4] I follow Ramstead et al. (2016) who, following Bruineberg and Rietveld (2014), define an ‘affordance’ as “a relation between a feature or aspect of organisms’ material environment [i.e., niche] and an ability availability in their form of life,” (p. 3; cf. Chemero, 2003).

[5] Though I do not discuss this topic further, the interested reader is directed to work on the ‘behavioral traditions’ of other animals (reviewed in Whiten, 2011). As has already been well-rehearsed, the key difference between humans and other species’ cultural proclivities seems to lie more in the ‘ratcheted’ memory of cumulative cultural evolution (Tennie et al., 2009), underlain by species-unique motives for sharing states (Tomasello et al., 2005).

[6] This is, of course, not by any means to imply that one is a slave to one’s (expectations of) the internal states of others. Indeed, issues such as novelty and exploration (Legare and Nielsen, 2015) are understood to be integral to both constraining and altering the manifold space describing a culture’s attractor dynamics. Though this is an issue of fundamental importance and one which lacks any applied research from the variational framework, due to space I leave these issues largely unexplored. The interested reader is encouraged to refer to work in the variational literature, for instance, Friston et al. (2012c; 2015b; 2017b,c) and Schwartenbeck et al. (2013).

[7] This is to say nothing about *why* the emergence of novel units of biological organization on which natural selection operates is so rare (Szathmáry, 2015). This is an interesting question to pursue within variational biology, and I may suggest that this has something to do with the fact that variational free energy is an ‘extensive’ quantity, that is, that free energy is additive in coupled systems (Constant et al., 2018; Friston et al., 2015a).

[8] It is worthwhile to, however, that Tomasello (2014b) highlights that, if necessary, humans can reflect several layers deep into recursive inference on others' mental states (cf., the problem of other minds; see Liebal and Carpenter, 2011). I do not pursue this topic any further in the present thesis, however important it may be.

[9] This gets into the problematic notion of 'innateness.' Just because some trait is adaptive (e.g., Begus et al., 2016; Marno et al., 2016) does not entail that it is selected for over evolutionary or phylogenetic timescales (McLoone and Smead, 2014). If external dynamics are such that there exists a large basin of attraction (i.e., set of initial states) for some phenotypic trait (i.e., attractor), then internal dynamics do not have to be modified as greatly over evolutionary timescales but are may be shaped over ontogenetic timescales to minimize free energy, as external dynamics make it likely that the trait emerges in a range of models encoding diverse full priors. An obvious benefit of this is flexibility in the developmental trajectory of the trait(s) over ontogeny (e.g., Frankenhuys et al., 2016). See McLoone and Smead (2014) and Tomasello et al. (2005) for useful discussion of this within the context of human social uniqueness.

[10] Interestingly, this suggests an *a priori* preference for interacting with others with traits perceived as self-similar, since sensory cues indicating overlapping generative models indicate that one can (reasonably) rely on existing shared predictions (common ground) and hence minimize the communicative effort required to attune representations. Pre-theoretically, such cues to self-similarity could potentially range from the communicatively explicit (e.g., linguistic communication to ensure model alignment; Pickering and Garrod, 2014) to the communicatively implicit (e.g., accent; Kinzler et al., 2007) and could include cultural or idiosyncratic items (e.g., clothing or religion; van Schaik and Carel, 2016; Dunham et al., 2011) or embodied aspects of the self (Richter et al., 2016). Compellingly, this *a priori* suggestion is in line with recent empirical reviews suggesting the centrality of self-similarity in guiding and constraining individual social motivations (Meltzoff, 2007; Jensen et al., 2014) and large-scale cultural evolution (Haun and Over, 2013; Jensen et al., 2014).

[11] The circularity here is duly noted: why do communicative systems minimize their free energy? Because they instantiate hierarchical structure and dynamics (Ramstead et al., 2017). Well, why do they instantiate hierarchical structure and dynamics? Because they minimize free energy. Indeed, such circularity is well-noted within the variational literature and suggests the problem of experimental unprovability for the entire paradigm (Allen and Friston, 2016). Specifically, the variational approach is (apparently) open to the criticism of 'just-so' stories (e.g., Berwick et al., 2013a) – any biological can (apparently) be said to minimize free energy given the starting assumptions of the whole paradigm. To this end, the reader is directed to discussion in, e.g., Bruineberg and Hesp (2017) and Allen and Friston (2016), where this question is pursued more fully. The importance of modeling studies informed by the variational formalism (e.g., Friston et al., 2015a) to complement empirical work is made central in Bruineberg and Hesp (2017). Additionally, the reader is invited to consider the nature of existing explanation in the biological sciences in relation to the variational formalism: the variational approach (proposes to) account for *all* of biological self-organization (Friston, 2012a; 2013a; Ramstead et al., 2017; Constant et al., 2018; Ramstead et al., under review). There is thus no phenomenon studied by the biological sciences that is not (proposed to be) subsumed by the variational formalism that one could point to in order to 'ground' their explanation in some outside phenomenon. (E.g., why is some theoretical point X reasonable to make? Well, unrelated theories say so-and-so, which accords with X. Hence, X appears reasonable. So-and-so phenomena can thus serve as unrelated-but-nonetheless-useful 'groundings' for one's theoretical

pursuit. They are useful insofar as their unrelatedness allows one to relate them to one's theory.) Instead, one can only non-circularly ground the variational formulation – that is, point to something in the world – within (the physics and geometry of) information *per se* (Sengupta et al., 2016). Depending on one's outlook, this is an interesting development.

