Active Inference & Behavior Engineering for Teams

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Abstract:

Comprehensive frameworks for Teams should include various functionalities and structures in order to capture the broad range of affordances available for modern Remote Teams, including, but not limited to, synchronous & asynchronous communications, memes, geospatial maps, hardware/software use, and contact escalation. We suggest that Systems Engineering provides guidelines to define the functions of Ontologies, Narratives, Formal documents, and Tools (ONFT) within the context of the life cycle of any System of Interest. Following this ONFT assessment it is possible to break out to sub-systems levels and mechanistic analysis. In this paper we explore how a new generation of ONFT for Remote Teams could be based on Active Inference, a process theory related to the Free Energy Principle. Effective ONFT based upon Active Inference could lead to the realization of lightweight and powerful epistemic tools to guide everyday decision-making in an embodied, enactive fashion. Such a technology for Remote Teams would lead to fundamental changes in various aspects of Team function, for example the efficiency of a Team's production of artifacts or self-reported "phenomenology of the working day".

Keywords: Active Inference, Free Energy Principle, Remote Teams, Communication, Technology

Contribution:

- Communication is fundamental in natural and designed teams; effective communication systems are needed to facilitate the organization and function of complex multi-agent systems.
- Under the Free Energy Principle (FEP), previous work has synthesized Active Inference (ActInf) with domains such as Narratives [1], Ontologies [2] and extended cognition in multiscale biological systems [3,4].
- Using the ActInf framework, here we explore various kinds of Communication in located teams and all-online Remote Teams (RT).
- Online work and RT are promising systems for theoretical study and direct applications of the ActInf framework because all states and updates in digital systems are observable.
- Here we bring the FEP-ActInf-Narrative nexus together with the applied approach of Systems Engineering (SE), to begin the work of formalizing the processes of RT formation and lifecycle management.

Driving Questions:

- How could we consider the coherence, narrative, and identity function of communication at the individual scale, as well as the scale of Teams & organizations?
- What kinds of methods for Teams (analytics, user interfaces, etc) could be deployed to address basic and applied questions of interest?
- How could we apply multi-scale Active Inference frameworks to Systems approaches such as *Ontologies, Narratives, Formal* documents*, and Tools* (ONFT)?
- How could we address concepts and models for epistemic values within the context of ONFT for Remote Teams (epistemic foraging)?
- How could Teams ensure narrative reliability? How can the epistemic and goal-oriented ends of foraging be jointly optimized by individuals and teams?
- What we could take from concepts and works on niche construction to aid development of ONFT approaches for modern, global Teams?
- Could we define approaches for personal behavior engineering by using ONFT in Teams communication?

Introduction

1. Teams are about function & communication
2. Modern Teams are Remote Teams
3. Systems Engineering provides frameworks for life cycle management of complex systems
4. Active Inference in Teams

Teams are about function & communication

Work is performed by teams, human and non-human (e.g. ants) [5–7]. The concept of Division of Labor describes how system subunits interact with each other and perform work [7,8] in Complex Adaptive Systems regulated by agent-agent and agent-environment feedback systems [7,9–11] (also see Task Allocation [12,13], Heterarchy [14–16], and ant semiotics [6,17,18]). In the context of remote and located Teams, heterarchical subsets of members and stakeholders allocate tasks based on practices (norms) and Roles (identities or assignments). Team members not only perform work, but they also send signals, exchange results, and contribute to shared and documented models in extended cognitive tools [19,20]. Tools can help both long-lasting and rapidly-assembling Teams deal with challenges which can't be solved or resolved by any single person. For example, good Team documentation software enables efficient usage of distributed expertise & transdisciplinary cognition, via allowing the affordance of interacting with the wisdom of previous teammates [21,22].

For humans, narratives are aspects of individual and shared generative models of the world [23]. For teams, multi-scale narratives emerge as individuals build a generative model of

their team. We highlight the phenomenological experience of an individual worker as they investigate high level narratives (Why does this company exist? What problems is it solving or impacting in the world?) as well as team-level narratives (Why does this team exist? Why is our part of the project important to the whole company?), Narratives become memetic when they can be shared and underwood in common, this process of communication leads to alignment based upon shared values, mission, etc.

Modern Teams are Remote Teams

There is a need to define Team communication in a more formal fashion, ideally drawing on insights from transdisciplinary theoretical (e.g. Complexity Science) and applied (e.g. Systems Engineering, Systems Innovation) approaches [24,25]. Modern Teams are composed of sets of human, collective, or non-human agents [26–29], often with high turnover rate (see Definitions) [21,30,31]. Today's Remote Teams (RT) are physically distributed, and increasingly use the internet to coordinate action and informationally connect team members [24,32,33]. When working with Instantaneous Remote Teams (IRTs), one also needs to consider the timing at a very fine scale – in IRTs, each team member could participate in different Teams in different capacities during one working day or even a single hour [31].

High Reliability Organizations (HROs) are organizations that contend with volatile environments in which many interactions can be considered non-routine. HROs are increasingly reliant on small, physically distributed, and sometimes temporary or rapidly assembled teams as a means of solving novel, complex problems [34–37]. Examples of these Teams include "tiger teams" in the oil and gas industry [34], and "swift market analysis response teams" (SMART) in the auto industry. Key rituals, protocols, and strategies for these IRTs have been incorporated into SCRUM and Agile Development frameworks for rapid development of software as well [37]. The rapidly assembled, or sometimes "instantaneous" remote team, is an emergent solution to a set of emergent problems. Human knowledge has expanded exponentially, consequently, fields of expertise began to divide into specializations as a basis to reduce time-to-application and learning requirements [38]. This subspecialization has achieved its goals at a cost: generally, no single individual and often no single team holds all of the knowledge and skills necessary to solve the novel problems emerging from the complex threat surfaces with which HROs contend, and as a result, reconfiguration is becoming a more normalized response [25,39,40]. This solution isn't unique to industry: National Navies are organizations which contend with complex threat surfaces in littoral environments, with the additional constraint that equipment repertoires are the product of decade-long investment cycles [25,41,42]. Consequently many National Navies have converged on the same outlook: that no single team or equipment configuration is adequate for the future of expeditionary warfare and indeed remote work [41–43].

