What may be known: methods for activating large texts and graphs in the climate crisis

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To my extended families: here, now, everywhere, and across all time.

Abstract

The escalating severity of the climate crisis, combined with information overload, hinders our ability to respond as interdisciplinary researchers. In this thesis, I propose anticipatory designs for a novel platform aiming to reveal information we already know in ways that facilitate dialogue between academic disciplines.

I introduce original contributions, including Semantic Forms (3D text-graph compositions), Query Isomorphs (dimensionally versatile graphlets), Ontological Semantic Network Summaries (to reveal ontological frameworks), and the Terroir of Text and Graphs (topological analysis of the relationship between knowledge artifacts and ecological place).

By modeling Query Isomorphs across Semantic Forms, Systemic Design methods, and Language Model vector graph renders, I demonstrate opportunities to use the versatility of visuospatial reasoning in conjunction with Topological Data Analysis for information complexity management. The tools I present in this thesis comprise a platform that would accelerate the synthesis of existing knowledge and extend the applicability of that knowledge across disciplines.

Keywords

visual epistemology, anticipatory design, Systemic Design, Sustainability Transitions, interdisciplinarity, transdisciplinarity, consilience, isomorphology, evidence synthesis, humanistic information design, Topological Data Analysis, Systems Oriented Design, gigamapping, Systematic Combination, Language Models (LM), Large Language Models (LLM), Small Language Models (SLM), Artificial Intelligence (AI)

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Abbreviations

2D – Two-dimensional

3D – Three-dimensional

4D – Four-dimensional

AbInt – Abundant Intelligences

AI – Artificial Intelligence

ASC – American Society for Cybernetics

CATG – Computational Analysis of Texts and Graphs

CBD – Convention on Biological Diversity

CERN – "Conseil Européen pour la Recherche Nucléaire" or European Council for Nuclear Research

CIHR – Canadian Institutes of Health Research

DF – Digital Futures master's program

DfST – Design for Sustainability Transitions

ECCD – Equity Centered Community Design

ER – Entity-Relationship

GAI – Generative Artificial Intelligence

GCCA – Global Center for Climate Action

GPT – Generative Pre-trained Transformer

GUI – Graphical User Interface

HATG – Human Analysis of Texts and Graphs

HDS – Harvard Divinity School

HITL – Human-in-the-loop

IAMD – Interdisciplinary Master's of Art, Media and Design graduate program

IPA – International Phonetic Alphabet

IPCC – Intergovernmental Panel on Climate Change

KA – Knowledge Activation

KSSTP – Knowledge Surfacing, Synthesis, Translation, and Production

KP – Knowledge Production

KSu – Knowledge Surfacing

KSy – Knowledge Synthesis

KT – Knowledge Translation

KTfST – Knowledge Translation for Sustainability Transitions

LLM – Large Language Model

MIT – Massachusetts Institute of Technology

MLP – Multi-level Perspectives

nD – Dimensional to any number of dimensions

OCAD U – Ontario College of Art and Design University

OGS – Ontario Graduate Scholarship

OSNS – Ontological Semantic Network Summaries

PAL – Perceptual Artifacts Lab

PES – Program for the Evolution of Spirituality

PH – Persistence Homology

PKM – Personal Knowledge Management

SDA – Systemic Design Association

SDfST – Systemic Design for Sustainability Transitions

SDG – Sustainable Development Goals

SFI – Strategic Foresight and Innovation master's program

SGS – School of Graduate Studies

SIMILE – Semantic Interoperability of Metadata and Information in unLike Environments

sLab – Strategic Innovation Lab

SOD – Systems Oriented Design

ST – Sustainability Transitions

STKA – Sustainability Transitions Knowledge Activation

TCA – Topological Capta Analysis

TDA – Topological Data Analysis

TTG – Terroir of Text and Graphs

UN – United Nations

UNFCCC – United Nations Framework Convention on Climate Change

VAL – Visual Analytics Lab

Anti-oppression Statement

I am committed to fostering equitable and just academic discourse by actively challenging oppressive language and practices. This thesis includes critiques of terms that are ableist, racist, colonialist, or otherwise oppressive. I quote the use of the terms “blind spots,” “black box AI,” and “stakeholder” to critique them and limit their perpetuation. I acknowledge that my efforts to dismantle harmful language while relearning more just terminology are an incomplete work in progress. As such, I welcome ongoing dialogue about my research and am committed to improving the anti-oppression and non-violence of my communication.

Artificial Intelligence Statement

I acknowledge using AI tools for surface-level improvements of my text, including grammatical correctness and improving readability. I did not use AI tools to arrive at or formulate my contributions, nor did I use them to generate or modify any images presented in this thesis. The AI tools I tested and used were Grammarly's AI Writing Assistant, Claude 3.5 Sonnet, ChatGPT 3.5/4/4 Turbo/4o/4-mini/o1-preview/o1-mini, and Google Gemini 1.5 Pro. I verified and edited my manuscript and take full responsibility for the content of this publication.

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I honour this land. I have been hosted on it as a refugee, settler, child, sibling, and student. Humans have lived in relationship with this place long before it was "discovered" by settlers. I understand this land to be part of the Dish with One Spoon Wampum Belt Covenant, and the territory of the Anishinaabeg, Wendat, and Petun First Nations, the Seneca, and the Mississaugas of the Credit River. I am grateful for my relationships with the people who are of this land, as well as guests here from across Turtle Island, Abya Yala, and beyond.

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1

Introduction

We are in a crisis of understanding. The magnitude and complexity of the climate crisis and its many related crises demand that we change the tools and methods we use to think. This thesis proposes a novel framework for activating large texts, particularly in the critical domain of climate resilience. In this thesis, I propose a response to the climate crisis that builds on the ways we reason with symbols and graphs as a means to accelerate interdisciplinary knowledge work.

The climate crisis is accelerating which imposes a shrinking timeline for innovating ways to face it. Furthermore, while we may need to create new tools and methods, we may already have solutions for climate crisis mitigation that lie unactivated in the silos of research repositories and their marginalia.

My thesis positions itself at the intersection of urgent global need and emerging technological possibility. At a moment in history when time saved in research could mean the survival of innumerable humans and other forms of life, the development of better ways to work with knowledge could hardly be more urgent.

1.1 Background and context

1.1.1 Research Problems and Significance

Our crisis of understanding demands new solutions, and fast. However, the growing amount of information makes it impossible to consider all data. As Drucker notes, "The expansion of access to any and all stored data that can be repurposed and remediated nearly boggles the mind" (Drucker, 2014, p. 194).

Working through all available information in every discipline to find climate resilience solutions would require an unsustainable amount of time and resources- if it is even possible. The endeavour of "developing the ability to cope with much larger amounts of information" (Sevaldson, 2022b, p. 34) can and should include developing tools that increase the efficiency of managing information complexity and facilitate conceptual translation between disciplines. Knowledge Activation, or activating connections between disciplines using computationally assisted methods of analyzing text and graphs, has the earth-changing potential to reveal solutions to global issues like the climate crisis. Paradigm-shifting solutions for climate resilience almost certainly exist already, and it is critical that we endeavour to find and apply them. Some new knowledge production will be necessary, but we may just need to activate the knowledge we already have.

1.1.2 Foundations of key ideas

Computational tools can accelerate climate resilience knowledge work. However, considering the integration of multi-disciplinary approaches required, we must co-inform "engineering capability with an imaginative sensibility" (Drucker, 2014, p. 195). To echo Drucker's epistemological and terminological shift in "*humanistic* forms of knowledge production" (Drucker, 2014, p. 10), I offer an etymologically-informed disambiguation of the term data.

The conventional use of the word *data* originates from one meaning of the Latin word *datum*: "something given or granted" (Oxford English Dictionary, 2024-12a), which removes interpretative agency from the 'receiver.' The Latin word *capta*, on the other hand, comes from the Latin word *capere* when it is used to mean "to take, receive, get, acquire" (Ashdowne et al., 2013) which shifts agency toward the receiver's choice in the *traditio* (tradition), or handing over (Oxford English Dictionary, 2024-12b), of knowledge.

Drucker defines capta as "a systematic expression of information understood as constructed, as phenomena perceived according to principles of observer-dependent interpretation" (Drucker, 2014, p. 131). Drucker adds that by "qualifying any metric as a factor of some condition, the character of the "information" shifts from self-evident "fact" to constructed interpretation motivated by a human agenda" (Drucker, 2014, p. 131). The use of the term data is obviously quite common. A shift towards using the term capta affects one of the foundational terms I use in this thesis, so I mention it here at the outset. The term Topological *Data* Analysis (TDA), a framework that uses topology to study the shape of information, is foundational to my literature review. To apply Drucker's terminology, I will use the term Topological *Capta* Analysis (TCA) to better align with the humanistic epistemological interpretative agency afforded by my thesis contributions. Although I generally agree with using the term *capta* and its emphasis on interpretative knowledge construction, its adoption requires a paradigmatic and linguistic shift that could detract from the clear directness needed to effectively explain my contributions in this text. For this reason I generally defer to the convention of the sources in my literature review when they use the term *data*. However, I remain open to fully adopting the term *capta* in future works.

My experience of knowledge involves a combination of both how I am changed by events *and* my interpretation of them. Given the conventional focus on how *data* are given facts, I will use *capta* in this thesis to emphasize my active grasping role in the act of interpretation.

1.1.3 Research Questions

Working within this background and context, I ask the following primary research question and seven secondary research questions:

RQ1 *What philosophical, mathematical, and computational approaches to textual/graphical analysis can accelerate knowledge work?*

RQ1.1 *What forms of spatial information visualization are there, and how can they inform the composition of network graphs?*

RQ1.2 *How can Computational Analysis of Texts and Graphs (CATG) identify isomorphic semantic structures within large network graphs?*

RQ1.3 *What methods can reveal the relationships between fundamental ideas in texts, graphs, or Large Language Models (LLMs)?*

RQ1.4 *Given the semantic versatility of symbols, how can a practice of collaborative symbol-making support knowledge production?*

RQ1.5 *How can CATG reveal relationships between place and text?*

RQ1.6 *What strategies can improve university knowledge management to accelerate research?*

RQ1.7 *What sort of knowledge work software would I want to build to incorporate my various findings and use spatial information visualization to identify isomorphic semantic structures, reveal the relationships between fundamental ideas, build on collaborative symbol-making, reveal relationships between place and text, and improve university knowledge management?*

1.1.4 Thesis Statement and Contributions

The climate crisis continues to accelerate faster than climate resilience research and operationalization can keep up. Novel approaches for Knowledge Activation can catalyze paradigmatic shifts in Sustainability Transitions (ST). The seven contributions of this thesis are a set of such novel approaches proposed for visuospatial Knowledge Activation (KA) using human-in-the-loop (HITL) Computational Analysis of Texts and Graphs (CATG), Human Analysis of Texts and Graphs (HATG), or both. These seven contributions would be used for the surfacing, synthesis, translation, and production of knowledge:

C1 *Semantic Forms*, a taxonomy of three-dimensional topic model compositions for HITL CATG, HATG, or both.

C2 *Query Isomorphs* as a means of Topological Capta Analysis (TCA) in HITL CATG using small graph chunks.

C3 *Ontological Semantic Network Summaries (OSNS)* as a means of revealing ontological relationships between ideas in a given body of research using HITL CATG, HATG, or both.

C4 *Symbol-setting*, a method for expanding the semiotic range of knowledge production using symbol co-creation in HITL CATG, HATG, or both.

C5 *Terroir of Text and Graphs (TTG)*, a method of HITL CATG that uses TCA to interpret and reveal semantic relationships between (a) texts and graphs, and (b) the features and systems of ecological place.

C6 *TCA Researcher Grouping*, a proposal to use TCA for grouping research collaborators more effectively using HITL CATG, HATG, or both; finally,

C7 *TCA Workspace*, a proposal for a collaborative platform for HITL CATG and HATG to:

(a) house all my thesis contributions (*Semantic Forms*, *Query Isomorphs*, *OSNS*, *Symbol-setting*, *TTG*, and *TCA Researcher Grouping*).

(b) facilitate their combined use with Systemic Design methods for visuospatial reasoning encountered through my literature review, such as gigamapping (Sevaldson, 2011) (Sevaldson, 2022b, p. 26) and Systematic Combining (Dubois and Gadde, 2002), (Kjøde, 2024).

The core of this thesis is a set of three tools for working with graphs of texts: Semantic Forms, Query Isomorphs, and TCA Workspace. Developing the TCA Workspace software platform has the potential to accelerate the surfacing and interpretation of interdisciplinary climate resilience knowledge using the computational analysis of texts and graphs. TCA Workspace would integrate Semantic Forms for the three-dimensional modeling of text graphs, Query Isomorphs for Topological Capta Analysis, and interdisciplinary symbolic co-creation as Symbol-setting. Furthermore, TCA Workspace would work co-benefit existing Systemic Design methods for managing complexity including gigamapping (Sevaldson, 2011), (Sevaldson, 2022b, p. 26), and Systematic Combining (Dubois and Gadde, 2002), (Kjøde, 2024). Epistemologically, TCA Workspace would function as a particle accelerator of ideas, where researchers would work with texts and graphs as activated webs of thought.

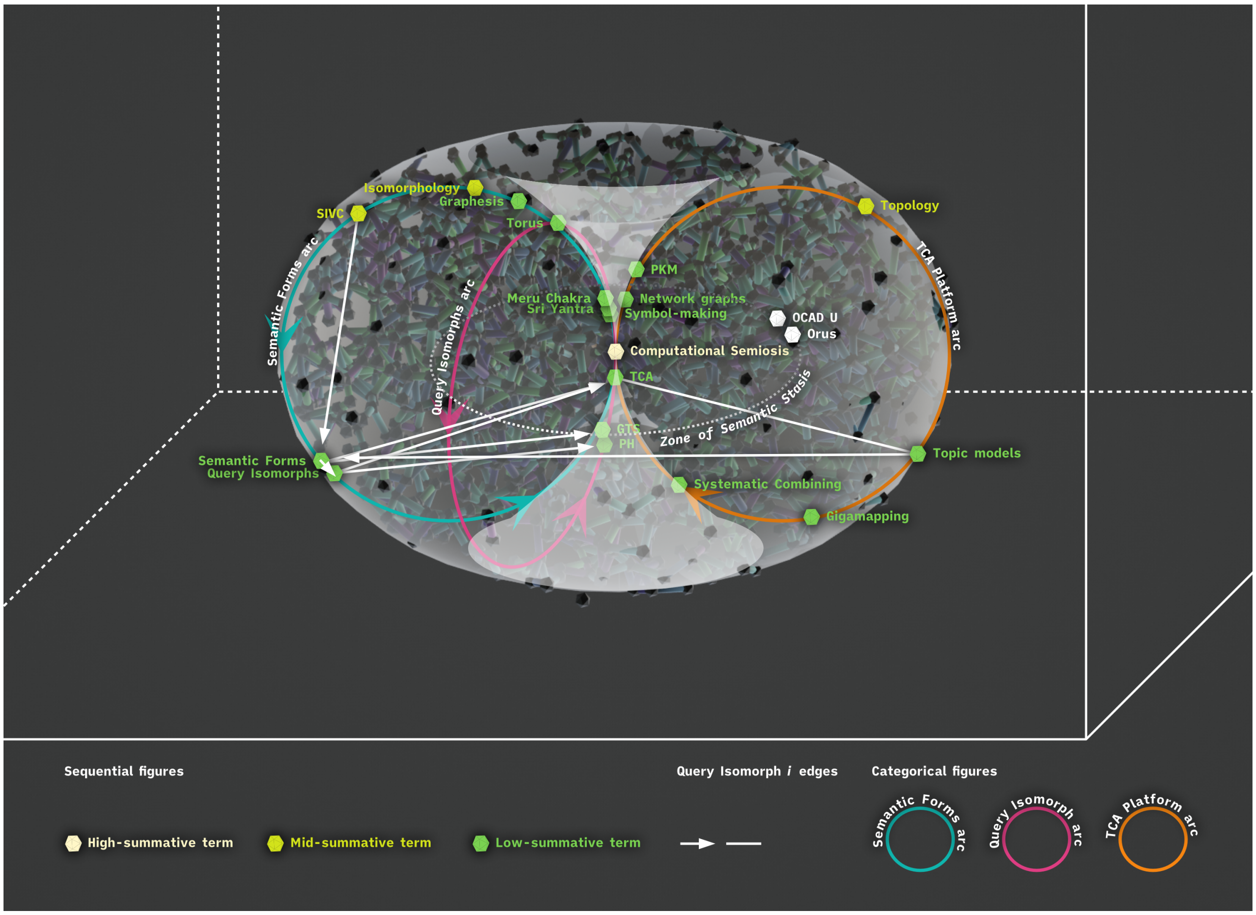

Figure 1.1: Preview of TCA Workspace illustrations. Horn Torus Semantic Form about Query Isomorph *i*. Render of how TCA Workspace would render a Query Isomorph about this thesis located in a Horn Torus Semantic Form network graph.

