Concept

MEi:CogSci Master's Thesis

1 General information

Title	Brain Network Configuration Under Threat and Solution Climate Framings
Subtitle (if applicable)	Graph Theory Analysis within an Enactivist Framework
Keywords	Functional Brain Networks, Framing, Graph Theory, Enactivism, Climate Change News.
Main research area	Network Neuroscience
Disciplines involved	Cognitive Science Neuroscience, philosophy, psychology, communication studies
Target group	Cognitive Scientists, (Network) Neuroscientists, Psychologists, Scientist working with Enactive Theory (Climate Communication Expert relevant)

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4 Thesis objectives

4.1 Extended abstract (max. 3000 characters)

Understanding how human cognition adapts to different contexts remains a central aim of cognitive science. Brain connectivity studies trace back to the beginnings of neuroscience and with the advent of fMRI technology in the 1990s, alongside ongoing advances in structural connectivity research, a new focus emerged on investigating functional connectivity. Among the tools developed for this purpose, graph theory became pivotal in modelling the brain as a complex network of nodes and edges, allowing for a systematic characterization of its organizational principles (Farahani et al., 2019). Building on previous work, my thesis investigates how different framings of climate change information (threat-oriented versus solution-oriented news), reconfigure whole-brain functional network organization.

In my study, I employ an enactivist framework, viewing cognitive engagement as a dynamic coupling between agent and environment. Rather than treating cognition as a passive processing of external information and resulting graphs as 'representations', I propose that encountering climate news is not merely a reception of facts but an enactment of meaning. My interest in enactivist terms lies in *sense-making.* Brain network configurations, although not a comprehensive measure in this study are assumed to capture some of the process. Changes in brain network configurations under relatively minor condition changes (frames) are investigated using graph theory analysis.

I will be using data from a pre-designed fMRI study, and where I am assisting with data collection. The study is part of the REASON project that investigates the interplay between climate reporting and social impact. During the fMRI study participants are exposed to climate-related statements varying in framing, with task blocks followed by post-task resting-state scans. Functional connectivity is computed by correlating time series data across 200 predefined brain parcels (Schaefer atlas), with resulting networks analyzed using graph theory. My focus lies on three global measures: global efficiency, small-worldness, and hub resilience, which together capture complementary aspects of brain network organization, from integration and segregation to stability under targeted disruptions.

The main research question guiding this project asks how threat versus solution framings influence the overall configuration of functional brain networks, both during active engagement and in the resting state that follows. Although this study is exploratory, some potential hypotheses posit greater segregation and lower small-worldness under threat frames, and enhanced integration under solution frames, consistent with different modes of cognitive-affective positioning. Beyond quantifying these network changes, I aim to interpret them through the lens of enactive sense-making, proposing that shifts in brain network configurations reflect context-sensitive couplings rather than internal representations. I seek to operationalize enactivist concepts within network neuroscience, contributing to an interdisciplinary understanding of how climate information is made meaningful at the level of whole-brain organization.

4.2 Detailed objectives

4.2.1 Review of topic

Following the enactivist tradition, cognition is not a representation of the world that is out there to be observed but emerges from the ongoing embodied, sensorimotor engagement with an environment that is continually co-constituted. Meaning is not given but arises from the action itself, so-called sense-making (Di Paolo et al., 2017). Thus even for those, not directly faced with the direct consequences of climate change, abstract climate fear/anxiety still arises from doing - choosing an article, reading an article, thinking about it, etc. These actions enact a world in which climate threats or solutions become "real" for the agent even in cases where the only directly experienced consequence of climate change is abnormally hot summer days. The action involves positioning which in this case does not mean agents' physical or temporal location (although those effects can not be discounted) but the cognitive-affective stance which emerges through iterative interaction with climate information. In other words, the question is where the reader positions herself in

4.2.1 Review of topic

engagement with the news, and how that engagement is reflected in changing functional brain network configurations.

Following, it is to be expected that depending upon the way climate news are framed (threat-oriented vs solution-oriented) it would lead to different brain network configurations, presumably underlying degree of abstraction. In psychology this has also been referred to as construal levels (Trope & Liberman, 2010): shifts in cognition from concrete to abstract modes, mediated by mental representation (which I reframe in enactivist terms as agent-environment coupling) that shape behavioural responses to climate change (Maiella et al., 2020; Wang et al., 2021). One potential neural correlate to be taken for this cognitive positioning is the Default Mode Network (mPFC/PCC), which has been linked to self-referential thinking (Davey et al., 2016) which is also a part of the so-called triple-network model involving frontoparietal network and salience network acting as a 'switch' (Schimmelpfennig et al., 2023).