Where emergent teams of any type are created in response to novel, complex problems, they cannot rely on effective informational compression via inflexible protocols, as the team

situation and even composition may be a moving target. Rapidly-forming teams sometimes are precluded from relying on compression via long-term bonding as would be found in traditional high performance teams. As such, it should be unsurprising that high performance, emergent teams responding to novel, complex problems generally rely on shared organizational culture, mission, and narrative [25,31,37,44–49]. In the context of both internet communities & in-person protests, memes can serve as rallying points as well as symbols that communicate mission-critical narrative information to team members [25,31,50]. Organizational culture in remote and located teams can be defined as the shared beliefs and values of an organization, as well as its collective processes, cognitive and physical [51–53]. Mission has three primary connotations: military [54,55], religious [56,57], and corporate [58,59]. In all three usages of "mission", mission-relevant narratives and symbolic (or even esoteric) communication are used for the purpose of compressed goal-setting.

In the context of team communication, narratives are dynamic, and in constant adjustment [38,60,61]. Narratives become recognizable through shared or attuned semiotics, iconology, and totemization [47,62–66]. Narratives can be created, perturbed, and managed [63] through the production of physical artifacts [67] as well as through ritual [68–70]. Narratives are a form of memetic compression, for example Linn's reduction of three centuries of American military philosophy into three "camps"; Guardians, Heroes, and Managers [71]. This concept of "narrative as dynamical analogy" is about finding the stable mappings within complex systems that allow for effective action, as is sometimes used in physics [72], computer science [73], and in memetics itself [74,75].

Rapidly formed teams and IRTs come together with clear limitations, the most important of which is the social cohesion and trust necessary for organizational sensemaking. Effective formation of small teams leads to optimal utilization of collective intelligence, and generally positive performance [37,76–81]. Conversely, failure to develop mutual trust and social cohesion can hinder performance [80,82–84]. When opportunities for a team (startup, governmental, research, or otherwise) are dynamic and require rapid reorientation, failures of team formation can be lethal [37,51,84,85]. Teams have both implicit and explicit organizational structures & networks of communication. These defined or undefined team structures (representations of networks of roles, positions, signals) have direct implications for the efficacy of communication and production of Team artifacts (physical, software, narrative, memes). Functional small teams can be argued to belong (exclusively or non exclusively) to at least one of three classifications characterized by the means by which members reduce uncertainty about the signals and actions of other members, presented here:

- **ONTOLOGICAL ALIGNMENT:** The first kind of group is composed of organizations which depend on very strict, clearly defined, compressed ontologies paired with strict processes that limit the potential for signal-error, creating high expectations of trust between

individuals who do not necessarily know each other or even expect to interact again, such as operating rooms, or air traffic control [34,51,86–88].

- **INTIMATE TRUST ALIGNMENT:** The second kind of group is found within organizations which depend on team bonding and practice over very long periods of time in order to create high-trust and "short-hand" communication that is very highly compressed even if ambiguous or indiscernible to external actors – this group includes organizations which create a "collective mind" during operations such as special operations units, fire departments, sports teams, aircraft carrier flight decks, and non-human cooperative hunting groups such as wolves [44,51,87,89,90].
- **NARRATIVE ALIGNMENT:** The third is composed of organizations which are aligned on organizational culture, narrative or mission [31,37,46,91,92]. These groups can be anonymous, and dynamic in composition or focus.

Here, by defining Teams in terms of their communicative structure, we include many informal groupings (internet chat rooms, crowds, protests, spontaneous public meetings) not classically considered as Teams. Our Team definition here is oriented towards capturing the diversity of communicating systems, rather than just the explicit organizational structures. In modern contexts, teams assemble and disassemble over short timescales, and are often composed of not just of humans but also non-human facilitation agents [26–29,93]. What is not a team, under this conception? The short answer to this question, which will be explored later in the context of Team Markov Blankets, is that non-communicating entities, or entities that are not part of the same informational niche, are not part of the same team. Non-communicating entities may still have alignment of values, mission, or even behavior – but they are not on the same team because they are in non-overlapping informational niches. All of these examples point to the need for a formalized system for today's RT that can meaningfully cope with all of these strategic and tactical challenges.

Systems Engineering provides frameworks for life cycle management of complex systems

To take a field from theoretical speculation to applied utility, we need a set of tools for defining and interacting with a System of Interest (SoI). In this case we are interested in behavior engineering of team narratives communication structures. Engineering is always about changing something in the world, and so behavior engineering in teams is no exception. Engineering can benefit from the Complexity Science perspective, but a conceptual approach alone is incomplete for the designing and implementing of real systems. To quote from the definitive Systems Engineering (SE) Book of Knowledge: "*Systems Engineering (SE) is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on holistically and concurrently understanding stakeholder needs; exploring opportunities; documenting*

requirements; and synthesizing, verifying, validating, and evolving solutions while considering the complete problem, from system concept exploration through system disposal" [94].

SE frameworks define usage of Division of Labor for life cycle management based on different functional Roles for each stage. For each task to be performed, Practices (e.g. architecture, development, testing) are supported through technologies relevant to each Role. SE defines "Practices" as the combination of discipline, work, products, tools and activities [95,96]. To provide actionable solutions to pressing needs, Systems Engineering defines the "functions" and objects of attention during work on SoI life cycle [95,96]. In SE, functions are also a key unit of analysis. These functions can be carried out by multiple humans, or one human may have multiple roles/functions. Thus the design imperative, within a Division of Labor context, is to configure the roles in order to produce functional outcomes. This refocuses the discussion away from spurious communication, and toward task-oriented or performance-oriented outcomes. The pursuit in SE of expected team outcomes is akin to the cybernetic idea that complex self-regulating systems must be goal-seeking in order to survive and thrive [97–99].