1.1.5 My prior work

In the OCAD U School of Graduate Studies, I am working across the programs for Digital Futures and Strategic Foresight and Innovation. As a brand designer, symbols and their connection to learning have been a longstanding interest of mine, and this sparked a strong desire for me to understand how to learn in a deeper way. This exploration led me to ways symbols could be represented in three-dimensional and multidimensional space over time. A significant breakthrough for me was understanding the two-dimensional Sri Yantra (Bühnemann, 2003, p. 2) alongside the three-dimensional Meru Chakra (Bühnemann, 2003, p. 31). My work at the intersection of theology, technology, and psychology led me to explore multidimensional forms as interfaces for capturing and examining complex ideas. My urgency in this work is to investigate ways of accelerating research, especially for climate resilience.

1.2 How this thesis is organized

The overall structure of my thesis is as follows: In the following chapters, this thesis will move from a literature review to secondary methodologies and methods, preliminary work, visuospatial models derived from theory, methodological and theoretical proposals derived from visuospatial models, a reflection on the literature review, a discussion of my contributions, and a conclusive call to action.

In Chapter 1, I introduced my thesis's background and context, research problems and significance, foundations of key ideas, research questions, thesis statement, contributions, and prior work.

In Chapter 2, Literature review, I present my mixed-methods scoping review. I frame the review with information about the climate crisis and various cognitive and social challenges it represents. I then present ways that approaches from design and computer science can help manage complexity. I then critique the terms "blind-spots," "black box AI," and "stakeholders." I end my identifying the gaps I observed in my literature review.

In Chapter 3, Secondary methodologies and methods, I present how I worked within the Research-Creation and Critical Systems Methodologies. Here, I present my methods, sampling strategy, and analytical approaches, including Systematic Combining and Meta-Systematic Combining.

In Chapter 4, Preliminary making, I present the art and design thought experiments that catalyzed this thesis: the composition of horn torus spatial information visualization. Next, I present my code and information analysis experiments in Personal Knowledge Management, topic models, and Small Language Models.

In Chapter 5, From theory and method to visuospatial models and back, I present the ways Semantic Forms, Query Isomorphs, and how they work together. Next, I present TCA Workspace. Last I present the theoretical and methodological contributions I arrived at through making visuospatial models: Ontological Semantic Network Summaries (OSNS), Symbol-setting, Terroir of Text and Graphs, and TCA Researcher Grouping.

In Chapter 6, Discussion of contributions, I retrace my research questions and present how my contributions respond to each.In this section, I also present the humanist post-structuralist design and multi-mathematical qualities of Semantic Forms, Query Isomorphs, OSNS, Symbol-setting, TTG, TCA Researcher, and the TCA Workspace platform overall.

In Chapter 7, Conclusion, I retrace the core problems I faced with research questions, present concluding syntheses, and offer a call to action.

2

Literature review

To address the compound crises of climate and information, we must produce new knowledge and activate existing knowledge from various disciplines. Solutions to the climate crisis may already exist but remain hidden in the overwhelming amount of information available. To rethink how we integrate knowledge, we must take an interdisciplinary approach.

2.1 Type of literature review

Following Grant and Booth's typology of reviews (Grant and Booth, 2009, p. 91-108), my thesis research uses mixed methods and a scoping review.

2.1.1 Mixed methods review

As a mixed methods review, I combine quantitative and qualitative research from different fields. My research project is an example of how mixed methods reviews should be, by their nature, interdisciplinary, which means they analyze various disciplines. Drawing from philosophy, computer science, and mathematics, I examine a "correlation between characteristics" to identify gaps in areas of literature (Grant and Booth, 2009, p. 94-95). In my research, I was unable to find studies, methods or platforms that propose or accomplish the following tasks simultaneously:

- Distinguishing the various modalities of knowledge and ranks them by their expense, including distinct definitions between modes of Knowledge Activation, including Surfacing, Synthesis, Translation, and Production. The limited subtlety in this subject makes climate resilience research more costly than it needs to be. It is imperative to distinguish and quantify the expense of various modalities of Knowledge Activation by their expense to reduce unnecessary costs in climate resilience research.

- Distinguishing three-dimensional forms by the various ways they capture and reveal reasoning and other semantic relationships as layouts for text graphs and graph chunks. The limited research in this area restrains exploration of Visuospatial Knowledge Activation in various fields, including neuroscience, learning psychology, and design. Visuospatial models facilitate understanding because they capture and reveal reasoning and semantic relationships in text graph composition and graph chunks.

- Distinguishing how capturing and revealing semantic relationships in text graphs can be distinctly non-computational with the *option* of being computational. In other words, I am pursuing solutions that do not impose but rather offer the option for computational analysis of texts and graphs (CATG), which keep humans in the loop (HITL). The limited distinction and combination of computational machine-driven and human-driven 'manual' methods in the visuospatial modes of Knowledge Production (a) hinders the use of valuable training data for LLMs that can support climate resilience research, (b) demonstrates that the practical applications of existing visuospatial modes of Knowledge Production lack a strong connection to research findings that indicate its value, and (c) limits the ways valuable technology can be used by climate resilience researchers. We must distinguish human-driven and machine-driven modes of VKA to take better advantage of each mode and the effectiveness of their combined use.

- Deployment of contemporary tools for the non-computational Human Analysis of Texts and Graphs (HATG) that relies on manual placement of words and visual elements in three-dimensional space (e.g. Systemic Design, Systems Oriented Design, Systematic Combining, Boundary Critique). The limited options in this area prevent us from using the full range of our human ability to reason in visuospatial modes of Knowledge Activation and the optical opportunities beyond the restrictions of two-dimensional information representation. We must build better tools for non-computational HATG using manual placement in three-dimensional space to more fully apply the creative potential of human VKA beyond two-dimensional limits.

- Methods that use HATG to train algorithms or LLMs. We must drive research in this area to increase the impact of LLMs in climate resilience research and overall research.

2.1.2 Scoping review

For my scoping review, I used a keyword search across various databases, including the terms information visualization, visuospatial, personal knowledge management, digital scholarship, and others.

To select the papers I read, I optimized for the depth of the coverage of each subject, opting for longer papers and publications whenever possible. I favoured primary research, which included more reflective pieces and experimental, qualitative, quantitative, and mixed-methods studies in various fields of mathematics and science, including systematic reviews.

I aimed to assess the "potential size and scope of available research" projects (Grant and Booth, 2009, p. 95). In doing so, I investigated whether any existing projects modelled the categorization of large groups of highly influential ideas in three-dimensional forms. Notably, I found only one example: Brian Sunter's Wikipedia graphs (Sunter, 2022, 2023).

I extended the scoping review method with a step recommended in systematic reviews, which often include a quality assessment step that inspired me to include recommendations for future research based on what remains unknown (Grant and Booth, 2009, p. 94-95). However, I cannot claim to propose what is *not* known; only what I suggest *may* be known.

2.2 Climate crisis: what is at stake

Despite the misinformation about climate change, there is a nearly complete consensus that human causes are to blame (Cook et al., 2016; Lynas et al., 2021). According to Pörtner et al., none "of the 20 2011–2020 Aichi biodiversity targets and none of the mileposts on climate trajectories intended to limit warming to 1.5°C have been met" (Pörtner et al., 2023, p. 1). The World Meteorological Organization (WMO) reports that the "past nine years, 2015–2023, were the nine warmest years on record" (World Meteorological Organization, 2024, p. 3). Despite this, greenhouse gas emissions continue to increase and "now exceed 55 billion tonnes of carbon dioxide equivalents" per year (Pörtner et al., 2023, p. 1). Key targets have not been met, and emissions continue to rise.

Our outlook is bleak if we do not work together: If the root causes of climate change and biodiversity loss are not properly "addressed or concrete actions to meet current political agreements [...] do not increase in pace and scale," the global sustainability targets "for 2030 and 2050 will likely fail" (Pörtner et al., 2023, p. 1). We need radical collective action that addresses "climate, biodiversity, and society" together, which "can help to avoid dangerous trade-offs and maximize cobenefits for humankind" (Pörtner et al., 2023, p. 1). To ensure a livable future, we urgently need bold policies that promote "interlinked human, ecosystem, and planetary health" through coordinated "institutions, governance, and social systems" at all levels, locally and globally (Pörtner et al., 2023, p. 1). Thus, we have to rethink how humans, our ecosystems, and planetary health are connected.

We need transformative policy and an integrated approach because of insufficient progress. Thus, new solutions are required, and fast. The changes required to achieve the aims of the United Nations Framework Convention on Climate Change (UNCCC), the Convention on Biological Diversity (CBD), and the United Nations (UN) 2030 Agenda for Sustainable Development and its Sustainable Development Goals "will rely on far-reaching mobilization and transformation actions of a type never before attempted" (Pörtner et al., 2023, p. 8). New solutions to the climate crisis must be brought to pass because we must "keep global warming below 1.5°C [...] to secure a livable future" (Pörtner et al., 2023, p. 8). We need rapid, unprecedented, and transformative actions to secure a livable future.

The climate crisis demands urgent, transformative action. Such action must include the development of better research tools. By failing to mobilize coordinated global efforts, we will miss critical targets and catastrophically worsen biodiversity loss, threatening all life.

2.3 Sociopolitics

Clinging to the hope that we are yet discussing humanities and not posthumanities, I posit that the climate crisis is a crisis of understanding, institutionally and socially.

The social change that comes from coming to a climate-related understanding can be expressed as "social tipping," a term used by Pörtner et al. (Pörtner et al., 2023). They explain that societal change demands aligning technology, policy, and human behaviour to fundamentally reshape our systems. This will facilitate "targeted and "contagious" interventions with positive impacts on climate, biodiversity and human well-being" (Pörtner et al., 2023, p. 7). Such coordinated efforts are crucial to address our global challenges.

A proposed action in the "solution space" emphasizes the relevance of using "integrated and multifunctional interventions" from a range of "adaptive solutions" rather than following a single approach (Pörtner et al., 2023, p. 1). Furthermore, more "innovative and flexible governance approaches" can allow local communities the autonomy to choose "between alternative pathways to transformative change" (Pörtner et al., 2023, p. 7). In short, Pörtner et al. present a vision of climate action that is characterized by diversity, flexibility, and local empowerment. This challenges more monolithic conventional approaches.

Social tipping is politically restricted by a lack of cohesive policies across sectors. This is especially evident "in separate UN conventions such as UNFCCC and CBD" and often conflicts with priorities of "national governments who in turn have their own siloed approaches" (Pörtner et al., 2023, p. 7). Although "integrated solutions for the nexus" of climate, biodiversity, and society offer benefits for "sustainable development" and address the "needs of the poor and vulnerable," the design and funding of these approaches are challenging "because they require the cooperation of multiple actors across scales" (Pörtner et al., 2023, p. 7). Social tipping requires reconsidering how governance systems operate within the interconnected problems of environment, society, and economy.

Social tipping as a shift in understanding is no small feat: "Activating such social tipping interventions necessarily involves a shift of individual and collectively shared social values away from individualism and materialism to principles such as responsibility, stewardship, and justice" (Pörtner et al., 2023, p. 7). Nonetheless, the more we do well, the more we will want to do well: "This vision of inclusive, integrative, and adaptive decision-making can overcome societal and political inertia" (Pörtner et al., 2023, p. 8). These solutions can "help society to avoid crossing biophysical tipping points and their worst impacts," while also contributing to a "more just and sustainable world" (Pörtner et al., 2023, p. 8). Social tipping towards sustainability will only be possible as an initiative of climate resilience if we collectively shift our baseline values. This includes a shift to de-emphasize individualism towards collective well-being and responsibility. A shift like this carries the hope of catalyzing a virtuous cycle that overcomes the inertia of social and political stratification and marginalization in a way that helps mitigate environmental catastrophe.

Rapid action is required, "which entails transformative change through transformative governance" (Pörtner et al., 2023, p. 7). To echo Pörtner et al., rapid action in governance draws "on collaborative solutions across integrated systems, involves" diverse actors and values "about nature, engages different knowledge systems through more equitable approaches, and adaptively manages complex interactions" (Pörtner et al., 2023, p. 7). In essence, we need these collaborative solutions within all relational structures.

Humans risk squandering our limited chances to shift away from siloed approaches that, as Pörtner et al. claim, reinforce sociopolitical inaction, individualism, and materialism (Pörtner et al., 2023, p. 7). If we want to maintain some of the international frameworks we call modern, we have to nurture the relationships and build the tools that bring about just, "inclusive, integrative and adaptive decision-making" across policy sectors and solutions with "cobenefits in terms of sustainable development" (Pörtner et al., 2023, p. 7-8). The impact of information technology innovation can fundamentally improve the sustainability of governance needs by improving collaboration across sectors.

Our predominantly capitalistic political and economic context inflicts harm to our ecology, which must be named and challenged. Timothy Morton asserts: "Since its beginnings, capitalism has used war and catastrophe to reinvent itself. The current catastrophe is no exception. We should reject the false choice between the "politics of possibility" and a "return to Nature." Instead, let's use this moment to imagine what sort of noncapitalist society we want" (Morton, 2012, p. 133). This includes redefining the politics of computer production "in the face of combined corporate and state power" (Chan et al., 2013, p. 1). As it stands, the domination of digital technology perpetuates imperialism (Kwet, 2018, p. 1), child labour at its worst (Amnesty International and Afrewatch, 2016, p. 36), and formidable health hazards to children and pregnant parents caused by e-waste (Heacock et al., 2016, p. 1). The ecological crisis demands a re-imagining of non-capitalist societal structures. It challenges the current paradigm where digital technology—despite its potential—often perpetuates imperialism, exploitative labour practices, and environmental harm.

