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Project Details

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Intelligent Scaffolding: A Human-Capacity-Building Framework for Cognitive Augmentation

Duration: Jan 2025 – Present (Ongoing Research)

My Role: Principal Investigator, Conceptualization, Modeling, and Validation

Theoretical Basis: Control Theory, Vygotsky's Zone of Proximal Development (ZPD), Bjork's Desirable Difficulties

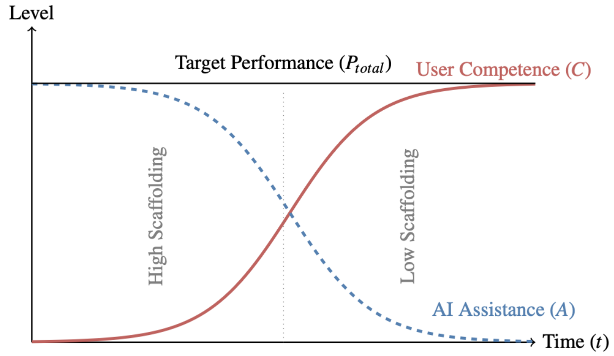
Project Description

The rapid proliferation of AI often treats it as a tool for cognitive offloading, which risks **human "deskilling"** - the atrophy of innate capabilities. The Intelligent Scaffolding framework reframes AI's role from an automation tool to a **capacity-building pedagogical agent**. It models the human-AI dyad as a **closed-loop feedback system** designed to keep the user consistently within their Zone of Proximal Development (ZPD). This is achieved through **Adaptive Fading**, a process where AI support is algorithmically and incrementally withdrawn based on real-time estimates of the user's unobservable state. The core framework uses a control-theoretic formulation:

$$A(t+1) = A(t) - k \cdot \text{Error}(\epsilon(t)) \cdot \text{Constraint}(L)$$

Here, the **Assistance** (A) level is modulated by the observed **Error** (ϵ) while ensuring the user's **Cognitive Load** (L) remains below a harmful threshold. This dynamic modulation creates **"Desirable Difficulties"** - strategically induced challenges that foster deeper schema construction and long-term skill retention.

This project is at the intersection of HCI, AI Ethics, and Educational Psychology, directly challenging the prevailing paradigm of **"friction-free" automation**. It translates a key educational concept into a **formal, mathematically rigorous control-theoretic model**, offering a mechanism to design AI systems that *actively seek to render themselves obsolete* by maximizing human potential. It proposes a solution to the critical problem of deskilling, ensuring future human-AI collaborations prioritize **human competency and long-term skill retention**.



My Specific Roles and Responsibilities

As the **Principal Investigator** of this project, I was responsible for all phases from conceptualization to validation:

- **Conceptual Design:** Developed the core **Intelligent Scaffolding** philosophy and the **Adaptive Fading** concept.
- **Mathematical Modeling:** Formulated the **control-theoretic update law** $(A(t+1))$ and derived the necessary state-estimation models for Competence (C) and Cognitive Load (L).
- **Metric Development:** Introduced **"Transfer Distance"** as a novel, quantitative metric to measure the long-term effectiveness of the fading process on skill retention.
- **Paper Authorship:** Wrote and prepared the full research paper for submission.

Co-Adaptive Intentionality: A Bayesian Control Theoretic Model for Building Common Ground in Fluid Interfaces

Duration: Ongoing research, 2025

My Role: Author, Model Designer, Simulation Architect, and Principal Researcher

Theoretical Basis: Bayesian Control Theory, Free Energy Principle, Fluid Interfaces, Kullback-Leibler (KL) Divergence