We draw on the OMG Essence framework [100] to explore the use of Alphas (*Abstract-Level Progress Health Attribute),* which are uncertainty-reducing sets of States and Checklists for that track changes in the performance of collective work. Teams, at any given moment, are focused on a single Alpha that rises to the level of group attentional awareness [101], akin to the emergence of high-level salience in hierarchical systems [4,102]. The Essence framework identifies seven Alphas as objects of attention in every software engineering project: Stakeholders, Opportunity, Requirements, Software System, Team, Way of Working, and Work [100]. These seven categories also apply well to RTs. In the course of the project the status of the team undergoes small and large changes, passing through states as work is performed. These states of teams and products are observable, in contrast to Alphas, the states of which we can only judge "by instruments"–by the state of artifacts.

It was proposed in Systems Engineering Essence framework [95,96] to expand applications of Alphas from software projects only to hardware and sociotechnical projects by changing Requirements and Software System to System Definition and System Realization. To capture some of the useful ideas from SE, we summarized several recent summary documents of Systems Engineering (Table 1 & Table 2). Despite the fact that SE approaches well established and have been used widely in the last decades it is still the general opinion that SE needs to interface with people outside the scope of a system, even though there is no way to directly engineer their behavior. One possible solution to this challenge of integrating internal and external SoI dynamics would be to set patterns and rules for internal and external communication [103]. We now turn to the enactive framework of Active Inference to provide inspiration for the design of communication patterns for RT that would facilitate modern teamwork.

Active Inference in Teams

Active Inference (ActInf, see Definitions) is a formal framework that frames goal-seeking behavior as an actor-centric dynamic feedback between internal and external states, mediated by sense and action [104–106]. ActInf is a process theory (as opposed to a state or variance theory [107,108]) based upon the Free Energy Principle [102,109] (Figure 1). In ActInf, generative models about the world (as opposed to descriptive, reactive, or analytical models) support ecologically-relevant functions of real systems [3,97,110] – for example a person trying to catch a ball with move towards where they predict the ball will intersect with their trajectory, and motor saccades of the eye during reading are related to real-time predictions about which visual information will be most informative [111,112]. ActInf captures informational and statistical aspects of these generative models and how they are updated and communicated by multiscale far-from-equilibrium systems [104–106,113,114]. ActInf thus presents as a promising approach to the quantitative study of complex system behavior [3,97,110]. In this article our focus is on situating team communication as a case of Active Inference, and exploring various avenues where ActInf approaches could be useful for modern teams.

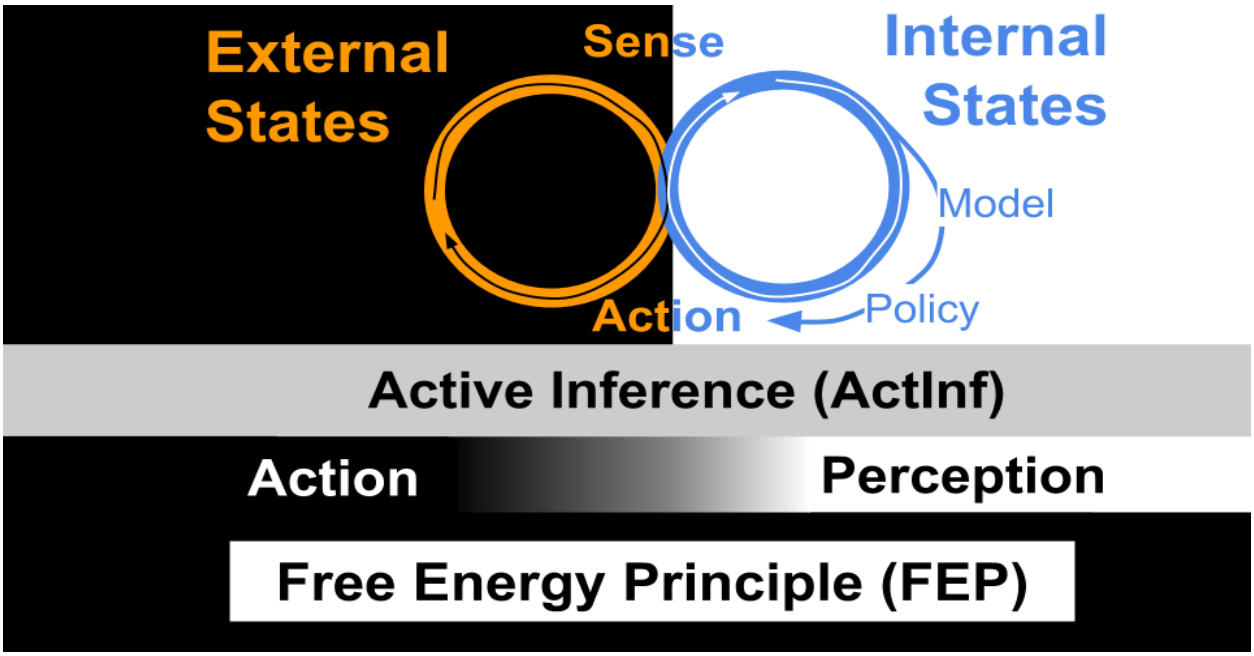

Figure 1. Active Inference (ActInf) is built upon the Free Energy Principle (FEP). Internal states (generative model and policy selection) are linked to external states (world states), via a Markov Blanket (border between dark and light) which is pierced by Sense and Action states.