However, in my study I want to investigate engagement with climate information as a whole brain event, thus instead of focusing on the changes in one region, I will be first investigating global graph measures that define the overall network: *global efficiency, small-worldness, and hub resilience*. These measures were selected because they collectively provide a multidimensional description of functional brain networks' organization, providing insight into specialization and overall brain integration(Rubinov & Sporns, 2010; Bassett & Sporns, 2017). Small-worldness in particular, the tendency for networks to exhibit both dense local clustering and short global path lengths, has been proposed as a defining characteristic for efficient neural communication (Bassett & Bullmore, 2017) and has been shown to showcase alterations under different cognitive loads and during development, as well as in neurological and mental disorders (Faharani et al., 2019). I aim to investigate whether some of those changes can also be observed in healthy subjects when task modality remains the same, and the only thing changing is the news frame.

4.2.2 Research question(s)

Main Research Question:

How do threat-oriented vs. solution-oriented climate news framings reconfigure whole-brain functional network configurations during task engagement and post-task resting states?

Sub questions:

- What changes in graph *global efficiency, small-worldness, hub resilience,* change underly brain network changes under solution vs threat news frames? How do these differ from the rest state?
- How do threat and solution-induced network reconfigurations modulate DMN integration during and after climate news exposure?
- Do post-task resting-state networks retain threat- or solution-induced change "echoes"? How do post-task resting-state networks differ from pre-task baselines?
- How can threat/solution-induced network reconfigurations be conceptualized as distinct modes of sense-making?

4.2.3 Hypotheses

My study is ***exploratory,*** but some potential hypotheses could include:

- Functional Brain network will show higher *small-worldness* measure under solution-based condition compared to threat frame condition.
- Threat-oriented climate news frames will evoke network segregation during task engagement, while solution-oriented news will enhance global integration, consistent with actionable sense-making.
- Threat-framed news exposure will reduce *hub resilience*.

4.2.3 Hypotheses

- Solution framing will showcase stronger frontoparietal hub centrality, while threat-oriented–DMN.
- News exposure will result in measurable differences in post-task resting states compared to the starting baseline, reflecting how functional networks have a history and are not static.

4.2.4 Theoretical and methodological concepts

Sense-making: (DiPaolo et al., 2017; Hutchins, 2014; Sepulveda-Pedro, 2024)
A term used in the Enactive framework to describe how living organisms relate to their world in terms of meaning. Initially applied to sensorimotor coupling, it has been proposed to expand sense-making to include socio-cultural contexts, to consider the social and cultural as the ecosystem of human cognition.

Functional Connectivity: (Hassett et al., 2024)
Temporal correlates between the activity of two neural units (in this study regions obtained from publicly available brain atlas).
Functional Brain Networks: Systems of regions with coordinated activity, supporting specific cognitive or affective functions.

Potential Key Networks for this study include:
Default Mode Network: Engages during self-referential thought and disengages during goal-directed tasks (Menon, 2023).
Salience Network: acts as a switch between DMN and executive networks (Schimmelpfennig et al., 2023).
Frontoparietal Network: associated with goal-directed behaviour
Graph Theory: (Hassett et al., 2024; Rubinov & Sporns, 2010)
Graph theory is a mathematical framework used in network neuroscience to analyze connectivity patterns and quantify the architecture of functional brain networks, including state-specific topological features. Those signatures can be used for task decoding, individual identification, and behaviour (Santoro et al., 2024).

- **Nodes:** Brain regions representing functional units.
- **Edges**: Connections between nodes, representing functional relationships.
- **Hubs**: High-connectivity nodes critical for information integration.
- **Segregation**: Local specialization, quantified by modularity
- **Integration:** Global communication efficiency is measured by the inverse of the average path length.
- **Small-Worldness**: Optimal balance of segregation/integration represented by high clustering + short paths
- **Hub Resilience**: Hubs' ability to maintain function during targeting

Framing: (Oliver et al., 2020)
Framing theory states how information is presented significantly influences how people perceive and react to it. Frame influences the choices people make and how to process that information framed. In my research, it is expected to set the contractual level.

Construal Level Theory (CLT) (Trope &Liberman, 2010)
CLT posits that psychological distance (temporal, spatial, social, or hypothetical) shifts cognition from concrete to abstract modes, mediated by mental representations. From an enactivist reinterpretation, I replace "representations" with variations in agent-environment coupling.