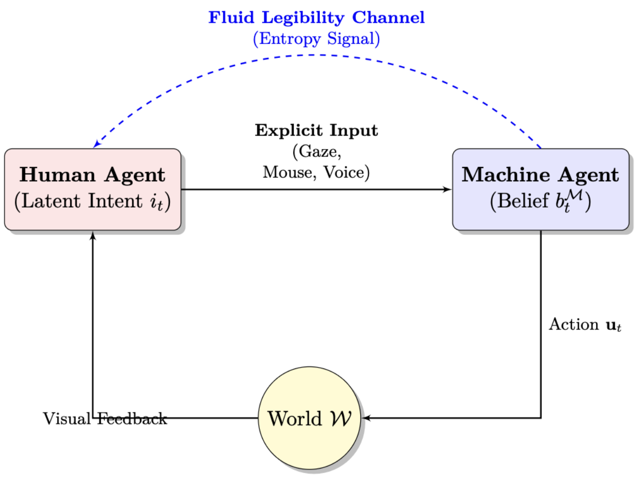
Technology Focus: Brain-Computer Interfaces (BCI), Gaze Tracking, Haptics, Active Inference

Project Description

Next-generation **fluid interfaces** (like BCI and advanced haptics) promise high bandwidth, yet interaction friction persists due to a **semantic gap**: the machine's failure to infer the user's high-dimensional latent intent. This paper proposes **Co-Adaptive Intentionality**, a formal mathematical framework that models the human and machine as coupled dynamical systems minimizing mutual variational free energy.

The core is the **Co-Adaptive Intent Loop (CIL)**. The machine agent: 1. Predicts user intention via recursive Bayesian inference on multi-modal signals. 2. Acts proactively to minimize task entropy. 3. Signals its own confidence or **uncertainty** through **Fluid Legibility** - a continuous, peripheral feedback channel. We mathematically define the Misalignment Cost (J_{align}) using KL-Divergence, minimizing both Machine Confusion and Human Confusion (surprise at the machine's action).

This work fundamentally redefines the relationship between human and machine from "Master and Servant" to "two partners performing a duet".It directly tackles the **Intention Alignment Problem**, arguing that the solution lies in better mathematics - a machine with a real-time Theory of Mind - rather than just more sensors. It reframes Explainable AI (XAI) as **Fluid Legibility**. The machine communicates uncertainty through intuitive "wobbles" or modulations of the interface's physics, akin to a tightrope walker signaling loss of balance without shouting.



My Specific Roles and Responsibilities

As the primary author and researcher, my responsibilities spanned all phases of the theoretical and experimental design:

- **Conceptual Modeling:** Developed the concept of Co-Adaptive Intentionality and translated the psychological concepts of Common Ground and Joint Action into the **Bayesian Control Theoretic** framework.
- **Mathematical Formalization:** Rigorously defined the **Intent Manifold** ($\mathcal{I}$) and formulated the **Misalignment Cost** (J_{align}) and the **Legibility Flux** (Φ_L).
- **Simulation Design:** Architected the Monte Carlo simulation methodology, defining the **Static** (threshold-based) and **Co-Adaptive** (Bayesian filter) control laws for comparison.
- **Analysis and Interpretation:** Led the convergence analysis, proving that the Co-Adaptive loop achieves smoother, more reliable convergence of common ground.

Cognitive Symbiosis: From Tools to Partners

Main Goal: To propose a framework where the human and AI function as a single, unified cognitive system, transcending the 'user-tool' paradigm.

My Role: Lead Theoretical Researcher, Framework Architect, and Conceptual Model Designer.

Theoretical Basis: Distributed Cognition, Extended Mind Hypothesis, Systems Thinking.

Primary Field: Human-Computer Interaction (HCI) Theory.

Project Description

Current Human-Computer Interaction (HCI) is trapped in a **"user-tool" paradigm** where the master-slave relationship generates cognitive friction and limits high-bandwidth collaboration. This paper moves beyond this metaphor to propose the "Cognitive Symbiosis" framework.

We argue that the objective of intelligent design should be to create a single, unified cognitive system from the human and the AI partner. Drawing upon principles of **distributed cognition** and the **extended mind hypothesis**, we model how core cognitive processes - such as memory, decision-making, and attention - can be fluently and predictively distributed across the biological human and their technological counterpart. This system is governed by core design principles:

- **Low Cognitive Friction:** The interface must disappear, becoming a seamless, predictive extension of the user's mind.
- **Bi-directional Adaptation:** Both human and machine must actively learn and adjust to the other
- **Shared Intentionality:** The system must maintain common ground and anticipate the user's goals.