[12] Variational Sociogenesis thus suggests that (i) at least certain abstract concepts such as syntax or some language module may not have to be 'innate' (e.g., Berwick et al., 2013b). Rather, this may be more helpfully construed as a product of domain-general ontogenetic learning mechanisms (such as gain-enhancement) reciprocally impacted by other scales within a hierarchically nested environment (Ramstead et al., 2017). A weaker, related claim suggests that (ii) humans possess unique expectations of the kind-generalizability of ostensibly-communicated information received specifically from conspecifics (Csibra and Gergely, 2011). The considerations of precision provided by Variational Sociogenesis speak against this and, indeed, counterevidence already exists (Schmidt et al., 2011; Szufnarowska et al., 2014). For instance, regarding (i), it has been shown that the neurocomputational architecture suggested here (Friston, 2010) can, e.g., parse syntactic (Bannard et al., 2009; Perfors et al., 2011b) and semantic (Thaker et al., 2017) categories from sparse input. Moreover, work in the variational approach has shown the promise of these neurocomputational models for implementing human-like online inference (recognition) of speech input (Kiebel et al., 2008; 2009; Yildiz et al., 2013). Under the active inference formulation of biotic dynamics (Friston, 2013a), learning (recognition) of sensory data (e.g., a noisy speech stream) entails (the capacity for) subsequent production of that same sensory input (cf. comprehension vs. production in child language development). Indeed, this is just what it means to embody a generative model: generative models statistically recapitulate sensory (e.g., linguistic) input (Kidd et al., 2017). Children learn to talk by being attending to that talk (Vouloumanos and Curtin, 2014; Begus et al., 2016; Marno et al., 2016). Thus, though Variational Sociogenesis does not by any means rule out model selection favoring *specifically* linguistic predispositions at the scale of function (i.e., biological adaptations for language; Berwick et al., 2013b), it does place heavy emphasis on the learnability of the communicative system in (early) ontogeny via a (principled) generative architecture underlain by domain-general processes of gain enhancement, in line with usage-based approaches to language acquisition (Tomasello, 2003; Lieven, 2016).

[13] Though I do not pursue this further in the present thesis, 'cooperative motives' underlying infants' points are suggested to be (i) a 'cooperativized' (Tomasello, 2014b) form of great ape imperatives (see Tomasello, 2008). In humans, the imperative motive is suggested to manifest as a continuum of 'requestive' motives, from more demanding to politer (Tomasello et al., 2007a). Moreover, there is suggested to exist (ii) declarative motives underlying pointing that are unique to *Homo* (Tomasello, 2008). Declaratives are proposed by Tomasello et al. (2007a) to be decomposable into two unique forms, namely, 'expressive declaratives' and 'informative declaratives' (see Figure 1. of Tomasello et al., 2007a). Other authors have challenged this ontology by proposing that, e.g., there exists an 'interrogative motive' that motivates infants to learn about their world from their caregiver. This motive has been proposed to either to (a) take the place of the supposed 'sharing' (declarative) motive proposed by Tomasello et al. (2007a) (Southgate et al., 2007); or to simply exist alongside it as another motive for infants' points (Begus and Southgate, 2012). For better or worse, I do not pursue these specific motives here, nor do I consider the relevant distinction between top-down versus bottom-up joint attention (Carpenter and Liebal, 2011). Rather, I simply note that each motive presupposes jointly shared attention towards some outside (Tomasello, 2008).

[14] Relatedly, I briefly note that precise sensory data may find their source in unfamiliar places (e.g., nonhuman primates), leading to quite interesting learning effects (e.g., Perszyk and Waxman, 2016; Ferguson and Waxman, 2016; Ferguson and Lew-Williams, 2016; Ferry et al., 2013). It is interesting to consider whether these learning effects are specifically mediated by the presence of similarities in the underlying (precise) auditory features of human speech (Zarate et al., 2015) and the (generally imprecise) auditory features of nonhuman chimpanzee calls. These effects are most likely at particularly early ages, prior to widespread perceptual tuning (Mauer and Werker, 2013) and may deserve closer inspection in future work.

[15] A more comprehensive account of how individual differences in sharing develop in ontogeny (e.g., Kidd et al., 2017) will likely complicate matters rather greatly. Variational Sociogenesis provides a principled framework, however, for considering (hypothesizing) these highly complex dynamics. It suggests that individual (i) mechanistic and (ii) ontogenetic differences in generative model dynamics combine with (iii) wider culture-specific factors such as, e.g., ingroup-outgroup dynamics (Kinzler et al., 2012) developing at the scale of (cultural) phylogeny; which themselves are (iv) differentially enmeshed in, and impacted by, phenotypical human life history patterns developing at the scale of function (Gurven and Gomes, 2017; Gopnik et al., 2017). Complicating matters further, this hyper-dense matrix of differentially weighted modulatory phenomena circularly interacts between and within scales of analysis (Ramstead et al., 2017) to shape, constrain, and enable how the relationship between precision and familiarity with regard to shared interaction (and hence attunement to the cultural Markov blanket) manifests itself at any one point throughout the lifespan in an individual human.

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