4.2.5 Methods

Predesigned fMRI experiment: *(I am only assisting)*
The fMRI study employs a within-subjects design where participants evaluate 54 climate-related statements (18 threat-oriented, 18 solution-oriented, 18 neutral) presented randomly for ≥45 seconds each, followed by ratings of threat/solution perception, valence, arousal, activation, and dominance via visual analogue scales (VAS). Electrophysiological and eye-tracking data are recorded during the task. Post-scan, participants complete psychological screenings (depression, anxiety, alexithymia, BIS/BAS) and climate-specific questionnaires (scepticism, environmental identity, prior engagement).

Data Processing Pipeline (fMRIPrep/Nilearn)

Data Analysis
Functional Connectivity (FC):

- Denoising: Removing physiological noise and artefact removal
- ROI-based: Schaefer-200 parcels (Yeo networks).
- Edge definition: Fisher-z-transformed Pearson correlation between ROI time series.

Graph Theory Analysis:
Global metrics:

- **Global efficiency**: measures how quickly information can travel across the entire brain network, with higher values indicating more efficient integration.
- **Small-worldness:** Quantifies the balance between local clustering and global integration, typical of healthy brain networks.
- **Hub resilience**: Assesses how robust the network's most central (hub) regions are to targeted disruptions, reflecting stability in information routing.

If hubs are identified follow up investigation of local measures.

Optional: in case no measures are found in static state graph measures or if there is time left:
Dynamic FC (Sliding window + k-means)

Statistical Analysis

- Within-subject: Paired t-tests (threat vs. solution FC/graph metrics).
- Between-subject: Correlation of network changes with climate care?
  (DMN modularity ↔ anxiety scores).
- Multiple comparisons: FDR correction ($p < 0.05$) in order to remove false positives

Data Interpretation Using Enactivist Framework

4.2.6 Expected insights and findings

I expect to gain further insight into how brain network organization changes to process climate change news, and whether those changes differ based on how information is presented (threat vs solution-oriented). Expected findings would include a collection of graph measures that underly different brain network states, followed by an interpretation of how those differences relate to the nature of the task. I am also attempting to see if there is a measurable difference between the resting state before and after the task. More broadly, findings are expected to provide some clues about how the way we engage/are coupled with the environment is reflected in the brain, especially in supposedly "representation-hungry" tasks.

4.2.7 Interdisciplinarity

One way to explain the interdisciplinarity of my project would be to list the disciplines involved, stating that while I am doing network neuroscience study the theoretical frame underlying the design and interpretation of the results takes equally from philosophy, psychology, communication studies etc. Alternatively and closer to my interpretation of interdisciplinarity, is to do away with trying to trace each theory and method used to its proper discipline, instead stating that how I am organizing this project is underlined by cognitive science goal at large–understanding how the mind works. Understanding how we engage/are coupled with the environment is a big part of it. To answer that question fully, would require way more than just one functional connectivity analysis of a set of fMRI scans from one experimental design study, but I do believe that the latter does lend itself to be used to probe into the big question by rephrasing it to fit the boundaries of the ongoing study I am joining. For me, interdisciplinarity is about prioritizing problems over discipline. Thus in this project, I am treating fMRI connectivity and graph theory not as an end goal, the answer to it all but as one of the available methods to provide (partial) answers to cognitive questions at hand. I would say that I am attempting to operationalize enactivism.

4.2.8 Relation to cognitive science

I already touched upon this point in the previous section, but for me, cognitive science is about confronting problems of understanding cognition first and then looking for the available tools to answer it. It is not about finding the golden method to solve all the problems. Functional connectivity and graph theory analysis is in some way a reductionist method, but it does not have to lead to reductionist interpretations about human cognition. I had this quote saved in my notes:

> *"Thompson and Varela portrayed the self as a legitimate, non-epiphenomenal object of empirical and quantitative inquiry, synthetically explainable in terms of mechanisms – the mechanisms of neuronal integration. It is on this basis that, converging with the non-substantialist approach inherited from its tradition, Varelian enaction challenges the Cartesian image of the self. It proposes to conceptualize the self no longer as a permanent, consistent center of conscious experience, but as a process – notably, a contingent, discontinuous, highly distributed process." (Ceruti & Damiano, 2018)*

I think of my study design as going in the direction of understanding these mechanisms of neuronal integration better.

4.3 References

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5 Structure, outline of chapter titles, and guiding questions

1 Introduction
What is the study about in the context of cognitive science
2 Theoretical Framework
What is enactivism and its relevance to network neuroscience?

