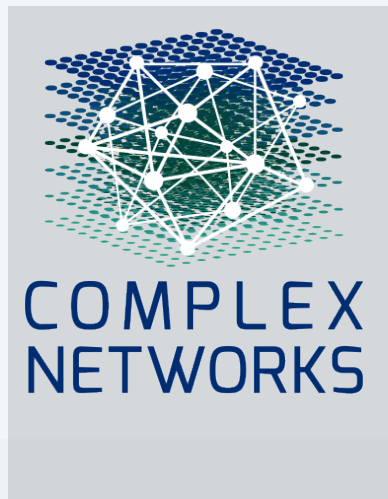# Cognitive MRI of AI Conversations:
A Single-User Case Study

Revealing the Hidden Topology of Thought

Alex Towell   **John Matta**

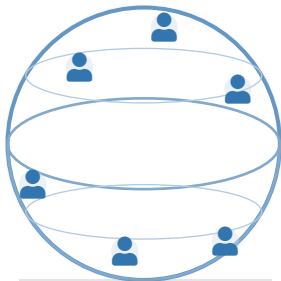*Southern Illinois University Edwardsville*

{atowell,jmatta}@siue.edu

COMPLEX NETWORKS

 Code & Data: github.com/queelius/chatgpt-complex-net

Why Now? The Scale of the Opportunity

1.7 Billion ChatGPT Users

Global Scale

Unprecedented access to

cognitive processes

Why This Matters

Dataset Type	Scale	Process?
Citation Networks	10^8 papers	**No**
Social Networks	10^9 users	**No**
LLM Conversations	10^9 **users**	✓

First-Time Opportunity

Traditional datasets capture **outputs** (papers, posts).
LLM logs capture the **iterative reasoning process** at global scale.
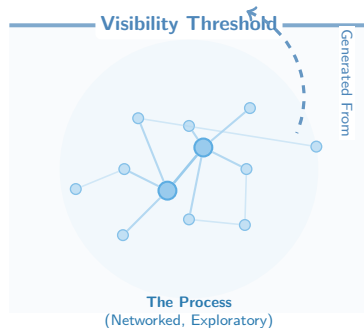
The Big Picture: Externalized Cognition

AI conversations are not just chat logs.
We view them through the lens of **Distributed Cognition**:

- **Thinking Out Loud:** The user offloads cognitive load to the machine.

- **The Iterative Loop:** Ideas aren't just "retrieved"; they are constructed through dialogue.

The "Cognitive Dark Matter"

Standard archives preserve the *result* (the paper). LLM logs capture the *process*—the false starts, synthesis, reasoning.

The Product
(Linear, Polished)

Visibility Threshold

Generated From

The Process
(Networked, Exploratory)

From Chat Logs to Network

Your Chat History

Python Error (Jan)

Banana Bread (Feb)

Debugging (Mar)

⋮

Just a timeline

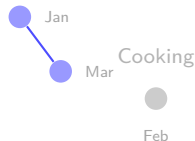**The Transformation**

$\longrightarrow$

Nodes: Each conversation $\rightarrow$ vector (embedding)

Edges: Connect if similarity $> \theta$ (cosine) (similar direction = similar meaning)

The Network

Coding

● Jan

● Mar   Cooking

●

Feb

Grouped by meaning

The Key Insight

Close in **time** $\neq$ close in **thought**.
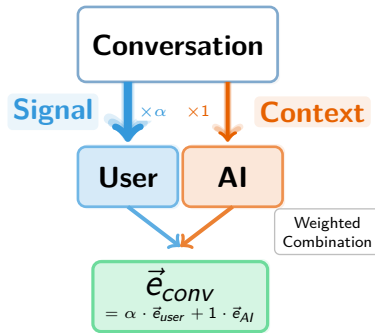Jan and Mar snap together. Banana bread floats alone.

Whose Voice Matters?

The Challenge: AI responses are verbose and generic.
The Intuition: User prompts carry the intent. But by how much?

Separating Signal from Context

- We separate **User Prompts** from **AI Replies**.
- **Weighting:** Introduce parameter α (user-to-AI ratio).
- **Question:** Does prioritizing the user actually improve structure?

Conversation

Signal $\times \alpha$ $\times 1$ **Context**

User **AI**

Weighted Combination

$\vec{e}_{conv}$
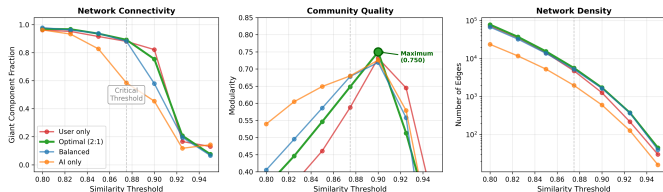$= \alpha \cdot \vec{e}_{user} + 1 \cdot \vec{e}_{AI}$

*Embeddings generated via nomic-embed-text (8k context).

