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

Revealing the Hidden Topology of Thought

**Alex Towell** **John Matta**

*Southern Illinois University Edwardsville*

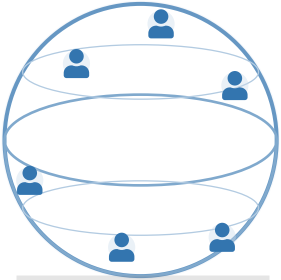
{atowell,jmatta}@siue.edu

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

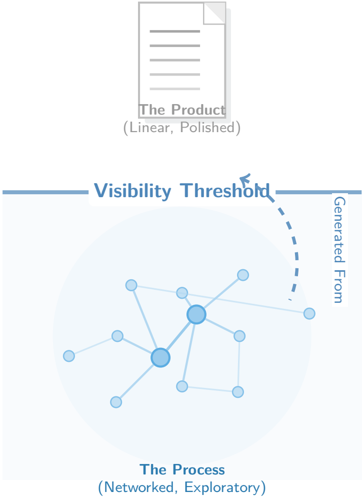
**AI conversations are not just chat logs.**

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.



# From Chat Logs to Network

### Your Chat History

Python Error (Jan)

Banana Bread (Feb)

Debugging (Mar)

⋮

*Just a timeline*

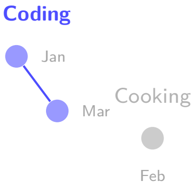
### The Transformation

→

**Nodes:** Each conversation → vector (embedding)

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

### The Network




*Grouped by meaning*

## The Key Insight

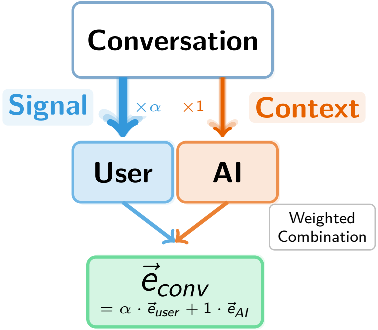
Close in **time** $\neq$ close in **thought**.
Jan and Mar snap together. Banana bread floats alone.

# 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

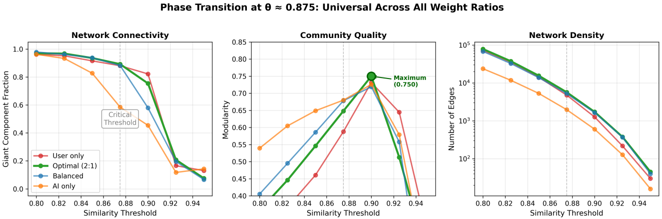
- We separate **User Prompts** from **AI Replies**.
- **Weighting:** Introduce parameter $\alpha$ (user-to-AI ratio).
- **Question:** Does prioritizing the user actually improve structure?

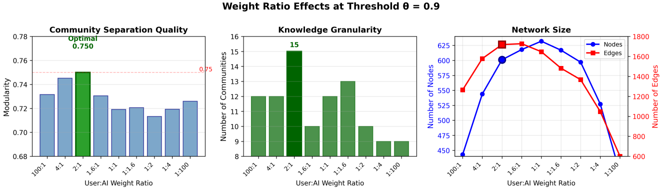



*Embeddings generated via nomic-embed-text (8k context).