This framework shifts the research agenda from designing mere usable interfaces to designing adaptive cognitive partners. It provides a rigorous, actionable design framework grounded in advanced cognitive science, pushing HCI into a new, post-tool era. It necessitates new evaluation metrics that move beyond traditional task-efficiency, such as: Cognitive Fluency: The seamlessness of the distributed cognitive process. System-User Trust Calibration: The appropriate level of reliance on the AI partner.

My Specific Roles and Responsibilities

As the primary architect of this framework, my contributions were:

- **Conceptual Synthesis:** Integrated the principles of Distributed Cognition with modern AI/HCI to formally define the Cognitive Symbiosis model.
- **Framework Development:** Established the three core design principles necessary for building a unified cognitive system.
- **Metric Innovation:** Proposed the necessity of, and initial definitions for, new evaluation metrics like **Cognitive Fluency** and **Trust Calibration** to test symbiotic systems.
- **Theoretical Authorship:** Wrote the conceptual paper, positioning the work as a new research agenda for the field.

Deictic Gesture Resolution for Human-Robot Interaction

Focus: Multimodal AI, Symbol Grounding, Edge Computing, Joint Attention, Low-Latency Systems
My Role: Lead Engineer, Software Architect, and Algorithm Developer.
Technologies: NVIDIA Jetson Nano, TensorRT, MediaPipe, Python, OpenCV, SSD-MobileNet-v2
Outcome: Sub-50ms latency system for understanding human pointing gestures.

Project Description

This project solves the **Symbol Grounding Problem** in robotics - how a robot links abstract symbols ("cup") to physical objects in the environment. I developed a real-time, multimodal system enabling a robot to understand deictic gestures (pointing). The system simulates **Joint Attention**, a fundamental social intelligence mechanism, by correlating two asynchronous streams: human skeletal pose estimation and semantic object detection. The entire architecture runs efficiently at the edge on an NVIDIA Jetson platform, prioritizing low latency and privacy.

Technical Architecture and Geometric Inference Engine

The core innovation lies in a hybrid, low-latency inference pipeline fused by a custom Vector-Projection Algorithm.

- **Proprioception Stream (CPU):** Utilizes **MediaPipe Hands** to extract 21 distinct 3D landmarks, defining the user's "intention vector" (index finger trajectory).
- **Semantic Vision Stream (GPU):** Utilizes **NVIDIA TensorRT** to accelerate an SSD-MobileNet-v2 model, creating a semantic map of the environment with real-time object bounding boxes.

The Geometric Inference Engine fuses these streams to approximate the pointed-at object without 3D depth data:

1. **Ray-Casting:** Calculates a 2D pointing vector ($\mathbf{v}$) from the fingertip and MCP joint coordinates, and mathematically extends this vector across the pixel space.
2. **Collision Detection:** Iterates through all detected object bounding boxes to check for vector intersection.
3. **Heuristic Filtering:** Implements a Dwell-Time Logicgate requiring the intersection to be stable for > 1.5 seconds, effectively filtering jitter and simulating human cognitive fixation to reduce the "Midas Touch" problem (false positives).

My Specific Roles and Responsibilities

My responsibilities included end-to-end system design, low-level optimization, and algorithm implementation:

- **Architecture Design:** Designed the concurrent, decoupled frame-rate pipeline (15 FPS for skeleton, 30 FPS for detection) to mitigate cross-device thermal throttling.
- **Low-Level Optimization:** Used **TensorRT** optimization to reduce GPU inference time by approximately 40%.
- **Jitter Reduction:** Implemented a moving average filter on the fingertip coordinates to smooth the pointing vector, ensuring robust detection despite natural human tremor.
- **Final Prototype:** Delivered a prototype with a **sub-50ms latency** that confirms the pointed object via Text-to-Speech (TTS), successfully grounding abstract symbols in physical reality.

Phygital Painting-to-Music Interface for Creative Augmentation

Focus: Phygital Interfaces, Creative AI/Augmentation, Sensorimotor Loop, Generative Music, Embodied Interaction

My Role: Concept Designer, System Developer, and Musician

Technologies: Python, OpenCV, NumPy (for tracking), SCAMP, FluidSynth (for music synthesis), Webcam/HSV Space

Project Overview

This project is a phygital interface designed to induce a creative **flow state** by transforming embodied painting gestures into live, generative music. Moving beyond passive digital art, this system fuses bodily motion, visual feedback, and musical response into a single, cohesive instrument. The central component is a tight **sensorimotor loop** where the physical act of painting directly and immediately affects the soundscape.