Rigorous Parameter Tuning: 2D Ablation Study

We ran a 63-configuration parameter sweep to maximize *Modularity* (Q).

Phase Transition at θ ≈ 0.875: Universal Across All Weight Ratios

Weight Ratio Effects at Threshold θ = 0.9

Two-Dimensional Sweep

1 Threshold (θ):
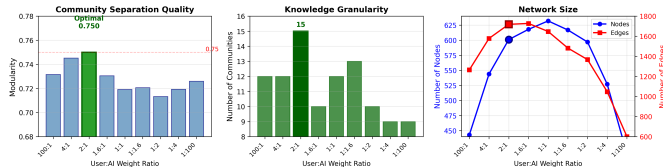- ▶ Phase transition at $\theta = 0.875$
- ▶ **Choice:** $\theta = 0.9$ (optimizes modularity)
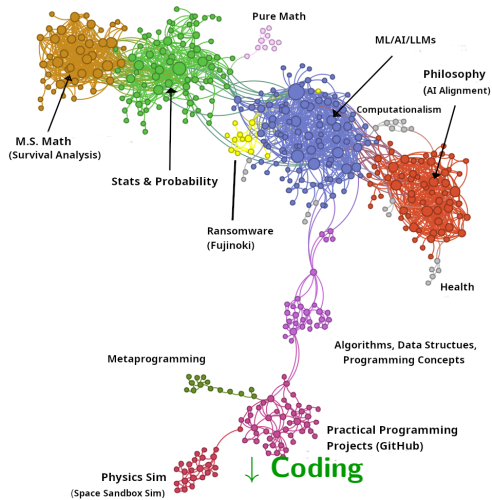- ▶ Below: hairball; Above: fragmentation

2 Weight Ratio (α):
- ▶ **Confirmed:** Peak at $\alpha = 2 : 1$
- ▶ User voice matters more → **Q = 0.750**

Data-driven validation of design choices.

The Cognitive MRI: 15 Knowledge Domains

Giant Component (single user):

- **Nodes:** $\sim$500
- **Edges:** $\sim$1,600
- **Modularity:** 0.750
- **Communities:** 15

Clusters emerged **organically** – no manual categorization.

Core-periphery: 25% dense core

Avg. path: $\sim$6 hops

Insight 1: Structural Heterogeneity

Knowledge isn't uniform. Theoretical and practical thinking have distinct shapes.

Theoretical Domains
(Math, Philosophy, ML Theory)

Practical Domains
(Programming Projects, Debugging)

"Small-World" Structures

- **Dense Clustering ($C \approx 0.58$):** Concepts are highly interconnected.

- **Recursive:** Frequent backtracking to refine core definitions (e.g., axioms, ethics).

Tree-Like Expansion
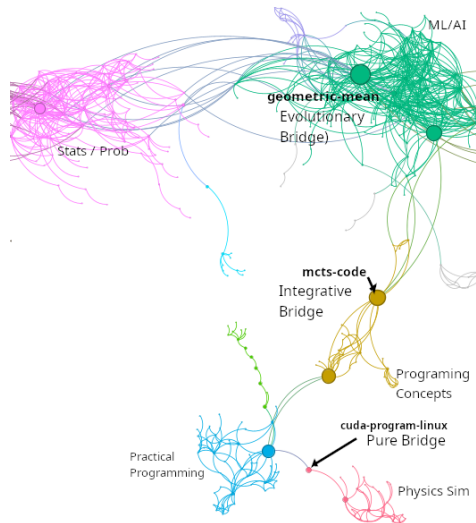
- **Branching ($C \approx 0.39$):** Task-based exploration without backtracking.

- **Independent:** Projects form isolated silos (e.g., *Metaprogramming* vs. *Physics Sim*).

Insight 2: A Taxonomy of Bridges

The network reveals three distinct bridging mechanisms.

1. Evolutionary Bridges
(e.g., Geometric Mean)

Conversations that **drift**: Stats → ML/AI → Programming.