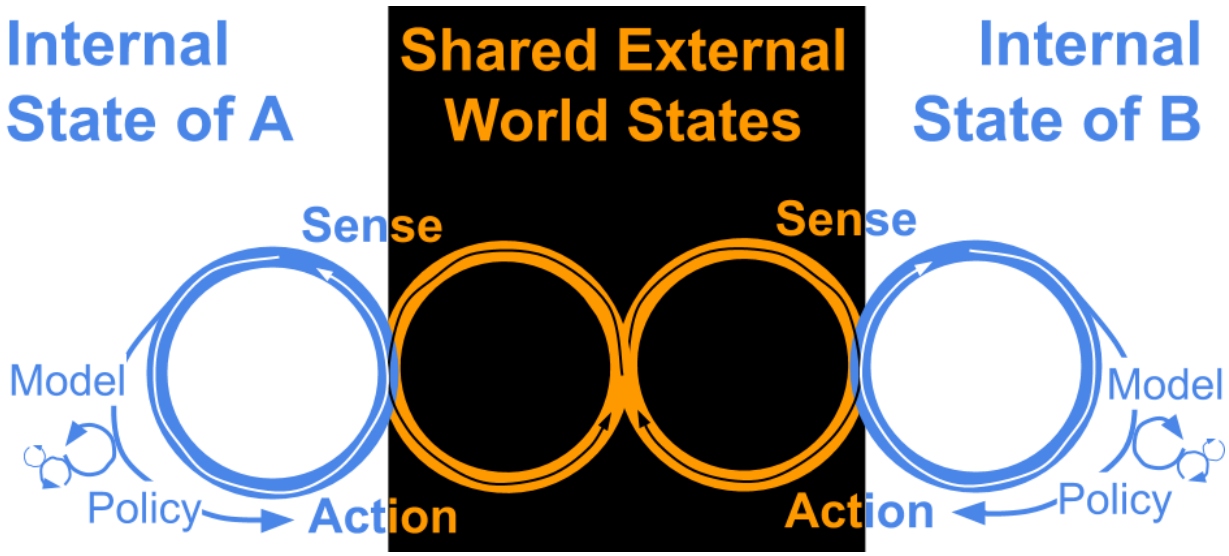

Figure 2. In the case of interacting systems, ActInf casts the commonly-accessible external world states as an epistemic information niche [115].

Here we briefly review several recent developments in the ActInf literature that are relevant for our use case of RT. The topics of communication, narrative, and culture have recently been contextualized within the context of ActInf and the FEP [116–119]. Communicating systems such as the brain [120,121] and improvising dyads [122] can be formally cast within the ActInf framework, making these varied systems amenable to powerful physics-based analyses. For humans, the study of semantic interpretation of text is known as hermeneutics, which lies at the base of many forms of communication. ActInf captures how multiple interacting agents perform improvisational hermeneutics at the behavioral timescale (via e.g. micro-scale turn taking [122]), scaffolded within cultural niches that play out at much longer timescales [123]. The expected status of communication within human teams is cooperative, facilitating the emergence of effective work on large and complicated projects [115].

In the case of goal-oriented team work, ActInf explores how agents communicate with each other in order to reduce each other's uncertainty about internal (mental) and external (world) states. In order to coordinate at higher scales, agents must be connected through communication channels (shared epistemic niche) as well as have the Bayesian prior belief that attunement or alignment is a desirable outcome (desirable since it would reduce uncertainty about achieving preferred future sensory states) [115]. Over evolutionary time, the priors that communication among similar agents is cooperative becomes entrenched through selection (assuming that coordinating agents have higher fitness) [4]. These evolutionary and developmental expectations about social interactions are enacted and shaped through real-time experience – giving a formal sense to the classic phrase "through others we become ourselves" [124,125]. We can adapt this phrase here to consider how teams form and perform, e.g. "through communication with others

we become a team", or "though reducing our uncertainty about the future we achieve our shared goals".

The rest of this paper is dedicated to exploring the features and implications ONFT for teams, using SE and the ActInf framework. We focus on the multiple levels of communication that teamwork entails (within and between teams), and some of the special aspects of modern Remote Teams (for example rapidly changing composition and augmented or non-human teammates). We explore the possibility of creating protocols for RT communication to succeed in the development of SoIs, based upon optimized message passing systems inspired by ActInf. This perspective for computational communication of RT extends naturally from recent work on ActInf in enactive and encultured communication.

SE approaches to implementing Active Inference in Remote Teams

Here we highlight the Remote Team (RT) as a tractable "model system" for studying the processes of Communication, Narrative co-construction, collective intelligence, organizational sensemaking, and organizational management online. The design of successful RTs, now more than ever, is essential for the health and productivity of modern society circa 2020. We use the multiscale action-oriented framework of ActInf to consider the communicative, psychological, and techno-social dynamics of RTs [4,97,112]. We consider how recent developments in online organization, gamification, and platform accessibility make formal systems for RT & Instantaneous Remote Teams (IRTs) a relevant technology for research and implementation [25]. Overall we aim towards Ontologies, Narratives, Formal documents, and Tools (ONFT) for RT within the ActInf framework.

First, we can recast the generalized AcfInf setting of Figure 2 into the specific case of two (or more) interacting team mates within a shared team informational niche (Figure 3). We use the concept of a Markov Blanket (MB, see Definitions) and communicating systems to define a team as the set of human and non-human agents that share a specific informational niche (Figure 4). In ActInf, the MB reflects the separation between internal and external system states, pierced by active and sensory states [126–128]. In the context of team communication, the MB is enacted by the informational boundaries of the team, though there may also be permanent or transient internal subdivisions [129], especially in large organizations with reconfiguring subteams. Communication among team members in RT can take various forms (Figure 5), including audio-visual relay (video chat), text messages (chat), file sharing, and other forms of information transfer (sensors, biofeedback, geospatial information).