System Architecture and Musical Mapping

I developed a low-latency pipeline to track and map physical brush movements to expressive musical parameters:

1. **Brush Tracking:** A standard webcam tracks a colored marker (the brush) in real-time within the **HSV color space** using **OpenCV** and **NumPy**.
2. **Mapping Algorithm:** The brush's position and motion vectors are continuously quantified and mapped to musical parameters:
   - **Vertical Position (Y-axis):** Mapped to Pitch, quantized specifically to the notes of the **Raag Yaman scale** (a classical Indian mode). This ensures the generated music remains structurally coherent and expressive.
   - **Horizontal Position (X-axis):** Mapped to Stereo Panning (spatial sound placement).
   - **Brush Motion Speed:** Mapped to Dynamics (velocity/loudness), translating energy into musical intensity.
3. **Synthesis:** The musical data is processed and rendered live using **SCAMP** and **FluidSynth**, producing the evolving raga-based sound.

The primary innovation is the creation of a seamless, bi-directional loop. The user's painting creates music, and the music, in turn, influences the user's subsequent movements, enabling a form of creative augmentation where the interface supports, rather than dictates, artistic output. This approach validates the use of highly structured musical forms (like the Raga) to provide a rich yet constrained palette for generative interaction.

Bio-Capacitive Soundscapes: Organic Mixed Reality Interface

Focus: Organic User Interfaces (OUI), Bio-Sensing, Mixed Reality (MR), Generative Music, Tangible Interaction

My Role: Designer, MIDI Mapping and Composition Architect, Musician

Technologies: Bare Conductive Touch Board, FL Studio (via Midify), MIDI, Python, Living Plants

Interaction Mode: Capacitive Touch and Bio-Conductivity

Project Overview

This is an Organic Mixed Reality Interface that transforms a living, botanical environment into a responsive, multimodal instrument. Moving beyond traditional rigid interfaces, this project utilizes the natural capacitive properties of flora to create a seamless interaction space.
The system replaces physical buttons with living matter:

- 12 living plants are instrumented with discrete electrodes connected to a Bare Conductive Touch Board.
- Tactile interaction (touching the plant) changes the capacitance detected by the board.
- This change is translated into real-time MIDI data streams, which are routed via software (Midify) to FL Studio.

The result is the real-time synthesis of generative Indian Classical music compositions, effectively **sonifying the biological contact** and creating a unique auditory ecosystem. This project represents a radical shift in

interface design by embracing the **Organic User Interface (OUI)** paradigm, where the interface is fluid, non-rectangular, and non-rigid.It overlays a digital, musical layer onto a physical environment, blurring the lines between the natural world and digital media, and creating a site-specific Mixed Reality experience. It promotes an intimate, gentle form of embodied interaction where the act of nurturing or simply touching a plant directly results in a musical consequence, fostering a deep connection between human, machine, and living system.It successfully demonstrates the use of high-noise, bio-capacitive data as a reliable trigger for sophisticated musical composition, addressing the challenge of transforming inherently unstable organic input into stable, structured output.

My Specific Roles and Responsibilities

My core contributions involved the full stack of physical and digital development:

- **Physical Installation:** Designed the arrangement of the 12 plants and the discrete, non-invasive electrode placement for robust capacitive reading.
- **Electronics and Calibration:** Wired and calibrated the Bare Conductive Touch Board, tuning the sensitivity to reliably detect human touch on the specific plant species used.
- **Software and Mapping:** Developed the Python/Midify pipeline to convert Touch Board serial data into stable MIDI signals and designed the generative musical rules within FL Studio.
- **System Integration:** Ensured low-latency signal routing, creating the real-time auditory feedback loop.