We must "imagine collectivity rather than community-groups formed by choice rather than by necessity"

(Morton, 2012, p. 135). Morton asserts: "We have barely become conscious that we have been terraforming Earth all along. Now we have the chance to face up to this fact and to our coexistence with all beings" (Morton, 2012, p. 133). In some ways, Morton's dedication in *Hyperobjects* (Morton, 2013) "To my extended families" [1] extends the notion of family beyond chosen family to include all beings in a heartbroken plea against our own self-destruction.

Notwithstanding the challenges of misinformation and disinformation caused by human machinations and AI hallucinations, the climate crisis remains a crisis of understanding. Herein lies the critical role of information and how it becomes Visuospatial Knowledge Activation as the bridge between the dangers we are in and the discovery of better solutions.

2.4 Cognition

2.4.1 Information overload

The unmanaged overflow of information we receive about the climate crisis is an obstacle we face, in addition to the challenges inherent to the crisis. Terms related to *information overload* are outlined by Eppler and Mengis (Eppler and Mengis, 2004, p. 326), and include *cognitive overload* (Vollmann, 1991), *sensory overload* (Lipowski, 1975), *communication overload* (Meier, 1963), *knowledge overload* (Hunt and Newman, 1997), and *information fatigue syndrome* (Wurman et al., 2001).

The relevance of information overload to Knowledge Production is not new. Bawden and Robinson note that overload was mentioned by name as a problem at the Royal Society's Scientific Information Conference in 1948. In it, Maurice Line comments: "Not for the first time in history, but more acutely than ever before," scientists feared that the overwhelming flow of information would exceed their ability to manage it, putting "science itself [...] under threat" (Bawden and Robinson, 2009, p. 183). Information overload and the difficulty of managing the vast amount of potentially relevant material is not a new challenge, but the rate and scale at which new information is produced and made available poses an increasingly serious challenge to researchers at a highly critical time. This complex of problems requires new strategies and new tools.

[1] Morton's dedication in *Hyperobjects* (Morton, 2013), "To my extended families", inspired my dedication statement in this thesis.

2.4.2 Hyperobjects

As complex as the question of information is, the question of information overload about the climate crisis is, of course, much larger. In *The ecological thought* (2012), Timothy Morton conveys this fearsome scope of being. Morton coins the term hyperobjects to mean "things that are massively distributed in time and space relative to humans", global warming being one of them.

Morton portends: "Hyperobjects invoke a terror beyond the sublime, cutting deeper than conventional religious fear. A massive cathedral dome, the mystery of a stone circle, have nothing on the sheer existence of hyperobjects" (Morton, 2012, p. 131).

Morton forebodes that in addition to global warming, hyperobjects like styrofoam and plutonium will be part of the lasting human legacy. These materials will outlast current social and biological forms, the same way plastic takeout boxes last for hundreds of years, and plutonium remains for thousands, longer than Stonehenge has existed (Morton, 2012, p. 130). Morton posits that hyperobjects, such as global warming and enduring pollutants, evoke a uniquely modern terror by existing on scales that dwarf human comprehension.

The illusion of current AI as a generator of knowledge would seem to elevate it to an authoritative position as a potential saviour in the climate crisis hyperobject. The possibility of mechanical agency notwithstanding, the set of relationships that any AI uses to generate media are the result of interpretations used in every step of its design—from the algorithm constructions to the words captured as tokens and stored in vector graph form. Let us remember that despite the means of constructivist designerly and literary definitions (like points, lines, words, and metaphors), we set the object—only to begin again—always in semantic motion. Nonetheless, setting definitions benefits Knowledge Production— even for a short while of centuries before we can observe deeper paradigms.

2.4.3 Coping by using design

Conversely to *overload*, methods exist for *coping* with more complex information visually. Considering the cognitive overload of the climate hyperobject, I turn here to the practice of design– specifically Systems Oriented Design (SOD). SOD is a graphing methodology developed by Birger Sevaldson which hones "the ability to cope with much larger amounts of information" (Sevaldson, 2022b, p. 34). Sevaldson asserts that visualization "is simply the best way to understand complex issues" (Sevaldson, 2022b, p. 34). They stress the designer's "inherent ability to work with complexity" and their "advantage in visual reasoning and thinking" (Sevaldson, 2022b, p. 34). SOD, thus, uses visualization alongside designers' capacities for visual reasoning to tackle the cognitive challenges posed by complex issues like climate change.

2.4.4 The visuospatial

Barbara Tversky's work in the neuroscience of the visuospatial examines the implications of how brains evolved to handle position in space before they evolved the ability to handle language. Neurologically and behaviourally, Tversky has found that "spatial thinking is the foundation of all thought" and that "the foundation for spatial thought is also the foundation for conceptual thought" (Tversky and Parrish, 2022). Building off Tversky, it is not an exaggeration to state that our sense of place in space precedes and fundamentally shapes communication, language, and reason.

2.5 Ideas and their 'place' of origin

Kant questions "whether ideas do in fact represent their objects and, if so, how (in virtue of what) they do so" (Gutting and Oksala, 2022). One proposal for addressing Kant's questioning of ideas and their representation is to adopt a post-structuralist posture of interpretation, as Drucker has (Drucker, 2014, p. 177-185), in which ideas are not uncritically used as "unproblematic vehicles of knowledge" (Gutting and Oksala, 2022). However, this does not constitute that representation has nothing to do with knowledge (Gutting and Oksala, 2022). In fact, the formal methods of Knowledge Production remain examples of how "some (or even all) knowledge still essentially involved ideas' representing objects" (Gutting and Oksala, 2022). Foucault considered that Kant made it possible to think about representation itself, and the ideas that are represented could be considered to originate in something besides representation (Gutting and Oksala, 2022).

This *other-origin* is addressed in theological terms as a transcendental agent unto itself who can choose to reveal themselves to people. Mircea Eliade asserts that humanity "becomes aware of the sacred because it manifests itself, shows itself, as something wholly different from the profane" (Eliade, 1987, p. 11). He defines hierophany as "the act of manifestation of the sacred", "that something sacred shows itself to us", a "mysterious act" in which "the manifestation of something of a wholly different order, a reality that does not belong to our world, in objects that are an integral part of our natural "profane" world" (Eliade, 1987, p. 11). Eliade proposes that the history of religions "is constituted by a great number of hierophanies, by manifestations of sacred realities" (Eliade, 1987, p. 11). As a further articulation, Eliade proposes a matrix of hierophanic complexity in two tiers: first, elementary, in which the sacred manifests in an ordinary object such as "a stone or a tree"; second, Elide proposes supreme hierophany with the example of Christian incarnation, in which a supreme God becomes flesh as a human. To underscore the differentiations between Eliade's two tiers in four differentiators, he proposes a general 'sacred [which] manifests' as a lower tier of divine force/entity, and "ordinary object[s], like a stone or a tree" as lower objects in the profane. Eliade's second and elevated tier of hierophany, *supreme hierophany*, is characterized as including a supreme and singular God- capital 'g'- into a human, considered by him an elevated caste of being. This anthropocentric elevation of humanity is certainly not the only way to weigh the value of being, and differing frameworks will be discussed later in the discussion of Indigenous perspectives on the diversity of intelligences and so-called Artificial Intelligence.

2.6 Language and knowledge

In linguistics, structuralism upholds that "language is a self-contained relational structure, the elements of which derive their existence and their value from their distribution and oppositions in texts or discourse" (The Editors of Encyclopaedia Britannica, 2024b). In contrast, poststructuralism holds that "language is not a transparent medium that connects one directly with a "truth" or "reality" outside it but rather a structure or code, whose parts derive their meaning from their contrast with one another and not from any connection with an outside world" (The Editors of Encyclopaedia Britannica, 2024a). Among writers whose work aligns with this movement are Roland Barthes and Michel Foucault.

Terry Eagleton summarizes Barthes's description of the shift in thinking from structuralism to poststructuralism as "a movement from 'work' to 'text'" (Eagleton, 2006, p. 120). Eagleton elaborates: "It is a shift from seeing the poem or novel as a closed entity, equipped with definite meanings which it is the critic's task to decipher, to seeing it as irreducibly plural, an endless play of signifiers which can never be finally nailed down to a single centre, essence or meaning" (Eagleton, 2006, p. 120). Herein lies the role of the network graph as a means of expressing decentralized meanings using signifiers like word, point, and line. Drucker points out that the "shift to expressive metrics and graphics" is crucial in moving from "*expression of constructed, interpretative information*" to "*constructed expression of perceived phenomena*" (Drucker, 2014, p. 130). Interpretation in this sense involves more than just "constructedness and inflection" (Drucker, 2014, p. 130).

Drucker offers a departure from the term data, which claims to convey fact. In practice, this is a leap of reasoning. Drucker characterizes "all information as constructed: as expressing the marks of its inflection in some formal way" (Drucker, 2014, p. 130). Drucker differentiates *data* from *capta*, which "is not an expression of idiosyncracy, emotion, or individual quirks, but a systematic expression of information understood as constructed, as phenomena perceived according to principles of observer-dependent interpretation" (Drucker, 2014, p. 131). Drucker goes on to clarify that to "do this, we need to conceive of every metric "as a factor of X," where X is a point of view, agenda, assumption, presumption, or simply a convention" (Drucker, 2014, p. 131). Overall, by "qualifying any metric as a factor of some condition, the character of the "information" shifts from self-evident "fact" [, or data,] to constructed interpretation motivated by a human agenda [ie. capta]" (Drucker, 2014, p. 131). Drucker challenges the notion of objective data, proposing instead the concept of 'capta' to emphasize that all information is inherently constructed, shaped by observer-dependent interpretation, and should be understood as a product of specific viewpoints rather than as self-evident facts.

2.6.1 Risks and opportunities of expanding narrow language

We turn here from a philosophical perspective to a more practical and linguistic scope. Specifically, cyberneticist Paul Pangaro's work on language in organizations is synthesized in his conversational model of co-evolutionary design. Pangaro examines conversation by building on influences from Hugh Dubberly, Heinz von Foerster, Michael C. Geoghegan, and Gordon Pask to develop his model of co-evolutionary design. In Pangaro's model, conversation is used to iterate and evaluate across four phases: (a) to agree on goals, (b) to "design the designing", or to design "a new space of possibilities" (c) to create new language, (d) to agree on means, back to (a), and so on (Pangaro, 2011, p. 185). Pangaro's model emphasizes conversation as a cyclical tool for organizational innovation.

To call in an equity-driven orientation for the linguistic work of information practice, I will expand the scope of point "A" in Pangaro's model, "Conversation to Agree on Goals" (Pangaro, 2011, p. 185). Antionette D. Carroll and her team at Creative Reaction Labs have developed a guide for Equity-Centred Community Design (ECCD), which charges the conversational component of Pangaro's co-evolutionary design with an ethos of justice-oriented intersectional co-creative solidarity. Creative Reaction Labs define "language setting" as developing "agreed upon definitions for any recurring terms you will use throughout your work" in ECCD (Creative Reaction Lab, 2018, p. 8-9). I will later propose Symbol-setting as a semiotic expansion of language setting and collaborative Knowledge Production.

I return here to Pangaro and his 2011 presentation for the MIT Design and Computation Group, where he examines the "Role of **Leadership and Language** in Regenerating Organizations" (Pangaro, 2011, p. 142)[2]. The bold text is in keeping with Pangaro's text. In this presentation, he argues that "an organization is its **language**" (Pangaro, 2011, p. 143). An organization is made of conversations: "who talks to whom, about what" (Pangaro, 2011, p. 143). The organization is perpetuated by conversation in that it leads to agreement, which leads to transaction (Pangaro, 2011, p. 143).

Pangaro presents the opportunities and risks of specificity. The opportunity lies in how "narrowing **language** increases efficiency" (Pangaro, 2011, p. 144). However, jargon developed in organizations "to solve specific problems" grows and leads to an overly narrow scope of communication over time (Pangaro, 2011, p. 144).

"Narrowing **language** also increases ignorance" (Pangaro, 2011, p. 145). An organization's specialized jargon, while efficient for current business operations, can become a barrier to innovation in "research, new discoveries, new approaches. Like all of us, they cannot recognize their own limitations. Constrained by the previously successful language, we do not know that we do not know. Consequently, we think we know- and thus cannot learn. Developed as a tool to increase efficiencies, the organization's language, paradoxically, becomes a trap" (Pangaro, 2011, p. 145). In other words, Pangaro warns that while specialized jargon enhances efficiency, it can inadvertently limit an organization's capacity to recognize innovation and adapt beyond its shortcomings.

Birger Sevaldson might frame Pangaro's narrowing of language as the problem of defaulting to simplification. As a paradigm that is widely "regarded as positive in our culture", Sevaldson cites examples from management and philosophy of science like the "managerial cliché" "KISS: Keep it Simple Stupid" and "Occam's razor" (Sevaldson, 2022b, p. 98). The danger of "modernist simplification" is that it attempts to "remove all symbolism and expression from design, and reduce it to its "essence"" (Sevaldson, 2022b, p. 98). Sevaldson asserts that it "is not possible to reduce human life to such simplifications, nor is it possible to rid the meaning, values, and symbols from design without losing out on the richness of our culture" (Sevaldson, 2022b, p. 98). I would add, as a premise of interdisciplinarity and syntopical consilience, that Pangaro's "narrowing of language" and Sevaldson's perspective on oversimplification are emblematic of disciplinary siloing that causes researchers to lose out on rich semantic depth.

Returning to Pangaro, conversely, "expanding **language** increases opportunity. The conversations necessary

[2] Bolded text in quotes by Paul Pangaro reflects his original emphasis and were preserved to honour his formatting.

for generating new opportunities come from the outside system. For an organization to survive, it must be able to acquire new, relevant language domains" (Pangaro, 2011, p. 147) Pangaro then claims that "to regenerate, an organization creates a new **language**. To support an organization's future viability, effective decision-makers actively introduce change into the system. They do so by generating new language that appropriate groups in the organization come to understand and embrace. This new language does not overtly challenge the pre-existing, efficient system, but rather creates new distinctions and supportive relationships" (Pangaro, 2011, p. 148). Pangaro argues that organizational growth and renewal depend on expanding language through external input and internal production of new terminology, which introduces change while supporting existing systems.

Sevaldson and P.W. Anderson discuss the epistemological risks of narrowing and expanding language and its impact on interdisciplinarity. Sevaldson claims that "adding up of elements changes the interplay between them so that new levels of interpretation are needed for each level of complexity" (Sevaldson, 2022b, p. 99). Anderson explains further that the reductionist scientific approach, while powerful for understanding "simple fundamental laws," does not provide a complete picture of a complex system (Anderson, 1972, p. 393). As complexity increases, new laws and concepts emerge that cannot be easily derived from simpler elements (Anderson, 1972, p. 393). Anderson emphasizes this point, stating that "Psychology is not applied biology, nor is biology applied chemistry" (Anderson, 1972, p. 393). Each complexity level requires its own set of theories and creative insights.