2.1 Enactivism
- Many Theories and interpretations
- Sense Making
- The challenge of "representation-hungry" tasks

2.2 Network Neuroscience:
- Connectomes broadly
- Functional Connectivity
- Graph Theory and Topology

2.3 Synthesis: Enactive brain networks in climate sense-making

3 Methods
What are the methods used and why?

2.1 FMRI experiment design
2.2 Data processing pipeline
2.3 Data Analysis
2.4 Data Interpretation

4 Results
What are the (data) results of the study?

4.1 Threat vs. solution framing graph measures
4.2 Resting-state carryover effects
4.3 Correlations with overall concern for climate change

5 Discussion
How can the results be interpreted in the employed theoretical framework?

2.1 Limitations of neuro data
2.2 Interpreting graph organization as enactive coupling
2.3 Implications
- Theoretical Implications 4e cognition
- Practical Implications for Climate Communication

6 Conclusions
What are the main takeaways from the study?

6.1 Key findings
6.2 Future directions

6 Working plan and schedule

Working-package (WP)	Start	End	Activities	Resources required	Mile-stones (M)
WP concept	March	End April	Preparing Thesis Concept	Thesis Template, Zotero, Research Journal, Supervisor consultation, Access to Journal Articles	M1
WP Theory	May	May	Further Literature Research based on identified gaps while writing Thesis Concept	Access to Journal Articles and books, Zotero,	M3
WP conference	April	April	Writing and editing my Abstract for the Conference	Thesis Concept, Feeback	M2
WP writing	May	Mid-June	Writing my Theoretical Framework section	Gathered Literature (M3), Research Journal, LaTeX (integrated with Obsidian)	M4
WP conference	June	June	Presenting my planned study at the conference, incorporating received feedback into my study concept	Powerpoint or Canva, receptive audience, Thesis Concept, Theoretical Background	M5
WP data	May	August	Assisting with fMRI experiment	Access to an fMRI lab with all equipment, PhD student supervision, participants, know-how and a to-do list for an fMRI study	M8
WP data	July	September	Writing data preprocessing and analysis script	Python Libraries: Nilearn, NumPy/pandas, NiBabel; MATLAB, Neurodesk **specifics to be chosen*	M6
WP data	September	September	Cleaning gathered data	Gathered Data (M8) fMRIPrep (automated), Python for custom scripts, tutorials and manuals, Neurodesk **specifics to be chosen*	M9
WP data	September	October	Analyzing the final set of data	Python (scipy.stats; network, seaborn/matplotlib etc.), MATLAB (Brain Connectivity Toolbox), tutorials and manuals, Neurodesk **specifics to be chosen*	M10
WP data	October	November	Doing data visualization	Pythong Nilearn (nilearn.plotting.plot_connectome); or MATLAB BrainNet Viewer, tutorials and manuals, Neurodesk **specifics to be chosen*	M11
WP writing	November	December (before Christmas)	Writing the first draft of my Master's Thesis	Gathered Literature (M3, M4), Research Journal, LaTeX (integrated with Obsidian), Zotero, supervision,	M12
WP writing	January	February	Editing my master thesis based on received feedback, submitting final version,	Gathered Literature (M3, M4), Research Journal, LaTeX (integrated with Obsidian), Zotero, supervisor review	M13

6.1 Milestones and results/"products"

Mile-stone	**Result/"product"**
M1	Thesis Concept
M2	Abstract for the Conference
M3	Literature Review
M4	Literature review turned into written Introduction and Theoretical Framework
M5	Conference Presentation
M6	Preprocessing Pipeline Script
M7	Data Analysis Script
M8	FMRI experiment data
M9	Cleaned fMRI data
M10	Data Analysis Results
M11	Visualizations
M12	First full Master Thesis Draft
M13	Final Master Thesis

7 Reflection

7.1 Paradigm(s)

Enactivism: challenges representational views of cognition, emphasizing that meaning arises through embodied, dynamic interaction with the environment. It proposes that cognitive processes are not input-output information processing events but active processes of sense-making. While much of sense-making has traditionally been explained in sensorimotor terms, newer enactivist approaches also tackle abstract, linguistic, and other forms of sense-making. In my study, enactivism frames the engagement with climate news as an active positioning that is reflected in functional brain network configurations.

Network Neuroscience: provides a framework to study the brain as an interconnected, complex system whose organization underlies cognitive and affective functions. **Graph Theory** (carrying its own theoretical implications) is used to capture organizational properties of functional connectivity patterns that can be reconfigured depending on context and task demands. In my study, network neuroscience allows me to quantify and interpret how different framings of climate information enact distinct patterns of brain network organization.