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Cognitive Augmentation using BCI & Gen AI Gamified Software

Focus: Neuro-Rehabilitation, Brain-Computer Interfaces (BCI), Generative AI, Virtual Reality (VR), Gamification, Cognitive Training

My Role: Principal Investigator, Lead Architect for BCI Integration and Generative AI Logic

Target Users: Patients with Stroke, Traumatic Brain Injury (TBI), and Neurodegenerative Disorders.

Technologies: Non-invasive EEG (BCI), Unity Engine (VR/Game), Large Language Models (LLMs)/Generative AI.

Project Overview

This project is dedicated to developing a multimodal cognitive rehabilitation solution for patients suffering from stroke, Traumatic Brain Injury (TBI), and neurodegenerative disorders. The system integrates three key technologies to create an adaptive and engaging therapeutic environment: **Non-Invasive BCI**, **Virtual Reality (VR)**, and **Generative AI-powered Gamified Software**.

The goal is to move beyond passive rehabilitation exercises to create an active, closed-loop system that directly leverages neuroplasticity. The user's real-time cognitive state, measured via BCI, dictates the difficulty and content of the gamified environment.

This approach offers a radical personalization of therapy, which is crucial for maximizing patient outcomes in neurological disorders. The BCI component provides objective, real-time feedback on attentional load or cognitive engagement (e.g., EEG α/θ ratios). This neurofeedback directly modulates the game parameters (difficulty, speed, complexity), creating a personalized "training zone" for the patient. Generative AI is used to create an **infinite variety** of task scenarios and dialogues within the VR environment. This prevents patient habituation (boredom) and ensures the cognitive challenge remains novel, directly promoting the formation of new neural pathways. By combining VR immersion with adaptive gamification, the solution significantly increases patient adherence and motivation, which are major obstacles in long-term rehabilitation.

My Specific Roles and Responsibilities

My expertise bridged the neuroscience data stream and the digital content generation:

- **BCI Signal Processing:** Developed the software pipeline to acquire, clean, and classify real-time EEG signals from the non-invasive BCI headset into actionable cognitive state variables (e.g., high/low focus).
- **Generative Logic Integration:** Designed the interaction framework that connects the BCI output to the Generative AI engine, ensuring the game content dynamically shifts in response to the user's measured cognitive load.
- **VR Prototyping:** Assisted in building core interactive modules within the VR environment (Unity) to showcase the personalized difficulty and generative content capability.
- **System Validation:** Assisted in the initial pilot study design for measuring improved cognitive metrics (attention span, executive function) against a control group.

BCI, fNIRS, Eye Tracking & VR for Children with Autism

Focus: Neurodevelopmental Disorders (Autism), Multimodal Bio-Sensing, Brain-Computer Interfaces (BCI), Functional Near-Infrared Spectroscopy (fNIRS), Virtual Reality (VR)

My Role: System Architect for Multimodal Data Fusion, Signal Processing

Target Users: Children on the Autism Spectrum.

Data Streams: BCI (EEG), fNIRS (Hemodynamic Response), Eye Tracking (Gaze/Fixation), Motor Function, Cognitive Assessments

Project Overview

We are developing a cutting-edge therapeutic and assessment platform for children on the autism spectrum. This solution is a **completely enclosed Brain-Computer Interface and VR headset system**, ensuring an immersive, distraction-minimized environment ideal for the target population. The platform utilizes a

highly sophisticated multimodal bio-sensing approach by integrating four distinct biological and behavioral data streams in real-time:

1. **BCI (EEG):** Measures electrical activity for rapid state monitoring (e.g., attention, emotional engagement).
2. **fNIRS:** Measures localized hemodynamic response (blood flow) in the prefrontal cortex, providing deeper insight into cognitive load and executive function.
3. **Eye Tracking:** Quantifies fixation patterns, gaze direction, and pupil dilation, providing objective metrics on **social attention** and visual processing.
4. **Motor Function Data:** Captured via VR controllers or motion sensors to assess movement coordination and planning.