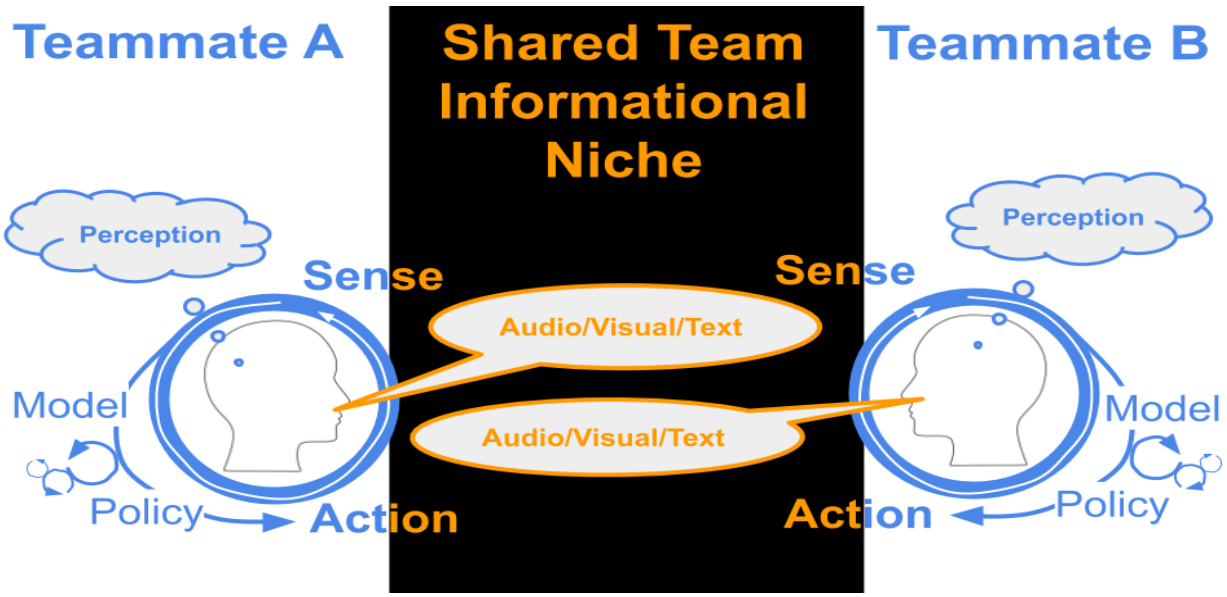

Figure 3. The Team consists of multiple interacting agents, sharing a joint informational niche. Each team member is engaged in sensemaking and the performance of work through the process of Active Inference.

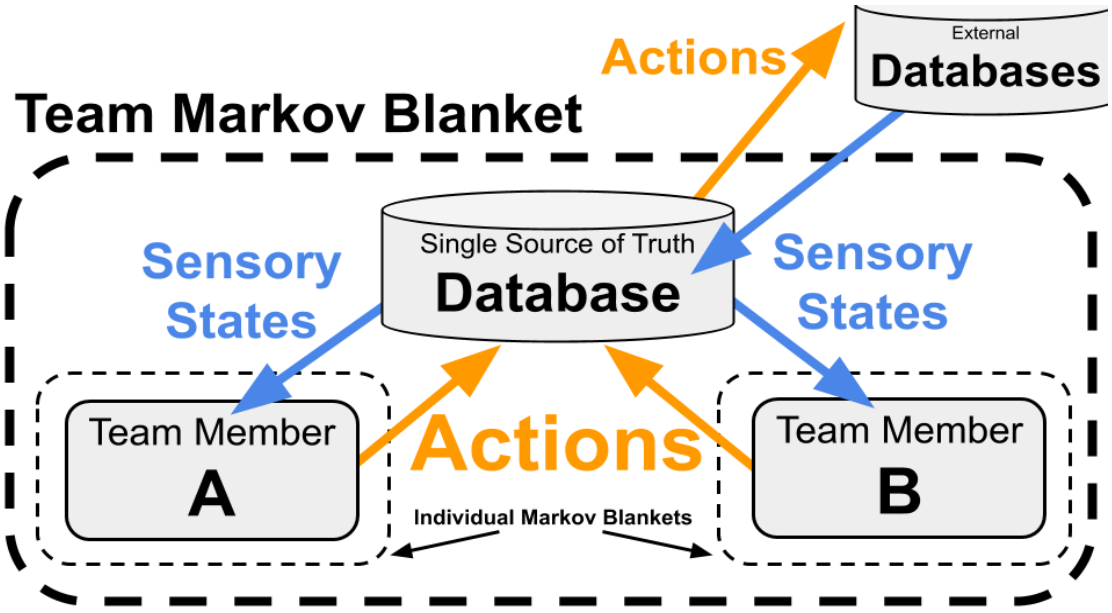

Figure 4. From a communicative perspective, Teams are defined by their coexistence within a Markov blanket. Individuals also possess their own Markovian boundaries, highlighting the need for multiscale formulations that are flexible enough to encompass diverse types of agents. The team is defined by its composition, shared informational niche, common internal model of the world, and affordances for external action.

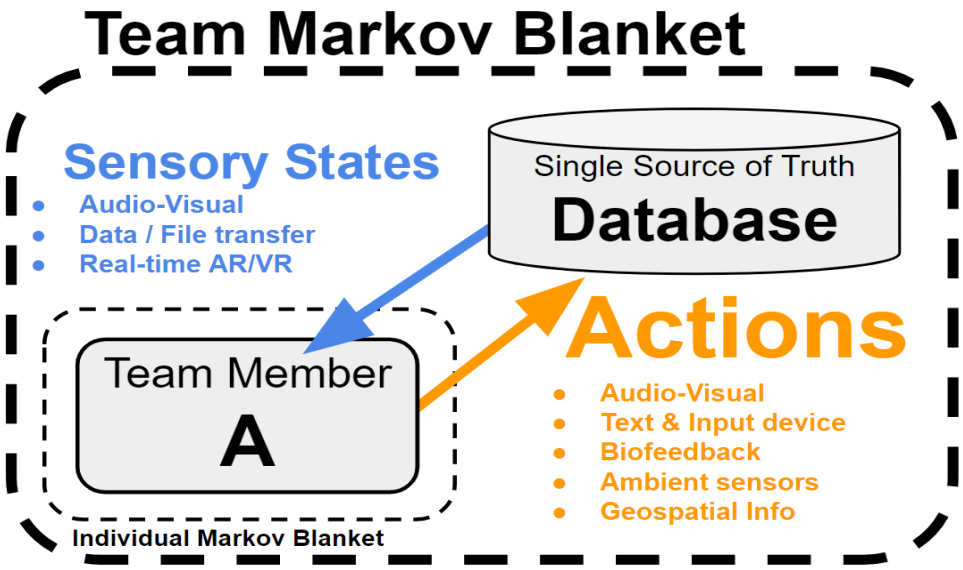

Figure 5. Here are the types of communication between a user and the Single Source of Truth (SSoT) Database. Within the scope of Team communication, a single mate may experience various kinds of sensory inputs, and participate in various action affordances. Not visualized here are communicative features such as synchronous/asynchronous dynamics, multiple team mates, or other attributes of RT.

