Altered emergent information dynamics in Alzheimer's disease and cognitive impairment

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Introduction

Alzheimer's Disease (AD) is a degenerative disease of the nervous system associated with a gradual cognitive decline in predominantly older populations. Given the emerging view that Alzheimer's disease should be considered a disorder of consciousness [1], we applied information decomposition to scans from N = 872 participants from the Alzheimer's Disease Neuroimaging Initiative (ADNI). Regions in an augmented Schaefer-200 atlas were ranked using their information processing dynamics in control participants to produce an information-based hierarchy of brain information processing. Departure from the healthy information processing hierarchy was associated with progression of AD.

In the current work we used a method recently applied to healthy individuals by Luppi et al. [2] to characterise brain regions in fMRI by their information dynamics. We parcellated scans from all 872 participants with resting-state fMRI data from the Alzheimer's Disease Neuroimaging Initiative
(ADNI) and placed them in an information processing hierarchy.

Preliminary results suggest a mild disruption of the information processing hierarchy (higher-order to lower-order information processing) between controls and patients with Alzheimer's disease, and an intriguing change in synergistic representations of information in subcortical regions.

Partial Information Decomposition

Partial Information Decomposition (PID) is a tool which answers how information from various **sources** provides information about a **target** [3].

For example, how do humans use both their eyes to obtain different information about the world?

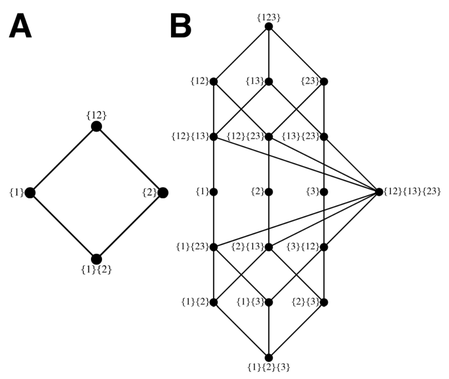
In PID, information is decomposed into components based on their **redundant**, **unique**, and **synergistic** representations by source variables.

Redundant information is provided by multiple sources about the target; it is data for which there is always a backup copy.

Unique information is provided only by **one** source; if that information is lost, then that information is no longer available from a backup.

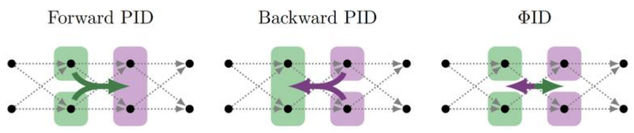
Synergistic information is only when using multiple sources together. The classic example is the ability to perceive depth – depth information can only be available in its entirety when using both eyes.

We applied the **MMI-PID** proposed by Barrett et al. [4] in 2015 to decompose the time delayed mutual information (TDMI) for pairs of ROIs In two extended parcellations from Schaefer et al. [5].

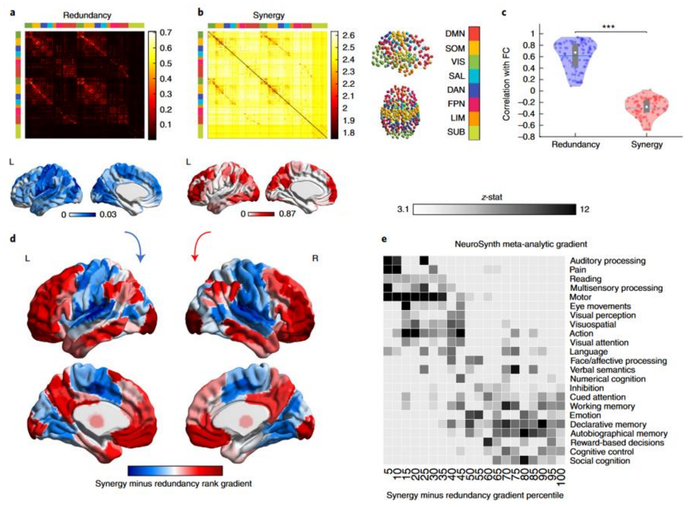


Integrated Information Decomposition (ΦID)

We used an extension of the PID concept called ΦID – **Integrated Information Decomposition** [6]. This extends the source-target structure of PID to further develop the language of information processing. We applied this decomposition to pairs of brain regions from ADNI's 10-minute resting state fMRI session.



The Information Processing Hierarchy



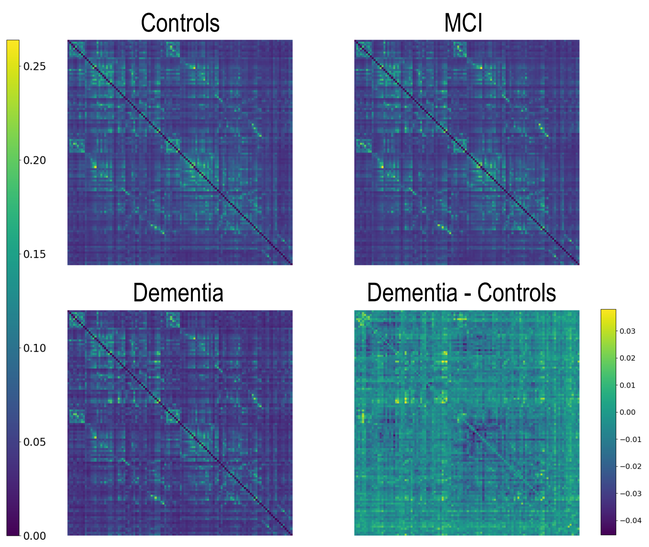
(Figure taken form Luppi et al., 2022 [2])

In 2022, Luppi et al. demonstrated a range of information processing styles across various brain regions. This hierarchy was produced by computing temporally persistent **synergy** and temporally persistent **redundancy**.