Sevaldson wrote that the "contradiction [sic.] between arts and science are constructed and have their roots in an old dichotomy between those fields. In design discourse, the arts are often dismissed as being intuitive, creative, and based on metaphors, etc. But intuition, creativity, and metaphors are all part of science. This dichotomy between art and science is relatively new and should not be taken as a given. There is no logic that moving away from art will make design more scientific" (Sevaldson, 2022b, p. 159). As Anderson wrote, "we must all start with a reductionism" (Anderson, 1972, p. 394), but this does not preclude integration of systems, ideas, and methods, and even disciplines.

Psychology not being applied biology notwithstanding (Anderson, 1972, p. 393), emerging fields in the natural sciences are evidence of disciplinary integration by converging towards the social sciences (Wilson, 1999, p. 208). Wilson notes the following four examples: first, cognitive neuroscience, which draws on cognitive psychology to "solve the mystery of conscious thought" (Wilson, 1999, p. 208-209); second, human behavioural genetics is investigating the impact of "genes on mental development" (Wilson, 1999, p. 209); third, evolutionary biology and Sociobiology are endeavouring to "explain the hereditary origins of social behavior" (Wilson, 1999, p.

209); fourth, environmental science necessitates the integration of disciplines beyond biology and social sciences, which are individually not flexible enough to grasp the natural environment fully as "the theater in which the human species evolved and to which its physiology and behavior are finely adapted" (Wilson, 1999, p. 209).

Pangaro differentiates the axiomatic differences of two key organizational roles: manager and entrepreneur. He illustrates that the Manager seeks efficiency within the organization, while the entrepreneur seeks opportunity outside, in the environment (Pangaro, 2011, p. 142-149). In the pursuit of interdisciplinary consilience, and analogous to these and other seemingly dichotomous perspectives, we may be syntopically proposing a third point of view to improve these and other opposing paradigms.

2.6.2 Language, abduction, and model building

In computational text analysis and knowledge representation, understanding the structures and patterns inherent in language is crucial for developing effective models that can navigate and interpret vast amounts of textual information. One such approach to capturing these structures is through the use of canonical graphs, as introduced by Sowa (Sowa, 2013, p. 53).

A canonical graph "is a conceptual graph that represents a pattern or schema that is typical for a given concept type" (Sowa, 2013, p. 53). Canonical graphs encode patterns typically associated with a given concept or relation type (Sowa, 2013, p. 53). Canonical graphs "can be used to select theories or other knowledge relevant to subjects described by those concepts" (Sowa, 2013, p. 53). For example, canonical graphs for verbs specify "case relations" or "thematic roles" and the constraints on their concept types (Sowa, 2013, p. 53).

Sowa illustrates how individual concepts can map onto a graph representation of the various interrelations of ideas, or a "lattice of theories" (Sowa, 2007, p. 12). In the figure titled "words → types → canonical graphs → lattice of theories" (Sowa, 2007, p. 12), Figure 2.1, a word branches out to multiple concept types, each represented by a distinct canonical graph. In turn, each canonical graph points to a different location within the lattice, representing intersections of theories and concepts.

Navigating this lattice involves selecting the most appropriate theory or combination of theories to explain a given phenomenon. This process is inherently abductive in a Peircean sense since it relies on inferring an explanation. I introduce abduction in more detail in the Knowledge Production portion later in this literature review. In a machine learning context, abduction plays a crucial role in nonmonotonic reasoning by providing "formal methods that enable intelligent systems to operate adequately when faced with incomplete or changing information" (Antoniou, 1997), where conclusions may change in light of new evidence. According to Sowa, all methods of nonmonotonic reasoning can be viewed as strategies for finding a path through the lattice to a preferred theory (John F. Sowa, 2007, p. 60).

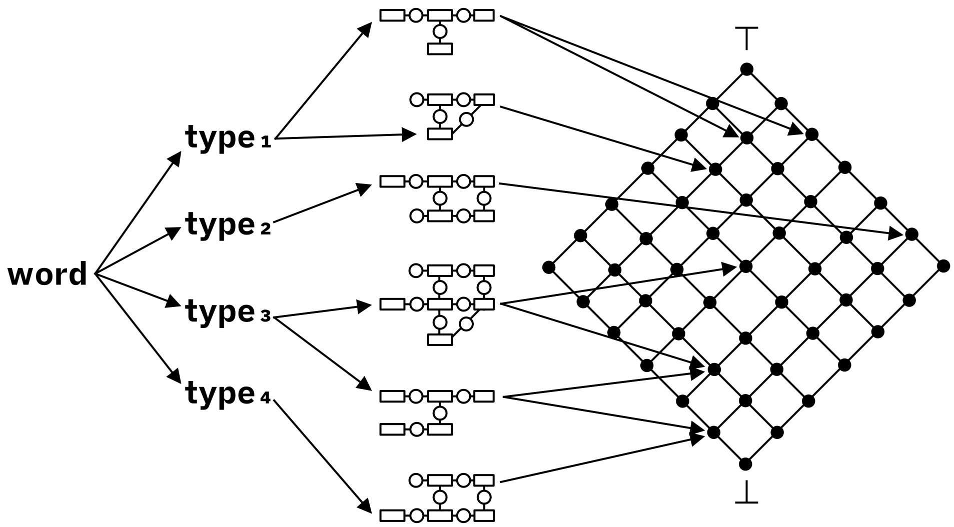

Figure 2.1: Conceptual graphs in the lattice of theories. Based on John F. Sowa's illustration "Mapping word fans to a lattice of theories", also named by Sowa as "words → types → canonical graphs → lattice of theories" (John F. Sowa, 2007, p. 12).

To navigate the lattice of theories, Sowa proposes the use of operators from the AGM (Alchourrón, Gärdenfors, and Makinson) framework for theory revision: contraction, expansion, and revision (Alchourrón et al., 1985). Additionally, analogy enables drawing parallels that transfer knowledge between different domains, computationally achieved by relabelling concepts and relations. It follows that we can understand the AGM operators and analogy together as a single unit:

- *Contraction* involves reducing the set of beliefs or theories to eliminate inconsistencies.
- *Expansion* adds new information or hypotheses to a set of existing beliefs.
- *Revision* modifies an existing theory to accommodate new evidence while maintaining theory consistency.
- *Analogy* allows for the transfer of structure from one domain to another, facilitating innovative solutions.

Sowa's figure "Four operators for navigating the lattice of theories" (Sowa, 2007, p. 11), Figure 2.2, visually represents these concepts. The lattice subgraph is depicted as a diamond-shaped structure with points labelled A, B, C, and D. Edges connecting these points are labelled with the AGM operators—Contraction, Expansion, Revision, and Analogy—illustrating the possible transitions between different theories within the lattice across node edges.

Sowa's quadruple operators iterate by revising old models. Sowa aligns this practice-oriented computational text analysis with George Box's famous statement: "All models are wrong but some are useful" (Box, 1979, p. 202) (Sowa, 2013, p. 25).

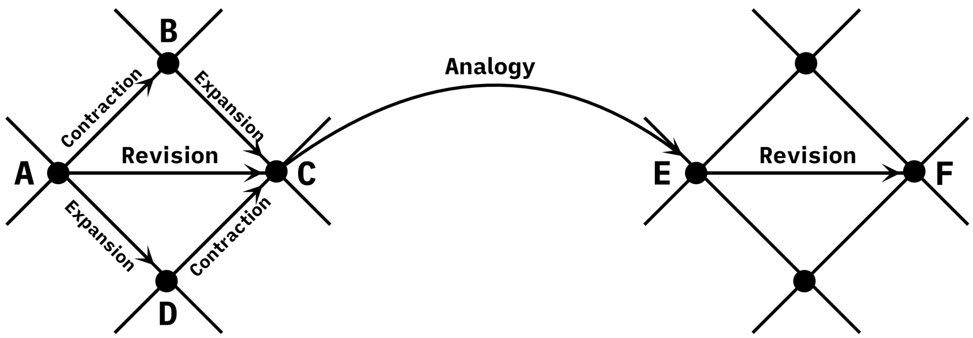

Figure 2.2: "Four operators for navigating the lattice of theories" based on John F. Sowa's illustration (Sowa, 2007, p. 11).

In the illustration titled "Model-Theoretic Semantics" (Sowa, 2013, p. 25), Figure 2.3, Sowa presents the relationships between the World, the Model, and the Theory:

- The World and the Model relate through Approximation, acknowledging that models are simplified representations of the complex world.

- Approximation leads to assessments of the model's quality: "Good, Fair, Poor".

- The Model and the Theory relate through Denotation concerning the truthfulness or accuracy of the theory in representing the model.

- Denotation leads to assessments of the theory's validity: "True, False" (Sowa, 2013, p. 25).

This "model-theoretic" (Sowa, 2013, p. 25) perspective emphasizes that models and theories help us understand and interact with the world, but they are incomplete. Recognizing this limitation requires ongoing refinement and adaptation, which is essential when dealing with wicked problems in STKA.

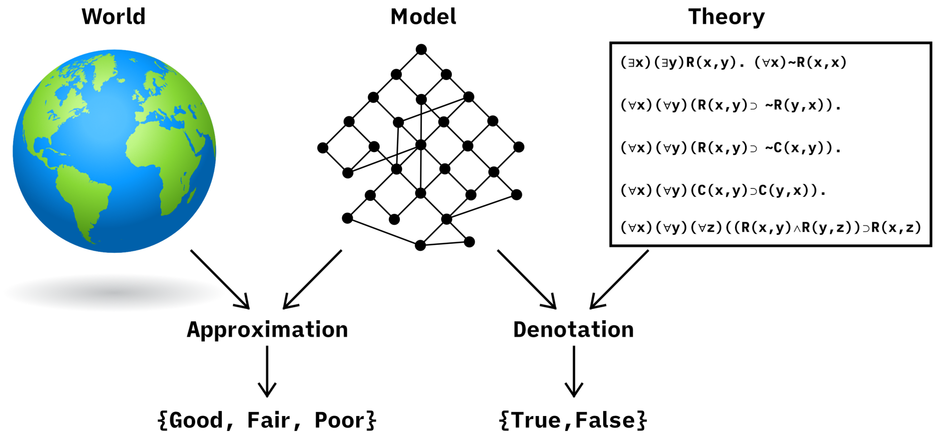

Figure 2.3: "Model-Theoretic Semantics" based on John F. Sowa's illustration (Sowa, 2013, p. 25).

2.6.3 Language, logic and computational graphs methods

2.6.3.1 Conceptual Graphs and Analogical Reasoning in Knowledge Representation

Understanding and processing complex information structures requires models that can bridge the gap between images, logic, and language. John F. Sowa introduces conceptual graphs as a means of capturing the richness of thought in a structured and computational form. Conceptual graphs are not as detailed as image-like mental models (Craik, 1952, p. 61), which can represent vast amounts of information "rarely expressed in words", but they offer a balance between specificity and technological feasibility (Sowa, 2008, p. 7).

Kenneth Craik's mental model hypothesis underscores the importance of internal representations: "If the organism carries a small-scale model of external reality and of its own possible actions within its head, it is able to carry out various alternatives, conclude which is the best of them, react to future situations before they arise, utilize the knowledge of past events in dealing with the present and the future, and in every way react in a fuller, safer, and more competent manner to the emergencies which face it" (Craik, 1952, p. 61).

Building on Craik's mental models, conceptual graphs act as a manageable abstraction of these mental models. Each graph represents one perspective on an infinite array of options, encapsulating a particular "conception" with its own ontology (Sowa, 2008, p. 8). However, the same reality can be represented with different ontologies, leading to different conceptual graphs for the same phenomenon (Sowa, 2008, p. 8).

2.6.3.2 Aligning ontologies for interoperability

A challenge in using conceptual graphs is the need to align diverse ontologies. Topics can be described at varying levels of detail, with different labels for concepts and relations (Sowa, 2008, p. 8). There is no universally accepted upper-level ontology that encompasses every academic discipline. However, multiple upper ontologies do exist in computer science, such as Cyc, OpenCyc, SUMO, DOLCE, BFO, and others (López-Gil et al., 2016, p. 3).

Analogous to the function of interoperability in upper computational ontologies, the challenge of operating despite different ontologies requires mapping ontologies so that systems can share and integrate knowledge effectively.

2.6.3.3 Peirce's Classification of Reasoning and the Role of Analogy

Sowa summarizes the four Peircean methods of logic, in addition to analogy, as follows: (1) deduction as "deriving implications from premises", (2) induction as "deriving general principles from examples", (3) abduction as "forming a hypothesis that must be tested by induction and deduction", and (4) analogy, in Peirce's own words, "combines the characters of the three, yet cannot be adequately represented as composite" (Peirce in Sowa, (Sowa, 2004, p. 20). Analogy is "more primitive, but more flexible than logic"; conversely, the "methods of logic are disciplined ways of using analogy" (Sowa, 2004, p. 20).

Sowa offers an analogy to illustrate analogy's relationship with the two other methods of logic: "Logic is to analogy as dancing is to walking. Dancing is a stylized form of walking that uses the same muscles and motions as walking, but in a more structured, disciplined form. Logic is a stylized form of analogical reasoning that uses the same mental processes, but in a more structured, disciplined form" (Sowa, 2004, p. 28).

2.6.3.4 Structure Mapping

Sowa outlines that "mapping one conceptual structure to another can have four logical effects:

1. Equivalence: $CS1 \equiv CS2$
2. Generalization: $CS1$ implies $CS2$
3. Specialization: $CS2$ implies $CS1$
4. Similarity: Neither one implies the other" (Sowa, 2004, p. 28).

Analogy utilizes all four kinds of mapping, while logic uses only the first three kinds. Sowa asserts that these mechanical and neurophysiological mechanisms underlie all kinds of structure mapping (Sowa, 2004, p. 28).

To operationalize analogical reasoning in computational systems, Sowa and Arun K. Majumdar developed the **VivoMind Analogy Engine (VAE)**. VAE employs three structure-mapping methods and conceptual graphs in analogical reasoning to compare and map conceptual structures: (1) **matching labels** "compares nodes that have identical labels, labels that are related as subtype and supertype such as Cat and Animal, or labels that have a common supertype such as Cat and Dog" (Sowa and Majumdar, 2003, p. 21). (2) **matching subgraphs** "compares subgraphs with possibly different labels. This match succeeds when two graphs are isomorphic (independent of the labels) or when they can be made isomorphic by combining adjacent nodes" (Sowa and Majumdar, 2003, p. 21-22). (3) **matching transformations** "If the first two methods fail, Method #3 [matching transformations] searches for transformations that can relate subgraphs of one graph to subgraphs of the other" (Sowa and Majumdar, 2003, p. 22). This method processes analogies of analogies and which requires more time (Sowa, 2004, p. 29). VAE is an example of the ways Computational Analysis of Texts and Graphs can support human reasoning via analogy, setting the stage for interdisciplinary computational reasoning.