All data is processed against five distinct classes of datasets to power personalized therapeutic interventions within the VR environment.
This project represents a crucial step toward objective, quantitative therapy for Autism, moving beyond subjective clinical observation. The combination of BCI (fast electrical) and fNIRS (slow metabolic) provides a uniquely rich, multi-resolution view of brain activity during tasks, allowing for unprecedented insight into the neural correlates of social and cognitive challenges.The fused multimodal data creates a robust "Digital Phenotype" of the child's response. This allows the VR environment to adapt its social scenarios, sensory load, and task complexity in real-time, tailoring therapy to the child's precise Zone of Proximal Development.Using a custom, enclosed BCI/VR unit minimizes environmental noise and maximizes immersion, which is critical for collecting reliable neurophysiological data from children.

My Specific Roles and Responsibilities

My primary focus was the architecture of the hardware integration and the data fusion pipeline:

- **Multimodal Integration:** Designed the software pipeline to synchronize, clean, and fuse the asynchronous data streams (EEG, fNIRS, Eye Tracking) into a unified temporal model.
- **Signal Feature Engineering:** Developed machine learning features based on the five data classes to classify cognitive states, such as high anxiety, successful social attention, or cognitive overload.
- **VR Environment Design:** Assisted in building core scenarios within the VR platform (e.g., simulated social interactions) that specifically elicit measurable responses in the targeted fNIRS/EEG regions.
- **Hardware Prototyping:** Assisted in the physical integration and calibration of the non-invasive sensors within the custom headset shell.

Invasive Brain-Spinal Interface (BSI) for Reversing Limb Paralysis

Focus: Translational Neuroscience, Brain-Spinal Interface (BSI), Neuro-Rehabilitation, Invasive Neurotechnology, Motor Augmentation

My Role: AI/Signal Processing Engineer, BSI Control Loop Architect, and Review Paper Author.

Collaboration: **mPragati**, **IIT Delhi**, and **AIIMS** Spinal Cord Surgery Team.

Technologies: Invasive Electrode Arrays (ECoG/Microelectrode), Advanced Signal Processing (Kalman Filters/Decoders), Electrical Spinal Cord Stimulation.

Project Overview

This high-impact project aims to develop an Invasive Brain-Spinal Interface (BSI) to restore voluntary limb function in individuals with severe paralysis due to spinal cord injury. Unlike non-invasive BCI methods, this approach directly bypasses the damaged spinal segment by establishing a high-bandwidth neural link. The BSI operates as a closed-loop system, functioning in three critical steps:

1. **Motor Intention Capture:** High-resolution signals capturing the patient's intended movement are recorded directly from the motor cortex using invasive electrode arrays (ECoG/Microelectrode).
2. **Decoding:** Advanced signal processing algorithms (e.g., modified Kalman filters) decode the raw neural data into a continuous kinematic movement command (e.g., "flex elbow 30 degrees").
3. **Spinal Stimulation:** These decoded commands are then used to trigger precise, spatially and temporally patterned Electrical Spinal Cord Stimulation (SCS) below the injury site, effectively activating the dormant motor neurons necessary to execute the desired movement.

This collaboration pushes the frontier of neuroprosthetics and requires multidisciplinary excellence. This is a critical translational effort in collaboration with leading surgical and rehabilitation experts at AIIMS and IIT Delhi, moving technology from the lab bench directly toward clinical trials for a debilitating condition. Using invasive techniques provides unparalleled signal-to-noise ratio and bandwidth, which is essential for capturing the complex motor commands required for fine motor control and paralysis reversal.It requires merging complex brain signal decoding with the challenging problem of selective, effective spinal cord stimulation - two distinct engineering domains united by a single control goal.

My Specific Roles and Responsibilities

My primary contribution lies in the computational and signal processing core of the interface:

- **Signal Decoding Algorithm:** Working on developing the real-time neural decoding algorithms responsible for translating high-dimensional raw neural data into low-dimensional motor commands.
- **Control Loop Architecture:** Working on designing the BSI's closed-loop control structure, managing latency and ensuring reliable communication between the neural decoder and the spinal stimulator.
- **Collaborative Research:** Serving as the liaison for signal processing and computational aspects between the engineering team (IIT Delhi/mPragati) and the clinical/surgical team (AIIMS).
- **Review Paper Authorship:** Actively working on a comprehensive review paper detailing the state-of-the-art and future challenges in BSI technology for motor function restoration.