# Rigorous Parameter Tuning: 2D Ablation Study

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



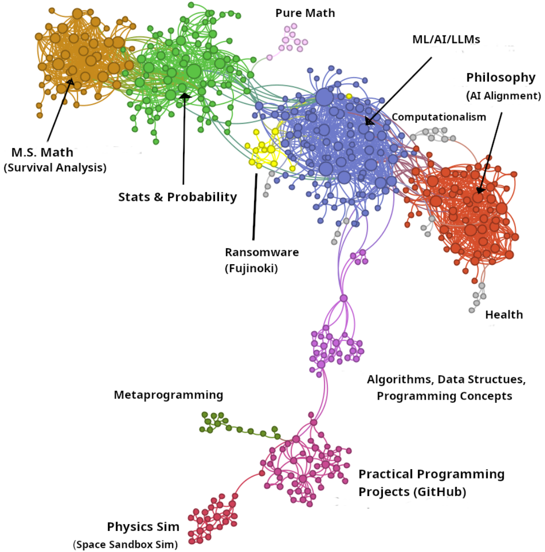




## Two-Dimensional Sweep

1. **Threshold ($\theta$):**
   - Phase transition at $\theta = 0.875$
   - **Choice:** $\theta = 0.9$ (optimizes modularity)
   - Below: hairball; Above: fragmentation
2. **Weight Ratio ($\alpha$):**
   - **Confirmed:** Peak at $\alpha = 2:1$
   - User voice matters more $\rightarrow$ **Q = 0.750**

*Data-driven validation of design choices.*

# The Cognitive MRI: 15 Knowledge Domains

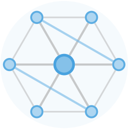


# Insight 1: Structural Heterogeneity

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

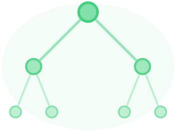
## Theoretical Domains

*(Math, Philosophy, ML Theory)*



## Practical Domains

*(Programming Projects, Debugging)*



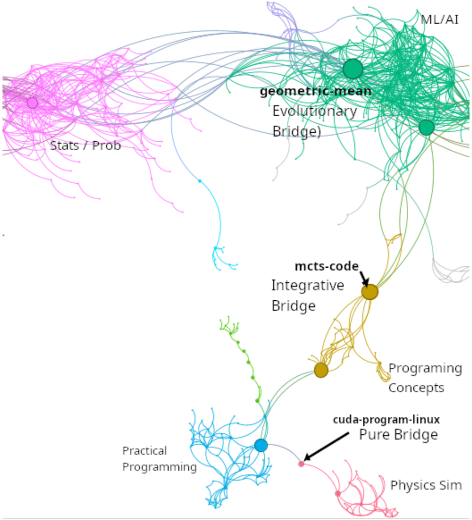
### "Small-World" Structures

- **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.

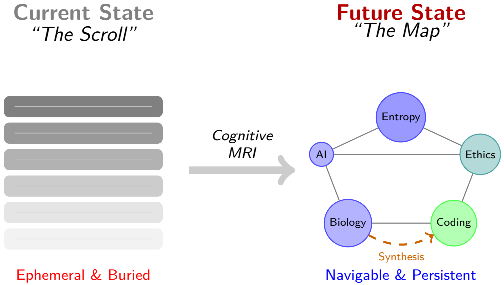
## 3. Pure Bridges

*(e.g., cuda-program-linux)*

**Rare shortcuts:** Physics Sim ↔ Programming.

# The Vision: Personal Knowledge Cartography

## Why do we need this map?



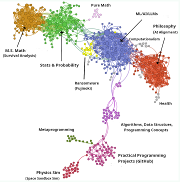

**Example Query:** *"Show me everywhere I discussed entropy."*
**Result:** Network lights up connections: Biology ↔ AI Theory ↔ Coding ↔ Ethics

**Problem:** Insights buried in infinite scroll

**Solution:** Navigate & synthesize across your entire history

# Cognitive MRI: A Proof of Concept

## Key Findings

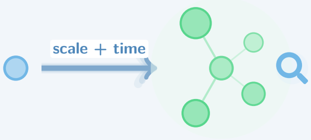



- **Method:** Tuned user-weighting (2:1) and link thresholds (for modularity).
- **Topology:** Heterogeneous (Hubs vs. Trees).
- **Bridges:** Evolutionary, Integrative, & Pure.

## Limitations


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

## Future Directions




- **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: ∼500 nodes, ∼1,600 edges

## Dataset Filtering

- Original dataset: 1,908 conversations (2–3 years)
- After similarity threshold ($\theta = 0.9$): ∼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

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

$\sigma_{st}$: 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)*