2.6.3.5 Concluding thoughts on flexibility and open systems

Natural language is "acquired by its users without special instruction as a normal part of the process of maturation and socialization" (Lyons, 1991, p. 1). The characteristic flexibility of natural language enables it to express everything from vague ideas to precise specifications. Formal theories–and computer language–cannot be vague, "but they can be underspecified", and they can be "organized to facilitate revision and reuse" (John F. Sowa, 2007, p. 18). As a result, Sowa recommends that formal systems work to "emulate the flexibility of natural languages" and "emphasize interoperability" (John F. Sowa, 2007, p. 18). In short, to develop knowledge representation methods, in graphs and otherwise, formal systems should work to prioritize interoperability between multiple contexts by incorporating the flexibility of natural language. Sowa summarizes this perspective with the words of Alfred North Whitehead, who wrote: "We must be systematic, but we should keep our systems open" (Whitehead, 1938, p. 8) (John F. Sowa, 2007, p. 18).

By integrating analogical reasoning and maintaining openness in our systems, we make the space to advance toward more interconnected models of knowledge—a necessary step in addressing complex global challenges with computer-assisted Knowledge Activation.

2.6.4 Network graphs

This section introduces network graphing in small chunks, three dimensions, more than three dimensions, and a historical example of a figure which is both two-and-three-dimensional.

2.6.4.1 Graph chunks

Pržulj et al. use the term *graphlets* to mean "network subgraphs" or "a connected network with a small number of nodes" (Pržulj et al., 2004, p. 5-6). Sarajlić et al.'s illustration of directed graphlets (Sarajlić et al., 2016, p. 3) includes node-line configurations in linear one-dimensional arrangements and two-dimensional shapes like triangles and rectangles.

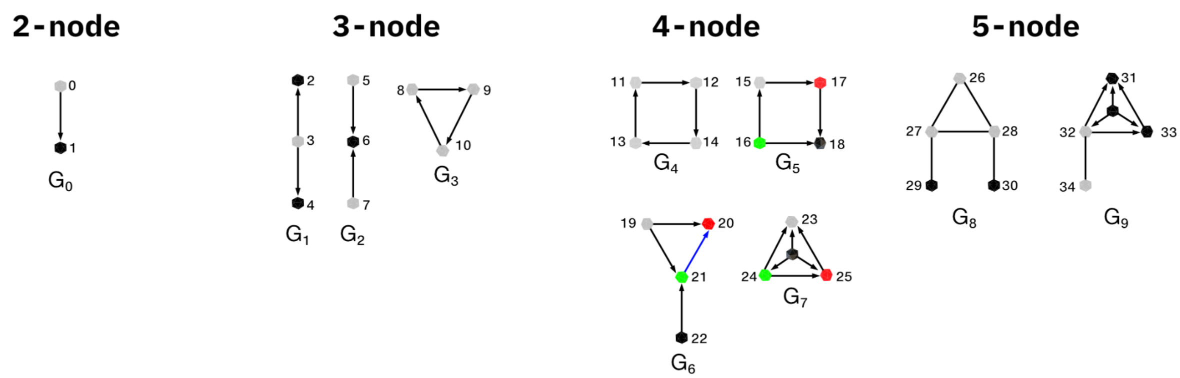

Figure 2.4: Graphlet configuration examples with one-dimensional network lines and two-dimensional network shapes in 3-node, 4-node, and 5-node configurations. Figure based on Sarajlić et al. (2016) Illustration of directed graphlets (Sarajlić et al., 2016, p. 3). This is a representative sample of the full Sarajlić et al. list of graphlets to give a sense of their combinations.

2.6.4.2 Benefits of visualizing networks in three dimensions

The mission of conciliating information from various disciplines into computational approaches for Sustainability Transitions requires managing a high degree of complexity. Network graphs in three or more dimensions can manage more entities and relationships and should be considered as a semiotic framework for complex knowledge work, such as interdisciplinary and computational Sustainability Transitions research.

To capture the interrelatedness of ideas in a graph in a level of detail that can be used to successfully run a Large Language Model requires capturing a large number of idea relationships in many more than two dimensions; in fact, small LLMs at present have billions of vector embeddings and thousands of dimensions of information. This serves as a baseline for contemporary applications of graphs in activating texts, but considering the *human* in human-in-the-loop graph interpretation, we must consider optics.

In a departure from the more general sense of the visuospatial, as per Tversky, and moving to a sight-centric discussion, detecting patterns and analyzing network graphs of texts relies on optics. Therefore, a pivotal meeting place of high-dimensional graphs and human interlocutors is the third dimension (with or without movement) since we can sense no further.

Ware and Mitchell report the following about their experiments: "With 2D viewing and 2D spring layout, a 33-node graphs yielded comparable error rates. Thus, we find roughly an order of magnitude increase in the size of the graph that can be "read" (where we consider "reading" to be the identification of short paths), when 3D viewing is available using stereo and motion depth cues" (Ware and Mitchell, 2008, p. 10) [3]

In brief, while the number of nodes that can be read accurately in two dimensions is considerably lower than the number legible in three dimensions, the complexity of graphs remains an ongoing consideration in pattern-finding, human-in-the-loop or otherwise. Nonetheless, the mission of conciliating information from various disciplines into computational approaches for climate resilience requires managing a high degree of complexity, prompting us to work with the full limits of the visuospatial, including computational methods for analyzing high-dimensional graphs. Network graphs operating in more than two dimensions could be pivotal.

2.6.4.3 Networks in more than three dimensions

Managing a high number of nodes in high-dimensional networks for human-in-the-loop Computational Analysis of Texts and Graphs requires limiting the number of visible nodes and plotting the nodes spatially to reveal their structures and substructures.

Existing approaches for managing complex networks

Filtration

Filtration methods simplify complex networks by reducing node numbers and highlighting node groups. Kovács et al. propose an iterative procedure where a graph undergoes repeated embedding and re-weighting of links based on geometric proximity between nodes. This approach re-quantifies connections between nodes in distinct

[3] Ware and Mitchell distinguish the number of links as a key factor to consider: "The degree of correlation we found was surprisingly high and the regression equation suggests that adding 25 more links for a given number of nodes results in an additional 1% increase in error rate" (Ware and Mitchell, 2008, p. 13). This 25:1 ratio can guide the dimensionality reduction of larger high-dimensional graphs for optically legibility and accessibility. Furthermore, Ware and Mitchell go on to discuss a variety of other factors that should be considered when working with three-dimensional network graphs.

node groups to reinforce intra-community connections while weakening inter-community links. This approach enhances the visibility and detectability of clusters within a given network (Kovács et al., 2024, p. 1). Kovács et al. call this procedure *Iterative Embedding and ReWeighting* (IERW) (Kovács et al., 2024, p. 2).

Bundling

Node-link diagrams in three dimensions for relational data often suffer from visual clutter, even more than two-dimensional graphs, hindering efficient data analysis. Zielasko et al. address this challenge with a three-dimensional cluster-based edge bundling algorithm inspired by force-directed edge bundling (FDEB). This method scales with graph size, supporting various structural styles in spatial data analysis. Zielasko et al. demonstrate this with simulations of macaque brain function (Zielasko et al., 2016, p. 1).

Holten and Van Wijk introduce self-organizing bundling, which further lessens visual clutter in large node-link diagrams. Unlike methods that require rigid hierarchy structures, this technique models edges as flexible springs that attract each other into bundles, minimizing the clutter of curvature variation (Holten and Van Wijk, 2009). The resulting models more clearly reveal high-level edge patterns, which facilitates graph exploration (Holten and Van Wijk, 2009, p. 1).

Clustering-Based Force-Directed Algorithms

In a turn from edges to focus on nodes, Lu and Si propose Clustering-Based Force-Directed (CFD) algorithms, which weigh nodes and clusters to reduce the clutter of edge crossing. Implementation of CFD improves the interpretability of large-scale three-dimensional graphs (Lu and Si, 2020, p. 2).

Spring Embedders for Force-Directed Layouts

Spring embedders, also known as force-directed algorithms, are versatile tools for "calculating layouts of simple undirected graphs" using "only information contained within the structure of the graph itself, rather than relying on domain-specific knowledge" (Kobourov, 2012, p. 1). Kobourov surveys "classical algorithms" and includes more recent "scalable multiscale methods for large and dynamic graphs" (Kobourov, 2012, p. 1). These algorithms produce graphs that "tend to be aesthetically pleasing, exhibit symmetries, and tend to produce crossing-free layouts for planar graphs" (Kobourov, 2012, p. 1).

Existing challenges of working with higher-order networks

Graphs, while convenient, "can only provide a limited description of reality" and "are inherently constrained to represent systems with pairwise interactions only" (Battiston et al., 2021, p. 1). However, many biological, physical, and social systems exhibit interactions beyond dyadic couplings, necessitating consideration of higher-order effects (Battiston et al., 2021, p. 1). For instance, research on neural systems highlights the statistical and topological significance of higher-order interactions (Battiston et al., 2021, p. 1). Complex systems represented as networks often require advanced mathematical structures from topology, such as hypergraphs and simplicial complexes, to account for higher-order interactions (Battiston et al., 2021, p. 2).

Studies have demonstrated that higher-order interactions can profoundly influence dynamics within networked systems, impacting processes from diffusion and synchronization to social dynamics and evolutionary processes (Battiston et al., 2021, p. 2). These interactions may even lead to "the emergence of abrupt (explosive) transitions between states" (Battiston et al., 2021, p. 2) highlighting the significance of addressing higher-order interactions.

While research on "dynamical processes on networks" conventionally focuses on node-state dynamics mediated by links, recent explorations into higher-order structures, such as hyperedges, suggest new approaches (Battiston et al., 2021, p. 2). Here, edges and hyperedges can possess dynamic states influencing and being influenced by nodes and higher-order interactions, thus transforming "static interactions" into "active agents" that "are coupled to the rest of the system" and evolving over time (Battiston et al., 2021, p. 2).

An outstanding challenge lies in defining "realistic models of topological co-evolution, where higher-order structure and higher-order dynamics evolve under the effect of mutual feedback." (Battiston et al., 2021, p. 4).

Inferring Higher-Order Interactions

Central to modelling real systems is the "reconstruction of higher-order interactions from data" (Battiston et al., 2021, p. 4-5). Methods combining data-driven modelling and Bayesian inference show promise in this area, offering effective approaches to reconstruction (Battiston et al., 2021, p. 4-5).

Current reconstruction techniques, particularly those reliant on temporal correlations, struggle with distinguishing direct causation from indirect paths and non-causal correlations. Addressing this challenge requires methodologies capable of intervention rather than relying solely on observational data (Battiston et al., 2021, p. 5). Bayesian inference of generative models, while addressing uncertainty in causal relationships, remains a pivotal direction for extending methods to incorporate varying higher-order interactions "that vary in time" and "describe emergent higher-order geometry" (Battiston et al., 2021, p. 5).

2.6.4.4 Graphs in two and three dimensions

The Vedic traditions steward a wealth of wisdom and visual culture. Mandala, yantra, and cakra (pronounced 'cha-kra', or ˈt͡ʃɑː.kɹə in the IPA) are disambiguated by Gudrun Bühnemann and others (Bühnemann, 2003, p. 13-56). In this thesis, I will discuss the Sri Yantra and the Meru Chakra.

While the terms 'Sri Yantra' and 'Meru Chakra' each have their own variations, I have found that in the context of North American discussions of Vedic visual culture, these terms are more frequently used. I refer to them in this way not to preclude other terms that may be more linguistically true to their Sanskrit origins but to help the reader find these forms should they seek them.

However, the 'Sri Yantra' and 'Meru Chakra' are also known by other names. Gudrun Bühnemann refers to the Sri Yantra as the "śrīcakra or śrīyantra, which is a configuration of a central point and sets of triangles surrounded by lotus petals, circles and a square" (Bühnemann, 2003, p. 2). For reference Figure 2.5 is a depiction of the Sri Yantra, and another depiction is available in *Maṇḍalas and yantras in the Hindu traditions* (Bühnemann, 2003, p. 31). Bühnemann continues to name the Sri Yantra as a *bhūpṛṣtha*, or "when a cakra is drawn a flat surface", and the Meru Chakra as a *merupṛṣṭha* or "when a cakra has the form of a mountain with different elevations" (Bühnemann, 2003, p. 31).

It may be surprising to the reader to find that there is an etymological link between mystical diagrams to technology in the word *yantra*, which "designates an instrument, machine, mechanical device or appliance (especially one used in warfare), and also a magic diagram" (Bühnemann, 2003, p. 28). Its verbal root yam means "to control" (Bühnemann, 2003, p. 28).

The Sri Yantra and the Meru Chakra are remarkable pieces of visuospatial culture in that they represent each other across dimensions: The Sri Yantra in two dimensions, and the Meru Chakra in three.

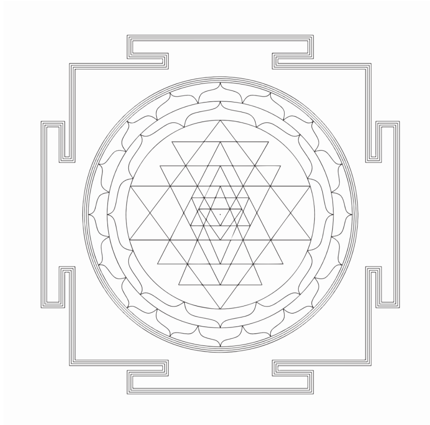

Figure 2.5: The Sri Yantra (AlexandraDesign, n.d.). Used with permission under the Adobe Stock education license.

Figure 2.6: The Meru Chakra, side view (Fortton, n.d.b). Used with permission under the Adobe Stock education license.

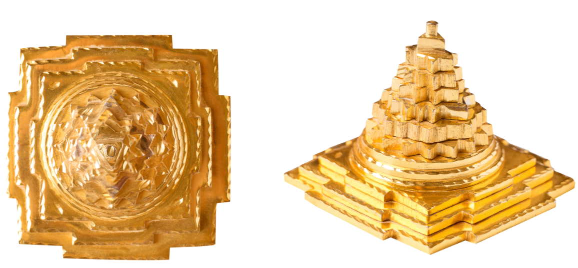

Figure 2.7: The Meru Chakra, top and side views (Fortton, n.d.a). *Left:* view from above to illustrate how the Meru Chakra is an extrusion of the Sri Yantra. *Right:* view from the side. Used with permission under the Adobe Stock education license.

2.6.5 The need for mathematically diverse approaches

A diversity of mathematical approaches is required to manage network graphs. To this end, I turn to *Beyond Euclid: An Illustrated Guide to Modern Machine Learning with Geometric, Topological, and Algebraic Structures (2024)*. In it, Sanborn et al. provide a thorough review of the various mathematical structures for plotting data, (Sanborn et al., 2024, p. 6) and the computational packages associated with them (Sanborn et al., 2024, p. 28).

Since networks can integrate many combinations of node relationships and have many more dimensions than the ones that can be visualized, higher-dimensional or higher-order networks are essential. In Global topological synchronization of weighted simplicial complexes (2024), Wang et al. claim that "Higher-order networks are able to capture the many-body interactions present in complex systems and to unveil new fundamental phenomena revealing the rich interplay between topology, geometry, and dynamics " (Wang et al., 2024, p.1).