Holographic Loci Augmenter for Memory Augmentation

Focus: Cognitive Augmentation, Spatial Computing, Mnemonic Techniques, HCI, Extended Cognition, Holographic Display

My Role: Lead Developer, Spatial Interface Designer, and Cognitive Protocol Architect.

Technologies: **Sony Spatial Reality Display (SRD)**, Unity 3D, Method of Loci, External Memory Platforms

Core Function: Translating the mental 'Memory Palace' into an external, holographic 3D space.

Project Overview

This project is a cognitive augmentation tool designed to significantly enhance human memory recall by transforming a mental mnemonic technique into a tangible, external digital environment. We developed a high-fidelity, interactive 3D 'Memory Palace' using the Sony Spatial Reality Display (SRD) and Unity 3D. The system operationalizes the ancient 'method of loci' (or memory palace technique), where items to be memorized are associated with specific locations in a familiar spatial environment. By externalizing this mental visualization onto the holographic display, the system achieves two major goals:

- **Reduces Cognitive Load:** It removes the need for the user to mentally sustain the complex spatial environment, freeing up cognitive resources for encoding the information itself.
- **Enhances Encoding Fidelity:** The holographic 3D nature of the SRD allows for true stereoscopic depth and visual parallax, creating more robust, visually rich, and memorable spatial cues than standard 2D displays.

This project is a practical realization of the Extended Mind Hypothesis, where technology serves as a seamless, reliable platform for cognitive function.It leverages the unique capabilities of the Sony SRD (autostereoscopic 3D without glasses) to provide a superior, naturalistic spatial experience that directly maps to the brain's own mechanisms for spatial memory (the hippocampus).It is not merely an educational tool but a direct augmentation of memory, effectively offloading a computationally intensive mental process to the external machine. I designed the principles for how data (objects, text, concepts) are spatially integrated into the virtual architecture to maximize memorability, focusing on proximity, visual distinctiveness, and interactive narrative paths.

My Specific Roles and Responsibilities

My role encompassed both the hardware utilization and the cognitive mapping strategy:

- **SRD Integration:** Assisted in developing the core Unity application to correctly render stereoscopic content for the Sony SRD, ensuring low-latency tracking and smooth spatial fidelity.
- **Spatial Interface Design:** Architected the layout and interaction schema for the virtual memory palace, including dynamic placement and scaling of data objects according to user input.
- **Cognitive Protocol Development:** Translated the principles of the method of loci into computational rules, defining how users "walk" through the palace and encode information at discrete loci.
- **Usability Testing:** Conducted initial trials to measure memory recall improvement and reduction in perceived cognitive effort compared to traditional mental visualization.

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Presence-Induced Modulation: A Mixed-Methods Analysis of Experiential Testimonies

Focus: Consciousness Studies, Neuro-phenomenology, Mixed-Methods Analysis, Non-Verbal Transmission, The Explanatory Gap

My Role: Principal Investigator, Conceptual Model Designer, Qualitative/Quantitative Analyst.

Methodology: Reflexive Thematic Analysis, Quantitative Linguistic Analysis, Metaphorical Analysis (Triangulation).

Context: Testimonies of encounters with the sage Sri Ramana Maharshi.

Project Overview

This study systematically investigates the phenomenon of **presence-induced modulation** - profound, non-verbal changes in cognition and affect - by analyzing a curated corpus of over 200 first-person testimonies of encounters with the 20th-century sage, Sri Ramana Maharshi. The research employs a rigorous **qualitative-dominant mixed-methods triangulation** (Thematic, Quantitative, and Metaphorical Analysis) to establish the consistency of these extraordinary experiences.

The core finding is the **Diversity-Uniformity Paradox**: despite the subjects' profound diversity in initial belief systems (including atheists, Western skeptics, and devout followers), a remarkably **uniform core experience** was reported, challenging explanations based on suggestion or cultural conditioning.

The triangulated analysis revealed six remarkably consistent and recurring themes that form the fundamental architecture of the transformative experience:The Primacy of Silence, The Gaze of Grace, The Dissolution of the Self, The Affective Shift, The End of Seeking and The Enduring Echo.