In the figure above, regions which are more **synergistic** (information processing based on "deduction") are pictured in red and regions which are more **redundant** (information processing based on "back up copies") are pictured in blue.

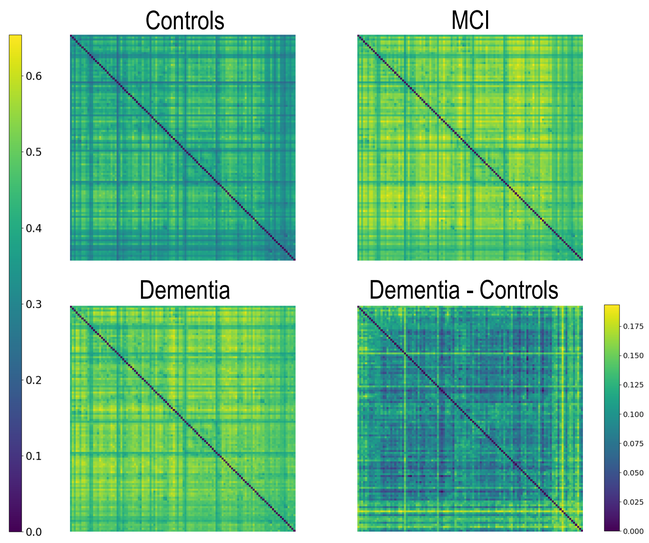
Information Representations in MCI and AD

Temporally persistent **redundancy** (rtr) across groups

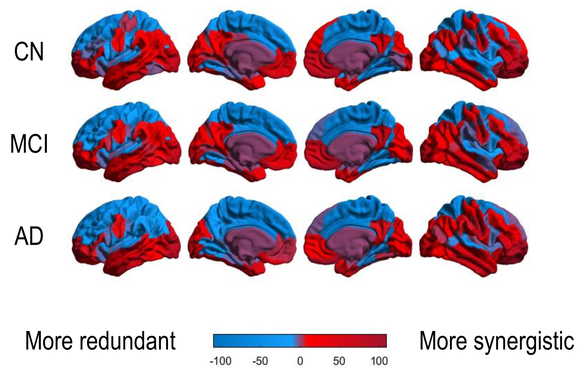


Information processing across most cortical regions appears broadly stable with some reduction in redundancy where it was highest; this could be interpreted as a reduction in available ***backup*** activation patterns.

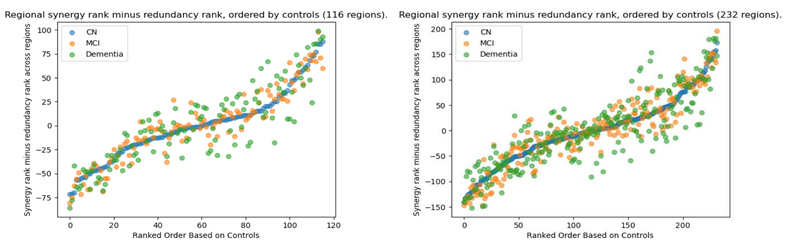
Temporally persistent **synergy** (sts) across groups



Synergistic processing is much more homogeneous across regions but appears to ***increase*** overall with progression to MCI and Dementia. Regions 101-116, which are **subcortical** regions, also seem to exhibit this increase more strongly.

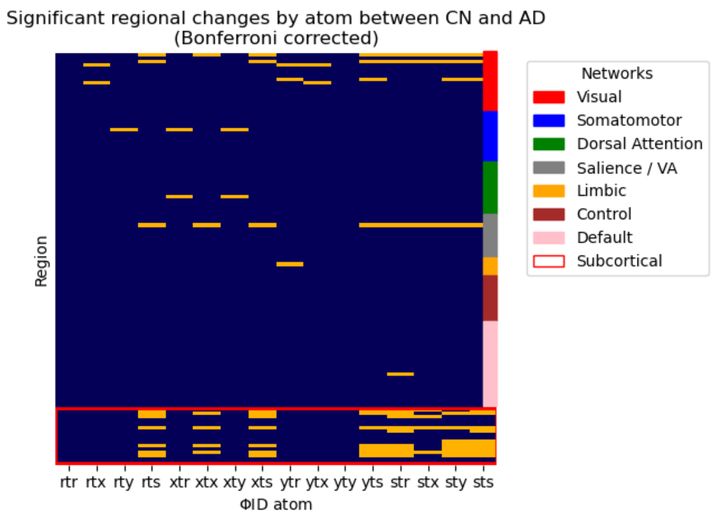


Synergistic Processing in Subcortical ROIs



While the broad hierarchy of information processing remains stable, deviation from that hierarchy seems to be markedly increased in Alzheimer's disease when compared to MCI.

TABLE SAMPLE			
CN	**CN**	**MCI**	**Dementia**
CN	1	0.946	0.866
MCI	-	1	0.899
Dementia	-	-	1



To see which regions were affected in their information dynamics the most, we ran multiple **t-tests** with a **Bonferroni** correction to adjust for the family-wise error rate. Most atoms exhibiting strong changes are related to **synergy dynamics (s)**.

Outcomes

- Preliminary results show a global increase in **synergistic** (more deductive) processing in MCI and AD.
- This is especially true in **subcortical interactions,** where representations are very strongly altered.
- This alteration might be due to compensatory mechanisms or a degradation of backup neural pathways. Future work could explore this further.

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Information

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