2.6.5.1 Topology

We now turn to the mathematics of topology, which is "concerned with the properties of a geometric shape that are unchanged when we continuously deform it" (Totaro, 2008, p. 383). Topological Data Analysis (TDA) utilizes Persistent Homology (PH), which "is a mathematical tool in computational topology that measures the topological features of data that persist across multiple scales" (Aktas et al., 2019, p. 1). Up to this point, we have used two-dimensional network graph terms like points and lines, but their higher-dimensional equivalents in topology require different terminology.

A simplicial complex, for example, is "a topological object which is built as a union of points, edges, triangles, tetrahedron, and higher-dimensional polytopes [or forms]" (Aktas et al., 2019, p. 4). Simplicial complexes are made of simplices (the plural of simplex). A simplex is a higher-dimensional analog of the point, line segment, triangle, and tetrahedron. "A 0-simplex is just a point, a 1-simplex is two points connected with a line segment, a 2-simplex is a filled triangle" (Aktas et al., 2019, p. 4). The vertex is a 0-simplex, the edge is a 1-simplex, triangle is a 2-simplex, and the tetrahedron is a 3-simplex. (Aktas et al., 2019, p. 4). When applied to network graphs like topic models, TDA can facilitate finding isomorphic graphs across multiple dimensions.

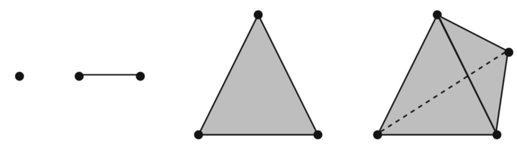

Figure 2.8: "0-, 1-, 2-, and 3-simplex from left to right" (Aktas et al., 2019, p. 4). Used with permission.

While geometry is valuable for categorizing and combining holistic compositions of network graphs and information visualizations, topology is uniquely suited to addressing networks with changing node positions at scale. TDA, in particular, is adept at handling the identification of network graphs across different scales and dimensions.

Simplicial complexes themselves are "higher-order networks that encode higher-order topology and dynamics of complex systems" (Wang et al., 2024, p. 1). Wang et al. specify that "simplicial complexes can sustain topological signals, i.e., dynamical variables not only defined on nodes of the network but also on their edges, triangles, and so on" (Wang et al., 2024, p. 1).

Synchronization in a topological network occurs when a group of simplices change en masse following a particular signal. Global Topological Synchronization (GTS) of networks is "a state of higher-order topological signals in which each simplex undergoes the same dynamics" (Wang et al., 2024, p. 1). In GTS, "the GTS of edge signals implies that every edge of the simplicial complex exhibits the same dynamics" (Wang et al., 2024, p. 1). Since the simplicial complex as a unit is built on the triangle, the "GTS of triangle signals implies that the dynamical variable associated to every triangle of the simplicial complex evolves in unison" (Wang et al., 2024, p. 1).

The "notion of *strength* or *weight* of connections between nodes" (Giusti et al., 2016, p. 11) results from quantifying an edge according to a chosen measure (Stolz et al., 2017, p. 2). In some applications, points in metric space are also weighted (Otter et al., 2017, p. 14).

A common problem in weighting is the loss of information through filtration used to assess hierarchical structure in weighted networks. "In some situations, like measurements of correlation or coherence of activity, the resulting network has edges between every pair of nodes and it is common to *threshold* the network to obtain some sparser, unweighted network whose edges correspond to "significant" connections" (Giusti et al., 2016, p. 11). However, the choice of threshold is difficult to choose because it can result in networks that discard "a great deal of information" (Giusti et al., 2016, p. 11). "Even in the case of sparse weighted networks, many metrics of structure are defined only for the underlying unweighted network, so in order to apply the metric, the weights are discarded and this information is again lost" (Giusti et al., 2016, p. 11).

Giusti et al. propose that filtrations can be used to assess hierarchical structure in weighted networks and weighted simplicial complexes without discarding any information. They add that more complex measurements of structure, like Persistence Homology, can provide more detail of the evolution of unweighted simplicial complexes as the filtration threshold changes (Giusti et al., 2016, p. 11). Leveraging PH in TDA, we can include the information that would otherwise be lost through conventional thresholding methods and derive more insight from the multi-scale relationships of data across various networks, thus powering a more robust STKA. Furthermore, Drucker's sense of 'capta' (Drucker, 2014, p. 131) reframes Topological Data Analysis in the context of humanist post-structuralist information design interface. Therefore, I propose the term Topological Capta Analysis (TCA) to refer to the Topological Data Analysis of information like semantic relationships in texts and graphs.

2.6.6 Artificial Intelligence (AI)

Mathematicians and early computer scientists wondered about the intelligence of machines nearly two centuries ago (Lovelace and Menabrea, 1842). Ada Lovelace translates the words of Luigi Federico Menabrea, who posits that "although it [the machine] is not itself the being that reflects, it may yet be considered as the being which executes the conceptions of intelligence" (Lovelace and Menabrea, 1842). In 1950, Turing expanded this discussion to consider the agency of the machine when he asked, "Can machines think?" (Turing, 1950, p. 433). As large as the changes have been since the first computers, the subject of machine intelligence has never been more pertinent than now. In our historical period, the recent rapid development of Artificial Intelligence (AI) coincides with the largest human-made ecological crisis ever. Ecological strain imposed to sustain AI will be discussed in the following section.

The developments that have led to contemporary AI are wide-ranging and diverse (Bergmann and Stryker, 2024; Tunstall et al., 2022; Vaswani et al., 2017; Goodfellow et al., 2016; Mikolov et al., 2013). In this section, I present a short introduction of the elements of AI that most relate to this thesis.

Artificial Intelligence (AI) relies on "the ingestion, analysis and optimization of vast amounts of human-generated images, texts and videos" (Crawford and Joler, 2018). AI processes extensive datasets with "an extraordinarily complex set of information processing layers" (Crawford and Joler, 2018), enabling them to handle complex tasks that mimic human intelligence.

Language models (LM) are algorithms trained on large text corpora which predict language sequences (Tunstall et al., 2022). LLMs are pre-trained to "predict the next word based on the previous words" in a task called *language modeling*. The unique automatization involved in this approach facilitates the use of "abundantly available text from sources such as Wikipedia" (Tunstall et al., 2022).

Transfer learning involves pre-training models on large datasets and then fine-tuning them on specific tasks, allowing AI systems to "make use of the knowledge learned from the original task" (Tunstall et al., 2022).

Machine learning allows computer systems to "improve with experience and data" (Goodfellow et al., 2016, p. 2). Deep Learning, as detailed by Goodfellow et al., is a distinct type of machine learning which "achieves great power and flexibility by learning to represent the world as a nested hierarchy of concepts, with each concept defined in relation to simpler concepts, and more abstract representations computed in terms of less abstract ones" (Goodfellow et al., 2016, p. 8) This hierarchical representation enables AI to tackle complex problems involving real-world knowledge.

One of the challenges in AI has been the limitations of hard-coding information. "Several artificial intelligence projects have sought to hard-code knowledge about the world in formal languages [...] None of these projects has led to a major success" (Goodfellow et al., 2016, p. 2). Representation learning in machine learning, however, allows computers to "discover not only the mapping from representation to output but also the representation itself" (Goodfellow et al., 2016, p. 4). This important shift enables LM and Large Language Models (LLM) to "tackle problems involving knowledge of the real world and make decisions that appear subjective" (Goodfellow et al., 2016, p. 3).

2.6.6.1 Graphs in AI

Graphs play an important role in Machine Learning (ML) and Artificial Intelligence (AI). One notable development is graph embeddings, which "represent the structure of a graph via the geometric relations of a set of points arranged in a low-dimensional vector space, where the points are the network nodes and some features of the original network are preserved" (Kovács et al., 2024, p. 1). Researchers can embed graphs into vector spaces to use tools from continuous metric spaces, particularly with "the possibility of computing distances between the points," to analyze and operate on complex network structures (Kovács et al., 2024, p. 1).

Graph embeddings have been foundational in a variety of applications, like link prediction, node classification, and community detection (Kovács et al., 2024, p. 1). Community detection is especially critical because "communities play key roles in the dynamics and functionality of networks" (Kovács et al., 2024, p. 1). Networks often contain "groups of nodes with a significant density of internal links," (Kovács et al., 2024, p. 1) while connections between these clusters are relatively sparse. This pattern of tight internal connectivity and looser external links defines these community structures within complex networks (Kovács et al., 2024, p. 1). Embedding methods often place closely connected nodes near each other in the embedding space, resulting in more easily identifiable communities "embedded as compact, well-separated clusters" (Kovács et al., 2024, p. 1). Identifying these clusters can then be achieved using data clustering techniques like k-means clustering or DBSCAN (Kovács et al., 2024, p. 1). Network communities, which provide deeper insights into complex system structures, can be efficiently detected through this embedding and clustering.

Identifying distinct communities, however, can be challenging, especially when different communities are connected by many diverse links (Kovács et al., 2024, p. 1). Even in these cases, embeddings can be supportive by capturing node proximities, "tending to place nodes within the same community closer together" (Kovács et al., 2024, p. 1). We can use this proximity information to refine embeddings, which can help us better define "compact community clusters that can be more easily identified using data clustering techniques" (Kovács et al., 2024, p. 1).

An innovative method that enhances community detection is the Iterative Embedding and ReWeighting (IERW) process. This approach "repeatedly arranges the network nodes in a vector space according to the topological relations between them and assigns weights to the links of the network in accordance with the geometric relations between the nodes in the previous [arrangement into vector space, i.e.] embedding" (Kovács et al., 2024, p. 2). Importantly, this approach introduces no new links, and only existing links are reweighted (Kovács et al., 2024, p. 2). IERW provides two opportunities: using conventional data clustering methods on the spatial node arrangements produced in the iterative embedding steps and applying community detection on weighted networks derived from link weighting processes (Kovács et al., 2024, p. 2).

Regarding node embedding, the node2vec method is widely used. It provides Euclidean node embeddings based on virtual network 'random walks', or 'explorations' similar to how a curious traveler meandering through a city without a fixed itinerary (Kovács et al., 2024). The core idea involves using the sequences of nodes encountered during these digital wanderings as input for the word2vec method, "originally designed to embed words from a large text corpus into a vector space" (Kovács et al., 2024). The node2vec technique simulates these serendipitous journeys through the network and captures both the immediate surroundings (local structural information) and the broader landscape (global structural information) of nodes within the graph. These computational random walks are analogous to how a traveller gains an understanding of both a specific neighbourhood and the overall layout of a city through their unplanned excursions.

Vectors and vector embeddings are foundational in representing and processing data within AI models. "Vector embeddings are numerical representations of data points that express different types of data, including non-mathematical data such as words or images, as an array of numbers that machine learning (ML) models can process" (Bergmann and Stryker, 2024). Since AI models operate through mathematical logic, unstructured data like text, audio, or images need to be quantified into numbers (Bergmann and Stryker, 2024). Vector embeddings achieve this by converting unstructured data into numerical arrays that capture meaning from their sources.

The isomorphic principle behind vector embeddings is that "the more similar two real-world data points, the more similar their respective vector embeddings should be" (Bergmann and Stryker, 2024). Shared features between data points are reflected in their embeddings, allowing models to perform tasks by comparing, transforming, combining, sorting or otherwise manipulating those numerical representations (Bergmann and Stryker, 2024). This numerical representation also facilitates interoperability between different data types by representing them in the same embedding space as a sort of common 'language' (Bergmann and Stryker, 2024).

In machine learning, vectors are one-dimensional representations of information used as a mathematical tool for organizing and processing information (Bergmann and Stryker, 2024). When it comes to machine learning vector space, it is more appropriate to refer to vectors as *tensors*, which are high-dimensional representations of information. Tensors extend the idea of vectors into higher-dimensional spaces and allow us to represent and manipulate multi-dimensional data arrays.

The terms "embedding" and "vector" are often used interchangeably, but they are distinct from each other (Bergmann and Stryker, 2024). Embeddings are "any numerical representation of data that captures its relevant qualities in a way that ML algorithms can process. The data is *embedded* in n-dimensional space" (Bergmann and Stryker, 2024). Vectors capture a number of coordinates by using magnitude and direction (Weisstein, n.d.c; Frank and Nykamp, 2024). Vectors are used in a variety of contexts, like physics, without necessarily being embeddings (Bergmann and Stryker, 2024).

Vector embeddings can transform nonmathematical data like words and images into numerical arrays that Machine Learning models can use by representing characteristics of a given data point into "an n-dimensional array of numbers" (Bergmann and Stryker, 2024). Vector embeddings often hold high-dimensional data. To compress data, we trim the dimensions into "a lower-dimensional space that omits irrelevant or redundant information"

(Bergmann and Stryker, 2024). This makes computational models more efficient by reducing complexity when needed. The dimensional versatility of vector embeddings allows us to precisely choose the number of dimensions best suited to a given data set when we make calculations in ML models.

Comparing vector embeddings relies on measures like Euclidean distance and cosine similarity. The core principle of vector embeddings is that "n-dimensional embeddings of similar data points should be grouped closely together in n-dimensional space" (Bergmann and Stryker, 2024). But, because embeddings can have hundreds or even thousands of dimensions, various mathematical processes need to be used to measure the similarity or difference of vector embeddings (Bergmann and Stryker, 2024). Euclidean distance calculates the straight-line distance between "corresponding points of different vectors" (Bergmann and Stryker, 2024). Euclidean distance is magnitude-sensitive and effectively captures quantitative data characteristics like "size or counts" (Bergmann and Stryker, 2024). Cosine similarity is a useful complement to Euclidean distance because it is "less sensitive to the relative frequency of words in training data" (Bergmann and Stryker, 2024).

2.6.6.2 Risks of AI

AI opacity risks

So-called "black box" AI is either noninterpretably complex or the way it functions is concealed (Garrett and Rudin, 2023, p. 1). I choose to use the term *opaque AI* to maintain the idea of noninterpretability while choosing not to use blackness as a pejorative. This section draws upon the current use of AI in the justice system, but the principles of AI opacity apply to the just use of AI in the high stakes of STKA, which requires as much research transparency as possible.

In the justice system, proponents of opaque AI claim that it produces "more accurate forensic evidence" (Garrett and Rudin, 2023, p. 1). However, when applied to tabular data and computer vision, "there has been no accuracy advantage" to opaque AI approaches (Garrett and Rudin, 2023, p. 8).

It is a "widely held myth" that using opaque AI "despite the risk to constitutional rights, is a necessary evil, because they have an inherent performance advantage over simpler or open systems" (Garrett and Rudin, 2023, p. 2). In fact, interpretable "glass box" AI models are actually available and can work better than their opaque counterparts (Garrett and Rudin, 2023, p. 4). Using interpretable AI, "we can far more readily validate the system and detect and correct errors in the system" (Garrett and Rudin, 2023, p. 4). Interpretability of AI is crucial in the justice system where the oppressive bias imbued into an algorithm (Noble, 2018) can be amplified further by people in power like "police, lawyers, judges, and jurors, [who] cannot fairly and accurately use what they cannot understand" (Garrett and Rudin, 2023, p. 4). In the criminal justice system, the use of opaque AI is "an avoidable and poor policy choice" when more transparent and interpretable options better benefit fairness and public safety (Garrett and Rudin, 2023, p. 3).