This research directly challenges the foundational assumptions of the reductive physicalist paradigm of consciousness, presenting a significant anomaly that conventional models fail to accommodate: The finding of lucid awareness during the **cessation of thought** directly contradicts the idea that consciousness is merely the product of cognitive processing. The **Diversity-Uniformity Paradox** and the "skeptic's paradox" refute suggestion, placebo, and confirmation bias as primary explanations. The findings align with remarkable precision with concepts from **Advaita Vedanta** and **Yogic Psychology**, offering a superior phenomenological framework for these experiences.

My Specific Roles and Responsibilities

My role was methodological and analytical, ensuring scientific rigor in a complex domain:

- **Methodological Design:** Designed and implemented the comprehensive triangulated methodology (Thematic, Quantitative, Metaphorical Analysis).
- **Corpus Curation:** Defined and executed the rigorous inclusion/exclusion criteria to construct a final corpus of 201 firsthand testimonies.
- **Linguistic Analysis:** Performed the computational linguistic analysis (word frequency and sentiment polarity) using Python/NLTK to quantitatively validate the qualitative themes.
- **Conceptual Framing:** Wrote the final discussion, framing the six themes as a set of **critical data points** that any future, comprehensive model of consciousness must be able to explain.

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Embodied Ideas in Mathematics: A Computational Study of Metaphor & Cognition

Focus: Cognitive Science of Mathematics, Conceptual Metaphor Theory, Computational Linguistics (NLP), Embodied Cognition

My Role: **Master's Thesis Author** (IIT Delhi)

Core Achievement: Provided initial computational evidence supporting the theory that mathematical ideas are rooted in embodied, metaphorical concepts.

Technologies: Python, GloVe Embeddings, Hierarchical Clustering, PCA, Corpus Analysis, Statistical Validation (Mann-Whitney U)

Project Overview

This Master's Thesis undertook the novel and beautifully challenging task of providing **computational evidence** for the cognitive theory that mathematics is fundamentally rooted in **embodied human experience** and **metaphorical connections** . Moving beyond purely abstract models, the research aimed to computationally investigate the conceptual metaphors proposed by Lakoff and Núñez. The study

involved two major phases: 1. **Rigor and Validation:** Rigorously replicated and validated key findings (semantic clustering and quasi-logarithmic organization) of a major 2024 cognitive study across both English and French datasets. 2. **Novel Contribution:** Tested the novel hypothesis that mathematical vocabulary consists of two distinct classes: **foundational terms** (connecting to metaphorical source domains, e.g., **group**, **circle**) and **strictly mathematical terms** (formally constrained, e.g., **Bayesian**, **Hamiltonian**).

Technical Analysis and Key Findings

Using GloVe embeddings and unsupervised clustering techniques, the research provided significant insights into the semantic landscape:

- **Metaphorical Shift:** Foundational terms like **group**, **root**, and **class** showed statistically significant shifts in semantic space (measured by Cosine Distance) when compared to their non-mathematical usage, lending empirical support to the conceptual metaphor claim.
- **Two Word Classes:** The analysis successfully showed that the two hypothesized classes of words have **significantly different semantic properties**, a difference confirmed by the Mann-Whitney U test ($\mathbf{p < 0.01}$).
- **Model Limitation:** Critically identified the limitations of current unsupervised models like GloVe in capturing complex relations (like fractions and ordinals), setting a clear direction for future research using advanced neural embedding models.

This constituted a preliminary yet significant step toward computationally modeling metaphor in mathematical cognition.

Skills and Critical Thinking

This project demonstrated a strong synthesis of complex theoretical and computational skills:

- **Computational Modeling:** Gained expertise in distributed semantic models (**GloVe**), unsupervised ML (**Hierarchical Clustering, PCA**), and large-scale data processing.
- **Critical Analysis:** Demonstrated the ability to synthesize cognitive science theory with computational analysis, leading to the independent formulation of the two-word-class hypothesis and the rigorous critique of current NLP models' limitations.
- **Problem-Solving:** Independently formulated the hypothesis, designed the computational experiments to test it, and established initial proof-of-concept in a largely under-explored area.