2. Integrative Bridges
(e.g., mcts-code)

Deliberate synthesis: AI/ML ↔ Programming.
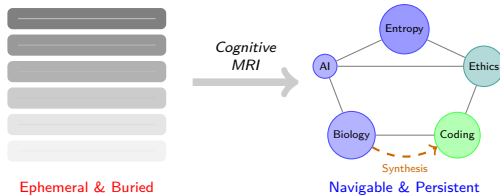
3. Pure Bridges
(e.g., cuda-program-linux)

Rare shortcuts: Physics Sim ↔ Programming.

The Vision: Personal Knowledge Cartography

Why do we need this map?

Current State
"The Scroll"

Future State
"The Map"

Cognitive MRI

Entropy

AI

Ethics

Biology

Coding

Synthesis

Ephemeral & Buried

Navigable & Persistent

Example Query: *"Show me everywhere I discussed entropy."*
Result: Network lights up connections: Biology ↔ AI Theory ↔ Coding ↔ Ethics

Problem: Insights buried
in infinite scroll

Solution: Navigate & synthesize
across your entire history

Cognitive MRI: A Proof of Concept
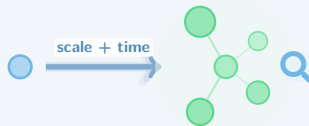
Key Findings

- **Method:** Tuned user-weighting (2:1) and link thresholds (for modularity).
- **Topology:** Heterogeneous (Hubs vs. Trees).
- **Bridges:** Evolutionary, Integrative, & Pure.

Limitations

N=1

- Single User & Platform.
- Snapshot in time.
- Exploratory (No "Ground Truth").

Future Directions

scale + time

- **Scale:** More users & cross-platform analysis.
- **Longitudinal:** Track knowledge evolution over time.
- **Validation:** User studies.

github.com/queelius/chatgpt-complex-net

Backup: Technical Details

Embedding Details
- Model: `nomic-embed-text` (8k context window)
- Dimension: 768
- Chunking: 500-token windows with 50-token overlap
- User-to-AI weighting: 2:1 ratio (validated via ablation study)

Community Detection
- Algorithm: Louvain (resolution $= 1.0$)
- Modularity: $Q = 0.750$ (15 communities discovered)
- Giant component: $\sim$500 nodes, $\sim$1,600 edges

Dataset Filtering
- Original dataset: 1,908 conversations (2–3 years)
- After similarity threshold ($\theta = 0.9$): $\sim$500 conversations in giant component
- Isolated nodes filtered: conversations with no semantic neighbors

Full methodology & code: ⚙ github.com/queelius/chatgpt-complex-net

Backup: Core Formulas

Weighted Embedding

$$\vec{e}_{conv} = \frac{\alpha \vec{e}_{user} + \vec{e}_{AI}}{\|\alpha \vec{e}_{user} + \vec{e}_{AI}\|}$$

$\alpha = 2$ (2:1 weighting)

Modularity (Newman's Q)

$$Q = \frac{1}{2m} \sum_{ij} \left[A_{ij} - \frac{k_i k_j}{2m} \right] \delta(c_i, c_j)$$

A_{ij}: adjacency, k_i: degree, m: edges

Betweenness Centrality

$$B(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$$

σ_{st}: shortest paths $s \to t$

Clustering Coefficient

$$C_i = \frac{2e_i}{k_i(k_i - 1)}$$

e_i: edges among neighbors

Backup: Privacy & Data Handling

This Study

- **Consent:** Author's own conversations
- **Export:** Official ChatGPT data export
- **Content:** Exploratory/academic only
- **Sharing:** Aggregated statistics, no raw logs

Code Release

- Framework is open-source
- Users run locally on their own data
- No data leaves user's machine

Future Multi-User Studies

- **IRB Required:** Formal ethics review
- **Informed Consent:** Explicit opt-in
- **Anonymization:**
  - Remove PII (names, emails)
  - Hash conversation IDs
  - Redact sensitive topics
- **Differential Privacy:** For aggregate statistics

Key Principle

Designed for **self-knowledge**—users mapping their own thought, not surveillance.

Backup: Methodology Alternatives

Why These Design Choices?

Choice	Alternative	Why We Chose This
Cosine Similarity	Euclidean Distance	Magnitude-invariant (length $\neq$ relevance)
	Jaccard (set-based)	Semantic continuity, not just keywords
Threshold ($\theta{=}0.9$)	Soft/fuzzy clustering	Clear community boundaries
	k-NN graph	Ablation validated hard threshold
nomic-embed-text	OpenAI embeddings	Open weights, 8k context, reproducible
	Sentence-BERT	Better long-context handling
2:1 Weighting	Equal (1:1)	AI responses dilute user intent
	User-only	Loses conversational context

All choices validated via 63-configuration ablation study (Slide 6)