The government must be required to justify using opaque AI in the justice system, "given commitments to defense rights of access, nondiscrimination, and reliability of evidence. [...] without a strong performance justification, there is little justification for not making algorithms open for inspection, vetting, and explanation."(Garrett and Rudin, 2023, p. 6). In any government use of AI "there should be a strong legal, evidentiary, and constitutional right to glass box evidence" (Garrett and Rudin, 2023, p. 6).

Ecological risks

More computing power in AI means the use of more energy resources, causing additional strain on the planet since energy often comes from non-renewable resources, which does not align with UN Sustainable Development Goals (SDGs) for affordable and clean energy (United Nations, 2024).

One way to measure how much energy an AI consumes is the number of its parameters. An AI learns a given number of variables or parameters during its training. OpenAI, the company that makes the popular Large Langauge Model ChatGPT, reported in 2020 that it trained GPT-3 with 175 billion parameters, which is ten times more than previous models (Brown et al., 2020, p. 1). Since then, it has been speculated that GPT-4 is ten times larger than that at about 1.8 trillion parameters (Schreiner, 2023). To give a quantified example, in 2023, "a common GPU training neural network model" produced approximately 625,000 pounds of CO2, which is about 5 times more than the entire lifespan of an ordinary car (Damkaci, 2023, p. 1).

In *Anatomy of an AI System* (2018), Crawford and Joler illustrate the various interrelated factors required for making and using the Amazon Echo "as an anatomical map of human labor, data and planetary resources" (Crawford and Joler, 2018). They highlight the disproportion of how small conveniences like "answering a question, turning on a light, or playing a song" require "a vast planetary network, fueled by the extraction of non-renewable materials, labor, and data" (Crawford and Joler, 2018). Moreover, "there are deep interconnections between the literal hollowing out of the materials of the earth and biosphere, and the data capture and monetization of human practices of communication and sociality in AI," highlighting the environmental and societal impacts intertwined with AI development (Crawford and Joler, 2018). Crawford and Joler draw attention to the ecological cost of AI.

And yet, we may need AI to develop solutions to the climate crisis. There are some emerging proposals to lower AI energy use and increase its performance, like advanced high current density power models and vertical power delivery methods (Wood, 2024, p. 1). However, we must codify an ecologically informed research production strategy for AI that limits its use in the various modes of Knowledge Activation.

Artificial Intelligence encompasses a range of technologies and methodologies that aim to replicate intelligent human behaviour. These systems are dependent on the growing quantity of natural resources required to sustain them and the data they are trained on, which reflects both the potential and the challenges inherent in any form of computational Knowledge Activation, particularly AI. Sophisticated analysis of network structures, like graph embeddings and vector representations, are central to the current ways AI processes complex data into communities and classifications. Graphs and AI are intertwined, and their development can be expanded to include computational methods of Knowledge Activation in the climate crisis.

2.7 Types of Knowledge Activation

In this section, I disambiguate the various kinds of Knowledge Activation and follow with a literature review categorized by its various components.

In this section, I differentiate the various modes of KA for the twofold purpose of disambiguation and energy strategy. Since research project complexity tends to correlate to research cost, I list four various KA modes from lowest complexity to highest: Knowledge Surfacing, Synthesis, Translation, and Production (KSSTP). In short, I refer to the complex of processes in KSSTP as Knowledge Activation (KA). I will occasionally refer to Surfacing, Synthesis, Translation, and Production in capital letters as abbreviations of each term.

Knowledge Activation results from activating texts and graphs. The data-information-knowledge-wisdom hierarchy, otherwise known as the Knowledge Pyramid, is often cited uncritically "in Computer Science, Management Information Systems and in Librarianship" (Frické, 2009). Critiques notwithstanding, the distinction between data, information, knowledge, and wisdom (DIKW) remains a useful framework for introducing what I mean by the activation of texts and graphs. In this thesis, I refer to "methods for activating large texts and graphs" as the ways people move from information to knowledge using Human Analysis of Texts and Graphs (HATG), human-in-the-loop (HITL) computational analysis of texts and graphs (CATG), or both. I use the term Knowledge Activation to mean moving "beyond simple dissemination of knowledge to actual use of knowledge" (Straus et al., 2009, p. 4) with additional subtleties. KA disambiguates a variety of other modes and considers a more interdisciplinary range of knowledge activity from medical Knowledge Translation.

Knowledge Surfacing is a term I propose to indicate the practice of revealing solutions that may be siloed in other disciplines or buried in paratextual elements like marginalia and footnotes. Knowledge re-surfacing is a given, considering the iterative processes involved. I list Knowledge Surfacing (KS) first in KSSTP, because I consider it an underused mode of Knowledge Activation that can be improved to significantly lower the cost of research. One example of visuospatial modalities of Knowledge Surfacing is Sowa's query graphs (Sowa, 1984, p. 313).

Knowledge Synthesis borrows from the term "evidence synthesis" used by Berrang-Ford et al. (Berrang-Ford et al., 2020, p. 1) to mean the consolidating of vast amounts of primary research into a means that narrows the amount of information processing required by even more conciliatory approaches, like the Intergovernmental Panel on Climate Change (IPCC) annual reports, which represent state of recent research in a given field (Berrang-Ford et al., 2020, p. 1). I propose Knowledge Synthesis as a necessary element of KA in which ideas are reconciled and combined within a similar semantic field. The requirement for more human intervention in this mode means additional cost, so I rank it second.

Knowledge Translation is a term that emerges from medical communication. In medicine it conventionally means the "dynamic and iterative process that includes the synthesis, dissemination, exchange and ethically sound application of knowledge to improve health, provide more effective health services and products and strengthen the healthcare system" (Straus et al., 2009, p. 4). More generally, KT operates on the premise that Knowledge Production, "distillation, and dissemination are not sufficient on their own to ensure implementation in decision-making" (Straus et al., 2009, p. 4). KT moves "beyond simple dissemination of knowledge to actual use of knowledge" (Straus et al., 2009, p. 4). In this thesis I use the term Knowledge Translation to mean "actual use of knowledge" with an emphasis on interdisciplinarity. In other words, I use the term Knowledge Translation to mean the lateral transposition and application of theory and method across and between disciplines. KT requires human intervention on the side of the semantic field of origin and the destination semantic field, so I place third after Knowledge Synthesis.

Knowledge Production is the illusively 'original' contribution. I do not tackle the epistemological and metaphysical questions of whether or not anyone can every really 'know', or whether any knowledge is in any way new. I assume that information can be new to a given group and that it can be operationalized as solutions, and builds on this as my definition of knowledge when it comes to Knowledge Activation (KA). Knowledge Production is the most expensive option. While I do not think Knowledge Production should be the first means of Knowledge Activation, I continue to assume that it is necessary.

The following sections of my literature review are categorized and informed by the various modes of KA (KSSTP).

2.7.1 Knowledge Surfacing

2.7.1.1 Searching with graphs

In addition to the text and image queries we are accustomed to today in search engines, querying using graphs of related ideas is also possible. John F. Sowa's query graphs, for example (Sowa, 1984) use Peter Chen's entity-relationship (ER) diagram notation to distinguish attributes as ovals and entities as rectangles (Chen, 1976; Rodina, 2024). Query graphs build on Sowa's conceptual graphs (Sowa, 2013, p. 53), lattice of theories (John F. Sowa, 2007, p. 12), and VivoMind Analogy Engine (Sowa and Majumdar, 2003, p. 21-29).

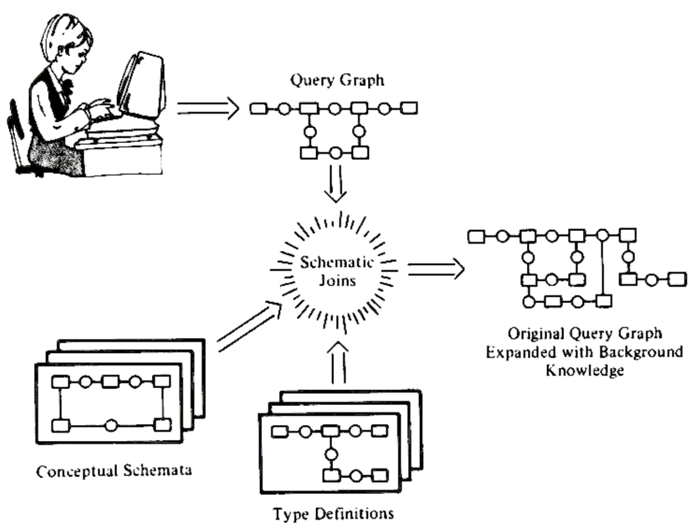

Figure 2.9: Sowa query graph within the larger database inference system (Sowa, 1984, p. 313). Used with permission.

2.7.1.2 Ontology and semantic networks

Sowa ties the network graph, ontology, and LLMs into his explanation of semantic networks, which are graphs for "representing knowledge in patterns of interconnected nodes and arcs" (Sowa, 2015). Sowa claims that semantic network programs "were first developed for artificial intelligence and machine translation," and that what "is common to all semantic networks is a declarative graphic representation that can be used to represent knowledge and support automated systems for reasoning about the knowledge" (Sowa, 2015).

However, earlier versions of semantic networks "have long been used in philosophy, psychology, and linguistics" (Sowa, 2015). In fact, the first semantic network we know of was found in the marginalia of Porphyry's commentary *On Aristotle's Categories*, written almost two millenia ago (Sowa, 2000, p. 4). "It was a small tree with Aristotle's categories arranged by *genus* (supertype) and *species* (subtype)" (Sowa, 2000, p. 4). Medieval logicians later expanded it into a hierarchy with more detail and was known as the "Tree of Porphyry" (Sowa, 2000, p. 4).

Sowa offers Porphyry's own description of the tree's hierarchy: "Substance, for instance is the single highest genus of substances, for no other genus can be found that is prior to substance. Human is a mere species, for after it come the individuals, the particular humans" (Sowa, 2000, p. 5). The categories between "substance" and "human" are both species of the categories above them and genera for the ones below them (Sowa, 2000, p. 5).

On the left of Sowa's tree of Porphyry is a column of labels, Supreme genus, Differentiae, Subordinate genera, Proximate genera, Species, and Individuals. Sowa goes on to explain that "The features that distinguish different species of the same genus are called *differentiae*. Substance with the differentia material is Body and with the differentia immaterial is Spirit. The technique of *inheritance*, which is used in AI and object-oriented systems, is the process of merging all the differentiae along the path above any category: LivingThing is defined as animate material Substance, and Human is rational sensitive animate material Substance" (Sowa, 2000, p. 4).

For the scope of significance, we must note that "Aristotle's categories with his *syllogisms* for reasoning about them and Porphyry's tree for illustrating them dominated the field of logic for over two thousand years" (Sowa, 1993, p. 2). So much so that "Aristotle's method of defining new categories by *genus* and *differentiae* is fundamental to AI systems, to object-oriented systems, and to every dictionary from the earliest days to the present" (Sowa, 2000, p. 4).

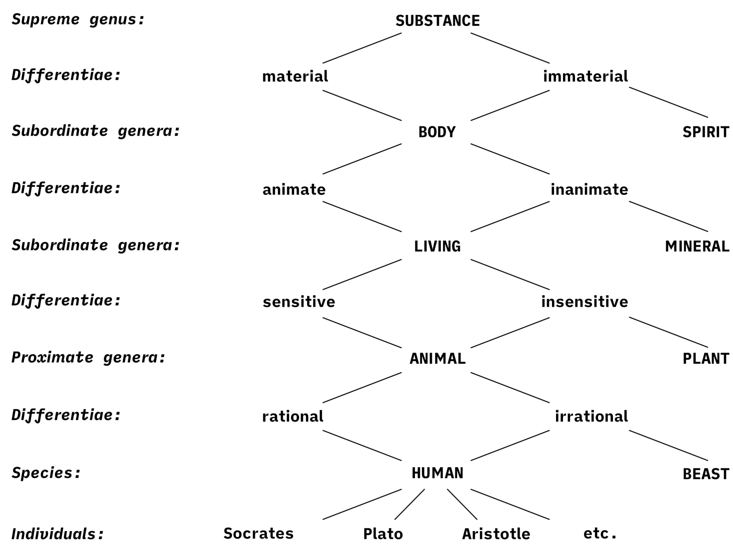

Figure 2.10: The Tree of Porphyry. Reproduction of John F. Sowa's version, which was translated from a version by Peter of Spain (1239) (Sowa, 2000, p. 5).

2.7.1.3 Topic Models

Similar to the *Syntopicon*(Adler et al., 1952a), a topic model catalogues relatedness between significant words in a group of texts. However, the topic model is a computational approach which applies "unsupervised learning on large sets of texts to induce sets of associated words from text" (Jurafsky and James H., 2024, p. 108). Topic models are also searchable, queryable, and graphable; so they are useful for "discovering topical structure in documents" (Jurafsky and James H., 2024, p. 108).

Topic models can help reveal the semantic field of a text, which Jurafsky and James define as "a set of words which cover a particular semantic domain and bear structured relations with each other" (Jurafsky and James H., 2024, p. 107). To give an example of various terms and how they can occupy different semantic fields, consider how hospitals use terms like surgeon, scalpel, and nurse, while construction uses terms like door, roof, and kitchen (Jurafsky and James H., 2024, p. 107).

2.7.2 Knowledge Synthesis

2.7.2.1 Evidence Synthesis

We may use many terms for processing information toward the various forms of Knowledge Activation. However, given our planetary situation, I refer to a term from climate research.

Evidence synthesis is the consolidating of vast amounts of primary research into a means that narrows the amount of information processing required by even more integrative science assessments, such as those produced by the Intergovernmental Panel on Climate Change (IPCC). This facilitates the work of IPCC assessments in its vast scope, which requires us to consider "more or less the entire recent scientific literature on climate change that has emerged during an assessment cycle" (Berrang-Ford et al., 2020, p. 1).

Methodologically, the expertise of climate evidence synthesis scholars "spans from more traditional quantitative systematic reviews to qualitative evidence synthesis methods such as thematic synthesis, framework synthesis, evaluation assessment, and meta-ethnography" (Berrang-Ford et al., 2020, p. 2-3). The breadth of methodologies in evidence synthesis reflects its versatility across various research paradigms.