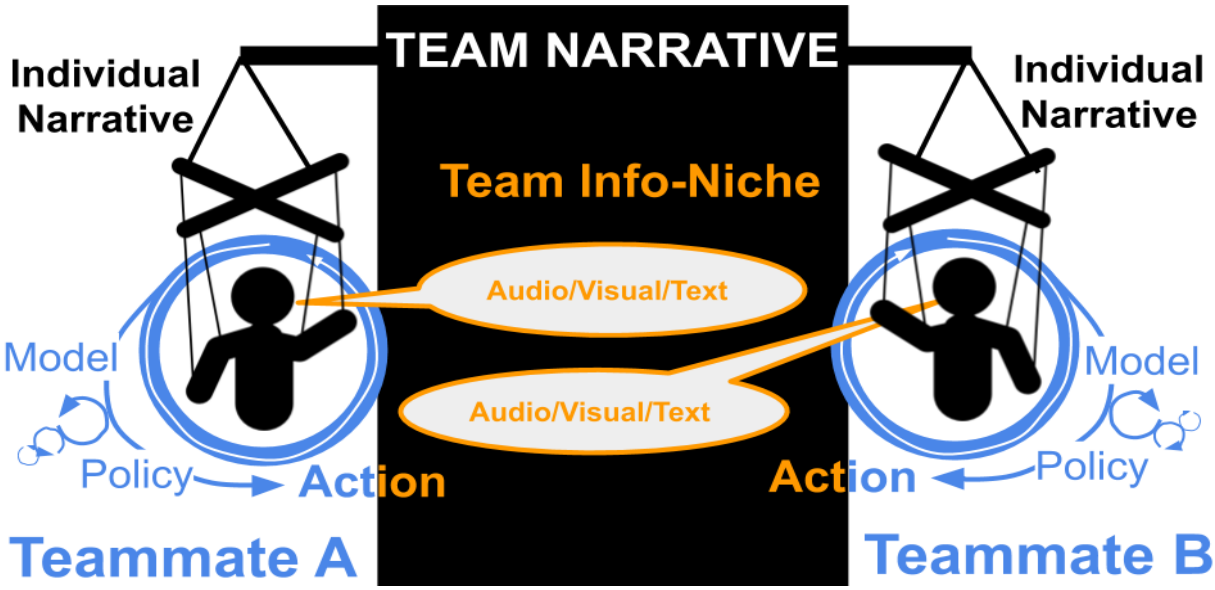

Figure 6. Team narratives are like a fulcrum or leverage point that shapes the observable communication patterns of teams. Multiscale Team narratives contextualize internal model and policy decisions of individual team mates, which influence their behavior (thus feeding back into the team informational niche and altering the narrative itself).

We consider narratives as tools that have functional roles in Teams (Figure 6). At the same time narratives can be generative models (enacted or latent generative dynamics). Our focus is on team behavior, in that we want to attune communication in the interest of achieving certain results. This focus on quality production of artifacts will be behaviorally accomplished in real teams through the design of effective communication and regimes of attention. This is consistent with recent developments in ActInf which frame cultures (of organizations, teams) as "cultural scaffolds" and "regimes of expectations" [97] that through communication are able to achieve higher-order goals [105].

Remote Teams (RT) are especially tractable for formal analysis of any kind, because most state transitions in the team are observable. In located teams, it can be challenging to capture the nuance of important communication techniques such as space use or body language. Conversely in an RT, while body language and other qualitative ostensive cues may still be critical, an observer can be sure that they are at least capturing all of the signals being exchanged (unlike, for example, a video camera in a conference room which may be able to capture where each person is in the room, but not what each person sees). Continuing with this mapping between RT and other far-from-equilibrium message passing systems graphs that perform Active Inference, we can consider all agents (human or non-human) as nodes that are connected via communicative edges. The structure of this graph is the realized communication system of the team, and thus the boundaries of the work-performing aspects of the team. Nodes that are informationally connected may be formally related (e.g. via an Org chart) or they may be organizationally unlinked.

Different kinds of communicative edges may reflect different types of relationships such as informant or close interpersonal linkage (friendship or "buddyship", reflecting a highly synchronized shared generative model). In the RT, because all communications are via online transfer, this exocortex is a key Enabling System [130,131]. This means that we can define the Enabling System in terms of all communication events (in Online space), and for each event provide defined roles & protocols. Narratives for communication are essential for all sorts of team relationships. Narratives can be social functions that create a cognitive niche, thus reducing collective/individual uncertainty [115,132]. Within the context of a narrative that sets the team goal and function, there is a process of exocortex-driven Division of Labor. Functional ontologies are relevant for the role-assignment stage, whereas the System-level ontology steps in to help workers make sense of what they should do.

We see Active Inference as something like a "two stroke engine" for Remote Teams (Act –> Infer –> Act –> …), accomplished through the communicative structure or "Syntax" of the RT (also see OODA loops [133,134]). In all cases, everything is based upon, or supported by tools. This means that work is performed through observable sequences of Events (taking place at a specific time with specific syntax/grammar) which result in meaningful progressions of events (narrative semantics). For an event to exist, there must be a measurable change in a system state

or Alpha [135]. From the perspective of the team members, communication about narratives is of the utmost importance, as narratives set the stage for interpretation of subsequent signals. Narratives are strong enough to serve as nucleating or rallying points for located protests as well as all-online IRTs, underlining the need to understand how memes and narratives interact in modern informational ecosystems [25].

Here we use the framework of ONFT to highlight specific areas where ActInf could be applied:

1. **Ontologies:**
    a. Active Inference could inspire action-oriented ontologies for Remote Teams, describing team composition, communication systems, work performance, informational channels, hardware/software, and more. This leads to the idea of interoperable RT from different organizations (e.g. using standards for metadata that allow for data transformation and Business, Operations, Legal, Technical, and Social inter-team communications and situational awareness such as those proposed through work on Coalition Battle Management Language [136–138])).
        i. Required ontological information for team communication could include (Date, Time, Sender, Role, Alpha). Optional information could include (Seals, Symbols, Context, and Signposts for regimes of attention).
    b. An ActInf-based ontology for Narratives would allow the design or control of narratives in RT. This might be facilitated by tools like Sentiment analysis, visualization techniques, and machine learning of social media data. Other researchers have sketched out common cases where narratives for online teams already exist, how could a formal structure make this more manageable?
    c. In terms of Team membership and informational ingresses/emissions, ontologies for multi-agent systems and Markov Blankets might allow for the design of internal and external representations of work performance [2].