7.2 Premises

The core premise of this study is that enactivist concepts can be productively applied to network neuroscience. In this study, I do not claim that obtained graphs are a comprehensive measure. They are imperfect abstracted representations (with many limitations which are explored later) of brain network activity. While acknowledging limitations, I posit they are useful abstractions allowing cognitive scientists like myself to use them to formally address critical questions underlying cognition, better understand the general organization principles of brain networks, and investigate their context-dependent changes.

7.3 Learning interest

I want to understand brain functional architecture and how it changes based on the context the subject finds herself. Overall, I want to figure out how the way we engage/are coupled with the environment is reflected in the brain. To answer that question fully, would require way more than just one functional connectivity analysis of a set of fMRI scans from one experimental design study, but I do believe that the latter does lend itself to be used to probe into the big question by rephrasing it to fit the boundaries of the climate news study at hand. As humans, we are always embedded in context, which as I expect is also reflected in brain network reconfiguration. Understanding that coupling better would help to understand human cognition contextually, as proposed by the various branches of 4E cognition proponents. I believe the enactivist framework can be applied even to "representation-hungry" tasks. If enactivism is to be considered a comprehensive theory of human cognition, it is necessary to also apply it to 'abstract' cognition tasks and contexts and demonstrate how such cognition remains fundamentally a sense-making process.

7.4 Limitations

This study has numerous limitations that could be classified under the following four categories:

- **fMRI Constraints**: fMRI is an indirect measure of neural activations which has inherent limitations including but not limited to:
  - low temporal resolution may miss rapid neural dynamics
  - sensitivity to noise that can obscure the signal
  - unnatural setting (scanner environment) may alter cognitive engagement.
- **Participant Demographics:** all recruited participants are planned to be students, which exacerbates WEIRD problem in science.

7.4 Limitations
- **Atlas Dependency**: Parcellation choice: e.g., Schaefer vs. AAL atlases yield different node definitions potentially influencing graph measures and leading to different results - **Averaging:** to compare conditions, data are averaged across participants, masking individual differences in network topology. *If dynamic connectivity analysis will not be performed time will also be averaged, assuming stationarity within blocks which would then ignore potential intra-block dynamics.

7.5 Open questions

- What causality underlies functional changes in the brain networks?
- To what extent do current network neuroscience methods capture context-sensitive sense-making? Is this different depending on the level of abstraction required by the task?
- How do individual differences shape brain network configurations under the same environmental conditions? What should be considered contextually relevant if personal history is taken into account?
- What are the limitations of interpreting fMRI-derived network changes as evidence of enactive processes? What measures could contribute to a more comprehensive analysis of the sense-making process?

7.6 Weak points

Functional brain network configuration analyses using graph theory may oversimplify the dynamic, enactive agent-environment coupling by focusing primarily on neural correlates neglecting bodily and ecological dimensions. There are also no phenomenological interviews, thus no first-person perspective to inform the interpretation. Claiming to capture *sense-making* within the graph resulting from processed data coming from laboratory-based neuroimaging study is a theoretical stretch, especially given that the translation of enactivist concepts into operational neuroimaging measures is still underdeveloped. This could lead to conceptual reductionism or misinterpretation. This could happen with graph theory measures, as I am not an expert in this area. However, by acknowledging these points, I hope to proceed with the study with careful consideration and reflections in the hope of avoiding potential pitfalls.

7.7 Failure criteria

This master's thesis would be considered a failure if no data analysis is performed and no results are reported. There may be no significant differences in graph measures comparing threat vs solution vs neutral conditions, however, I would not consider it to fall under failure criteria, as long as the methodology part was robust and results are reported and reflected in the discussion part. In case of a failure to obtain fMRI scans (for example due to unforeseen end of the REASON project), publicly available data sets will be used, adapting the research question to their study design.

7.8 Novelty

Connectivity studies are not novel, nor is the application of graph theory for identifying functional connectivity. The novelty of my project lies in investigating the framing effect. Task-based functional connectivity studies are usually focused on investigating network configuration based on the modality of the task (eg., visual vs auditory). I am attempting to find whether and how relatively subtle changes depending on how information is framed, change brain network configuration when modality remains unchanged. An enactive framework, for interpreting these changes, not as brain-embedded representations, but as *coupling*-dynamic reciprocal interaction between a person and their environment is also a novel graph theory application.

7.9 Possible ethical concerns

For the fMRI study participants will be required to express informed consent. However, risk, privacy and safety concerns can not be ruled out. Incidental findings, such as brain tumours, are also to be noted. Further ethical concerns, have to do with interpreting and reporting data fMRI data with good scientific practice, trying to acknowledge the limitations of the data and being explicit regarding obtained results, vs their interpretation.