2. **Narrative:**
    a. Narrative alignment is dynamic and grows between members of teams through peer or “horizontal” bonding [84]. Organizations which consist of many teams may experience narrative alignment via both horizontal and vertical bonding, that is, bonding with team-mates and members of other teams as well as bonding with supervisors [84]. The highest level of narrative alignment might be best described with the military term “esprit de corps”, where mutual sense of mission, trust, ideals, culture, and shared threats allow alignment to transcend self-interest, specific unit membership, and limits on intimate relationships [84,139–142]. Narrative alignment associated with “esprit de corps” creates behavioral ideals, objectives,

heroic tradition, and culture or “regimes of expectations” for individuals to align and conform with in order to cope with high levels of uncertainty [1,4,71,83,97,142,143]. ActInf frameworks for RT could promote a digital “esprit de corps” that is observable and also tractable to interface with.

b. The value of communication patterns in the RT could be quantified in terms of value for the team narrative, as proxied by novel evidence for (updated distribution of) shared generative models. This is similar to how backpropagation training of neurons in an artificial neural network updates parameters based upon contribution to error, or how Numer.ai rewards machine learning models proportionally to how they contribute to the success of an automated trading bot [144].
c. At different levels, we can associate different functions for different generative narratives of interest. We need to be able to name, trace, and document the states of narratives (as well as capture pluralistic interpretations of multi-person narratives).
d. A focus on function and role performance within a narrative context could improve the performance of work and the experience of team members. This is because narratives are functions that provide Identity and Meaning across multiple scales. From a SE perspective, Narrative is just another SoI that we can reduce our uncertainty about, towards the end of system design and cybernetic control. Just as with other Complex control questions, we are able to design/control at the Systems level by making the right abstraction for coarse-graining (here, Markov Blankets that allow us to ignore hidden internal states).

3. Formal Documents:

a. ActInf could inform the design of documents that relate multiscale event frameworks – Each event has prerequisites, inputs/outputs (functionalism), consequences & outcomes, Roles, Problems in focus, expectations, and predictions. Formal documents capture which engineering metadata needs to be present (e.g. reference data format) in order to perform life cycle analysis on SoI.
b. Formal Documents for the Work Day and Week could improve the experience of workers.
    i. Morning documents: providing narrative alignment and informational update for the day.
    ii. End-of-day documents: providing closure to the day, filling out information about progress.
    iii. Monday documents: providing narrative Alignment for the week (mission, culture, identity, collective sense-making, where are we in the bigger niche?)
    iv. Friday documents: providing closure for the work week.

4. **Tools:**
    a. Tools are required in all of the above domains so that professional, innovative, effective, inclusive Remote Teams can implement effective ActInf frameworks of any kinds. Current common (and often free) tools include chat, file-sharing, voice/video, CRM, Single Source of Truth software, etc. Such tools will be helpful for ActInf-based teams, and also new kinds of tools may be required.
    b. Given the total observability of RT, toolkits such as SPM [145,146] and multiscale analytics could help attune RT communication towards desired products. Human-in-the-loop machine learning systems based upon ActInf could allow for actions and perceptions to be designed and controlled in real-time at a fine scale [104,147].
    c. For RT communication across platforms, it would be helpful to design common database formats that link protocols, for example using an API connector like Matterbridge [148]. This would allow a nuanced tradeoffs between centralized/private/decentralized backends that used custom metadata, and user-facing platforms with customizable UI/UX and dynamic data updating. This kind of "total comms" understanding, and ability to design effectively within the space of possible RT, would reduce platform fragmentation and increase worker effectiveness.
    d. Inspiration from nature (biomimicry) could provide new tools and perspectives on how different work functions could be performed by different cognitive niches [6,149].
    e. Computer-assisted design (CAD) Tools for communication charts would allow the formalization of "Markov communicative blankets". This could facilitate the formation of collective cognitive entities that can then be understood, compressed, templated, optimized, and reconsidered from multiple perspectives [150].
    f. Tools for regimes of synchronous & asynchronous attention would allow for the optimal design of ostensive cues and salient epistemic signals – "events only happen when the listener is paying attention".

The future of the Free Energy Principle and Active Inference is bright but uncertain. Through our cybernetic communication and actions in the now, we reduce our uncertainty about the hereafter.

Tables

System Fundamentals	System
	Behavior
	Complexity
	Emergency
Representing Systems with Models	Model
	Model-based Systems Engineering
	Modeling Language
Engineered System Context	Product Systems
	Service Systems
	Enterprise Systems
	System of Systems
	Cyber-Physical Systems
Systems Engineering Standards	Modeling Standard
	Related Standard
Generic Life Cycle Stages	Concept Stage

	Development Stage
	Production Stage
	Utilization Stage
	Support Stage
	Retirement Stage
Systems Engineering Management	Planning
	Assessment and Control
	Decision Management
	Risk Management
	Configuration Management
	Information Management
	Measurement
	Quality Management

Table 1. Description of SE Knowledge Areas, adapted from [151]

Alpha	State	Description
Stakeholders The people, groups, or organizations who affect or are affected by a system.	Recognized	Stakeholders have been identified.
	Represented	The mechanisms for involving the stakeholders are agreed and the stakeholder representatives have been appointed.
	Involved	The stakeholder representatives are actively involved in the work and fulfilling their responsibilities
	In Agreement	The stakeholder representatives are in agreement.
	Satisfied for Deployment	The minimal expectations of the stakeholder representatives have been achieved.
	Satisfied in Use	The system has met or exceeds the minimal stakeholder expectations.
Opportunity The set of circumstances that makes it appropriate to develop or change a software system	Identified	A commercial, social, or business opportunity has been identified that could be addressed by a software-based solution.
	Solution Needed	The need for a software-based solution has been confirmed.
	Value Established	The value of a successful solution has been established.

	Viable	It is agreed that a solution can be produced quickly and cheaply enough to successfully address the opportunity.
	Addressed	A solution has been produced that demonstrably addresses the opportunity.
	Benefit Accrued	The operational use or sale of the solution is creating tangible benefits.
System definition A set of core technical activities of systems engineering, including the activities that are completed primarily in the front-end portion of the system design.	Conceived	It is clear how the system will be defined.
	Consistent	Consistent System definition has been created.
	Coherent	The requirements provide a consistent description of the essential characteristics of the new system.
	Used for Production	System definition is used for system production.
	Used for Verification	System definition is used for testing.
	Used for Operation	System definition is used by stakeholders for operation.
	Used for Disposal	System definition is used for system disposal.
System Realisation The activities required to build,	Raw materials	Raw materials for system realization are available and allow manufacturing of the parts with required properties.
	Parts	Parts have been produced and are ready for integration.

integrate elements, and ensure that a system both meets the needs of stakeholders and aligns with the requirements.	Demonstrable	The system has been assembled from the parts and is ready for testing.
	Ready	The system (as a whole) has been accepted for deployment in a live environment
	Operational	The system is in use in an operational environment.
	Retired	The system is no longer supported and disposed and/or recycled.
Team A group of people actively engaged in the development, maintenance, delivery, or support of a specific software system.	Seeded	The team's mission is clear and the know-how needed to grow the team is in place.
	Formed	The team has been populated with enough committed people to start to pursue the team mission.
	Collaborating	The team members are working together as one unit.
	Performing	The team is working effectively and efficiently.
	Adjourned	The team is no longer accountable for carrying out its mission.
Way of Working The tailored set of practices and tools used by a team to guide and support their work.	Principles Established	The principles, and constraints, that shape the way-of-working are established.
	Foundation Established	The key practices, and tools, that form the foundation of the way of working are selected and ready for use.
	In Use	Some members of the team are using, and adapting, the way-of-working.

	In Place	All team members are using the way of working to accomplish their work.
	Working well	The team's way of working is working well for the team.
	Retired	The way of working is no longer in use by the team.
Work Activity involving mental or physical effort done in order to achieve a result.	Initiated	The work has been requested.
	Prepared	All pre-conditions for starting the work have been met.
	Started	The work is proceeding.
	Under Control	The work is going well, risks are under control, and productivity levels are sufficient to achieve a satisfactory result.
	Concluded	The work to produce the results has been concluded

Table 2. Alphas and their states, adapted from [86] and [100]

Definitions & Acronyms

- RT – Remote Team
- IRT – Instantaneous Remote Team
- MB – Markov Blanket
- SoI – System of Interest
- ActInf – Active Inference
- FEP – Free Energy Principle
- ONFT – Ontologies, Narratives, Formal documents, and Tools
- **Definition:** "Active Inference" (ActInf)
    - Active inference (ActInf) is an action-oriented process theory that is related to the formal multiscale framework of Free Energy Principle (FEP) [3,109]. ActInf posits that action-perception cycles link external and internal systems, through sensory and active states that bidirectionally constitute a system-specific boundary known as a Markov Blanket (MB). ActInf is related to areas such as Cybernetics [152], Niche construction [110], Information foraging [111], linguistics [105], Variational Bayesian machine learning techniques [104].
- **Definition:** "Engineered System"
    - An open, concrete system of technical or socio-technical elements which is the focus of a SE life cycle. Its characteristics include being created by and for people, having a purpose and satisfying key stakeholders' value propositions when considered as part of a broader system context [94].
    - An engineered system is a system designed or adapted to interact with an anticipated operational environment to achieve one or more intended purposes while complying with applicable constraints [153]**.**
- **Definition:** "System life cycle"
    - The evolution of a system, product, service, project or other human-made entity from conception through retirement [95,154].
- **Definition:** "System of Interest" (SoI)
    - The system whose life cycle is under consideration [154].
- **Definition**: "Team"
    - A set of communicating nodes, where nodes represent actors (people, augmented people, computers). Teams with coherence (of communication, narrative, or function) tend to be involved in a shared work. The performance of this functional work is in feedback with Team informational connectivity, as well as the extent of attunement of shared beliefs, policies, goals, values, and worldview among stakeholders.
    - Team composition and mission are all subject to continuous change, this paper begins to address how formal systems for complex systems could be deployed in remote teams, to maximize desired ends amidsts constraints and uncertainty.

Instantaneous Remote Teams (IRTs) are generative online-native teams that can have rapid evolution of mission, personal composition, skill set, and approach.

- Team members are engaged in task allocation, using different practices and managing the group's lifecycle, exchanging results are relevant for the operation of the System of Interest (SoI), within the common Markov blanket, using shared Ontologies, Narratives, Formal documents, and Tools (**ONFT**).

Appendix

As empirical results we want to show some examples of Team_Comm work on this paper. It was done by an all-online Remote Team which joined forces to get an overall result which was not possible individually (at least in the same timeframe) due to the interdisciplinary nature of the research. This team originated unpredictably, following the independent actions of members in a shared information niche (Discord channel of the Lex Fridman podcast). Subsequently the team's communication moved to the platform of Keybase which allowed for the construction/development of a private informational niche. Several of the topics addressed in this paper can be unpacked here in relationship to how we carried out this work:

- Using Division of Labor
    - Different members of the Team_Comm have backgrounds in academia, Complexity Science, Systems Engineering, and Remote Team management. We thus treated the paper as a System of Interest, and through work on its life cycle our communication was able to prepare the paper in accordance with best research and SE practices.
- Using ONFT
    - We were working explicitly with FEP/ActInf and SE Ontologies, figuring out places of interconnections/interconnection of concepts from different domains. At online weekly meetings we communicated and aligned shared Narratives on different levels: about motivation working on these domains, to rise and address questions about information we lack, about future application of such approach. We were using different tools to support coordination, communication and activities of Team_Comm, as well as to create our own information niche and SSoT, based on Discord (discord.gg/gpqmQgJ), Keybase channels and subteams (public Keybase team @karlfriston.freeenergy, shared Keybase username @ActiveInference). We created an external informational presence for Team_Comm activities around ActInf which includes Twitter (@InferenceActive) and Youtube (bit.ly/3lg9ztk).
- Using Alphas
    - We were training to focus on different aspects in any given time, following the SE approach with Alphas for Strategy and Governance in the beginning, later on System taking pre-print as an artifact and SoI which states we changed during Team_Comm work.

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