Berrang-Ford et al. and the Campbell Climate Solutions Coordinating Group (CSCG) propose that there are two forms of evidence synthesis: ex-ante, our current understanding of climate evidence synthesis, and ex-post, which is severely lacking. "Ex-ante evidence synthesis" asks: "What are alternative climate futures and how do human responses and solutions shape them?" The ex-ante approach benefits from comparing climate models for factors like "forcing, feedbacks, impacts, and mitigation pathways," assessing "vulnerability, adaptation planning, and integrated scenario analysis" (Berrang-Ford et al., 2020, p. 2). "Ex-post evidence synthesis" asks: "What climate solutions have worked, under what conditions, for whom, and why?" The ex-post approach benefits from systematic reviews, "evidence and gap maps, meta-synthesis of lessons on efficacy and adequacy" (Berrang-Ford et al., 2020, p. 2). This approach best characterizes the CSCG which was established to "accelerate learning" and build a "comprehensive evidence base on climate solutions" (Berrang-Ford et al., 2020, p. 2). Ex-post evidence synthesis evaluates the effectiveness of implemented climate solutions through systematic reviews and meta-analyses, aiming to accelerate learning and build a comprehensive evidence base for future climate action. However, there is currently a void of ex-post evidence synthesis compared to the ex-ante form of evidence synthesis (Berrang-Ford et al., 2020, p. 2).

Berrang-Ford et al. offer a critique of the status quo of evidence synthesis: "Transparent evidence synthesis is particularly infrequent in climate research using qualitative research" (Berrang-Ford et al., 2020, p. 1). Many social scientists perceive that systemic approaches are too rigid for "critical inductive inquiry" (Berrang-Ford et al., 2020, p. 1). However, "qualitative research is critical for understanding the human dimensions of climate change" and social science insights are essential for comprehensive learning "about climate solutions" (Berrang-Ford et al., 2020, p. 1). The scarcity of transparent, qualitative evidence synthesis in climate research (stemming from methodological rigidity), hinders our comprehensive understanding of climate solutions' human dimensions.

Berrang-Ford et al. promote "the adaptation and application of qualitative and mixed methods evidence synthesis methodologies" (Berrang-Ford et al., 2020, p. 3). To learn "from the available evidence on climate solutions," we must reflect on the "methodological diversity in primary evidence" by using a diverse array of "qualitative and mixed methods evidence synthesis methodologies" (Berrang-Ford et al., 2020, p. 3). A diverse range of qualitative and mixed-methods evidence synthesis approaches will allow us to learn more from the complexity of climate solution evidence.

The CSCG advocates for the development and implementation of innovative technologies to enhance evidence synthesis, particularly focusing on automation and computer-assisted methods for systematic reviews and environmental assessments (Berrang-Ford et al., 2020, p. 3). A critical role of information technology innovation towards Visuospatial Knowledge Activation is how much it can help mitigate the climate crisis with evidence synthesis.

2.7.2.2 Reaching towards pan-disciplinary ontology

The crushing volume of available information has long driven my work. Approaching learning in the face of such vast amounts of knowledge requires guidance. As I felt I was navigating the planets of disciplines in the universe of knowledge, I searched of a deeper guide for ideas and texts beyond the scope of a dictionary and the encylopedia to activate knowledge.

In a sense I am grappling with ontology. In philosophy, it is a "systematic account of Existence" (Gruber, 1995, p. 1). In computer science, "what "exists" is that which can be represented" (Gruber, 1995, p. 1). In both, ontology can be considered "an explicit specification of a conceptualization" (Gruber, 1995, p. 1).

The Syntopicon

The Great Ideas: a Syntopicon of Great Books of the Western World (1952), a project overseen by Editor-In-Chief Mortimer J. Adler, provides one approach to how we can account to which ideas exist. The editors of *The Great Ideas* called it "a syntopicon of the great books—literally, a collection of the topics which are the main themes of the conversation to be found in the books" (Adler et al., 1952a, p. xii). As an exercise of long-ranging interdisciplinary topic consolidation, *The Great Ideas* project offers an example of success, though not without serious flaws.

There are a number of critical reasons *The Great Ideas* might have found limited adoption. I will note that no women, let alone non-binary people, are among the authors in the *Great Books of the Western World* (1952) (Hutchins, 1952). The collection of texts centers European, cis-gender, male, patriarchal, top-down approaches to knowledge. In effect, the project is culturally imperial by presenting western ideas as universals. As a person at the intersection of many identities that have suffered under the oppression of people who are represented in these texts, I have many reasons to categorically discount this collection of volumes. Yet, I turn to it. Why? I am in some ways defiantly motivated by the exclusion of my representation. I propose the *Syntopicon*, not as a flawed end, but as a practice, which can expand to represent, include, and conciliate more knowledge.

Therefore, I turn to identify key qualities of the *Syntopicon*, which serve as an example of information praxis. "Syntopical reading" aims "to discover the unity and continuity" of "thought in the discussion of common themes and problems from one end of" a body of texts "to the other" (Adler et al., 1952a, p. xii). "This great conversation across the ages is a living organism whose structure the Syntopicon tries to articulate" (Adler et al., 1952a, p. xii) . In short, the *Syntopicon* serves as a means of discovering unities among themes in a historical scope of intellectual dialogue.

Consilience

Whewell proposes that "Fundamental Ideas," or "the contributions of our mind to how we perceive and understand what we experience," can be "discipline relative": "An idea can be fundamental even if it is necessary for knowledge only within a given scientific discipline" (Hepburn and Andersen, 2021). The scientific method depends on clarification of fundamental ideas, or what Whewell called "Discoverer's Induction" (Hepburn and Andersen, 2021). Whewell's sense of induction emphasizes "the role of ideas in the clear and careful formulation of inductive hypotheses" and goes beyond "collecting objective facts" (Hepburn and Andersen, 2021). The scientist engages in the subjective process of "Colligation of Facts", which is a "creative act" in which the scientist invents theory (Hepburn and Andersen, 2021). Whewell called "Consilience of Inductions" when "induction, which results from the colligation of one class of facts, is found also to colligate successfully facts belonging to another class" (Snyder, 2023). In other words, Consilience of Inductions is when theories incorporate more facts through testing (Hepburn and Andersen, 2021). Whewell proposed that this method of "clarification of fundamental concepts, clever invention of explanations, and careful testing" could uniquely facilitate the discovery of "true laws of nature" (Hepburn and Andersen, 2021).

Edward O. Wilson asserts: "Trust in consilience is the foundation of the natural sciences. For the material world at least, the momentum is overwhelmingly toward conceptual unity. Disciplinary boundaries within the natural sciences are disappearing, to be replaced by shifting hybrid domains in which consilience is implicit. These domains reach across many levels of complexity, from chemical physics and physical chemistry to molecular genetics, chemical ecology, and ecological genetics [...] Each is an industry of fresh ideas and advancing technology" (Wilson, 1999, p. 11). Whewell's "Fundamental Ideas" and "Consilience of Inductions" emphasize the creative and subjective aspects of scientific discovery, which Wilson extends to advocate for interdisciplinary unity in the natural sciences, highlighting the increasing interconnectedness of scientific domains.

Wilson, then, expands Whewell's definition of consilience to "the possibility of consilience beyond science and across the great branches of learning" (Wilson, 1999, p. 9). Understood this way, the *Syntopicon* is an example of how we might endeavour towards Wilson's consilience by syntopical reading. Whewell and Wilson's sense of consilience, syntopical or otherwise, does not work to the exclusion of necessarily differentiated methods, and presents an opportunity to increase the efficiency of STKA.

Wilson's diagram of quadrants unified by concentric circles could be understood as a topographical map of Lenat et al.'s model of ontology and domain models where the upper ontology unifies domains that stand "apart in the contemporary academic mind", each with "its own practitioners, language, modes of analysis, and standards of validation", (Wilson, 1999, p. 9) such "that sound judgment will flow easily from one discipline to another," with "agreement on a common body of abstract principles and evidentiary proof" (Wilson, 1999, p. 11).

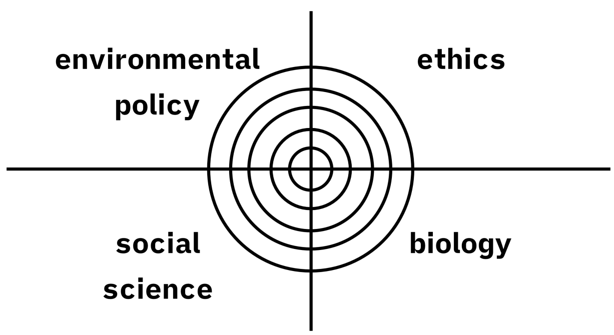

Figure 2.11: Consilience across four disciplinary boundaries. This figure is based on Wilson's illustration (Wilson, 1999, p. 10).

If Wilson saw the technology we have today for information processing, he might repeat the encouraging words he wrote in 1999 and say: "There has never been a better time for collaboration between scientists and philosophers, especially where they meet in the borderlands between biology, the social sciences, and the humanities" (Wilson, 1999, p. 12). In a cosmically Schrödingerian and Dickensian twist considering the climate precipice we are in, we are in a historical moment that is both the best of times and the worst of times for interdisciplinary collaboration.

In a time when the subject of Artificial General Intelligence (AGI) that matches human ability is top of mind, perhaps Wilson's consilience is more aptly named general consilience (GC). It may be that GC is only achieved in AGI and beyond the limits of human language and only capturable as a high-dimensional model or some other hyper-lingual expression of knowledge. Furthermore, it may be that our survival is tied to the GC of AGI. The cautions and safeguards built into the governance of AI are pivotal to balancing agency over our own knowledge and effective Sustainability Transitions.

The limited set of terms and models in the "search for consilience might seem at first to imprison creativity," but Wilson argues: "The opposite is true. A united system of knowledge is the surest means of identifying the still unexplored domains of reality. It provides a clear map of what is known, and it frames the most productive questions for future inquiry" (Wilson, 1999, p. 295).

Overall the pursuit of answers would benefit by being framed as the practice of asking better questions. As Wilson puts it, "Historians of science often observe that asking the right question is more important than producing the right answer. The right answer to a trivial question is also trivial, but the right question, even when insoluble in exact form, is a guide to major discovery. And so it will ever be in the future excursions of science and imaginative flights of the arts" (Wilson, 1999, p. 295).

The way we think about knowledge matters. Consilience, Syntopical or otherwise, has the potential to synthesize knowledge across the disciplines most critical for STKA.

Syntopical consilience as a form

The visualization of various hierarchies of ontologies is used in Lenat et al.'s graph of their Semantic Research Assistant (SRA) (Lenat et al., 2010, p. 7). They visualize various domain models unified around a middle ontology, which is in turn encapsulated into an upper ontology. This computational expression of what Adler calls "syntopical reading" is also in line with what William Whewell called "Consilience of Inductions" (Snyder, 2023; Hepburn and Andersen, 2021). The individual domain models and the overall form of SRA ontology 'mountain range' also resemble the Meru Chakra (see Figure 2.7).

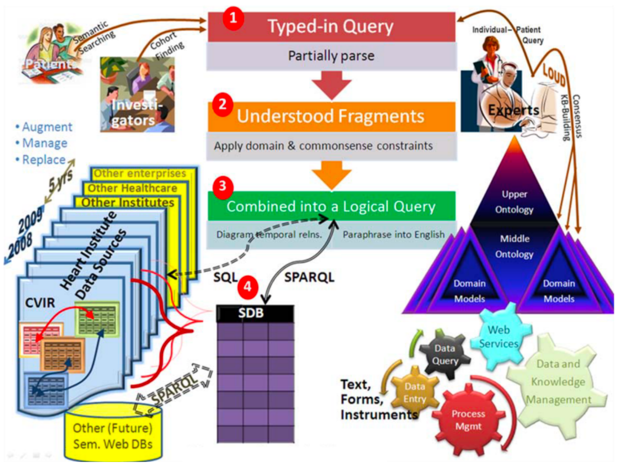

Figure 2.12: The Semantic Research Assistant (SRA) query-handling workflow (Lenat et al., 2010, p. 7). Used with permission.

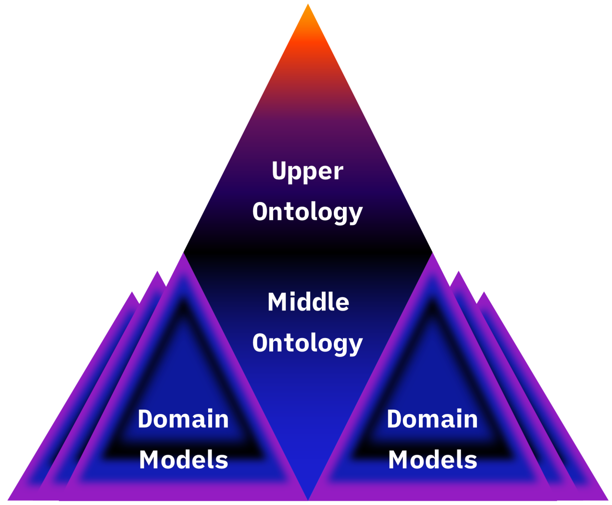

Figure 2.13: Detail based on the Lenat et al. SRA query-handling workflow (Lenat et al., 2010, p. 7).

2.7.3 Knowledge Translation

I borrow the term Knowledge Translation (KT) from healthcare as a term that can be used within information as a whole, in sustainability or otherwise. In 2009, the Canadian Institutes of Health Research (CIHR) defined KT as "a dynamic and iterative process that includes the synthesis, dissemination, exchange and ethically sound application of knowledge to improve health, provide more effective health services and products and strengthen the healthcare system" (Straus et al., 2009, p. 4).

Climate crisis mitigation is facing overlapping challenges with health care systems when it comes to information management. In Knowledge Translation in Healthcare (2009), Straus and Tetroe report that healthcare systems are "faced with the challenge of improving the quality of care and decreasing the risk of adverse events" (Straus et al., 2009, p. 3). "Globally, health systems fail to optimally use evidence, resulting in inefficiencies and reduced quantity and quality of life" (Straus et al., 2009, p. 3). The "science and practice" of KT can help answer these challenges (Straus et al., 2009, p. 3). Similarly to the mission that drives KA in the climate crisis, closing knowledge-to-action gaps drives KT because providing evidence from research is "necessary but not sufficient for providing optimal care delivery" (Straus et al., 2009, p. 3). We might even take on the characteristics of care used in KT to further elevate the quality of human relationships we want to foster in all climate resilience KA. Knowledge Production, "distillation, and dissemination are not sufficient on their own to ensure implementation in decision making" in the "move beyond simple dissemination of knowledge to actual use of knowledge" (Straus et al., 2009, p. 3-4). This insufficiency is also present in climate crisis mitigation outcomes in a Sustainability Transitions Knowledge Activation (STKA).

2.7.3.1 Interdisciplinary visual methods

Symbolic representations of information facilitate the analysis between knowledge domains. For example, Goethe's studies of morphology are activated into practice by Gemma Anderson-Tempini's work. Anderson-Tempini "presents drawing as a means of developing and disseminating knowledge, and of understanding and engaging with the diversity of natural and theoretical forms, such as animal, vegetable, mineral, and four-dimensional shapes" (Anderson-Tempini, 2018, back cover).

Anderson-Tempini defines isomorphology as "an alternative approach to classification through drawing" that "adapts Goethe's morphological approach" [4] to "the study of form and symmetry in whole organisms towards a focus on the parts of organisms" which "initiates a move from observation to abstraction" (Anderson-Tempini, 2018, p. 11) [5]. She proposes a set of "conceptual forms [...] abstracted from nature". Specifically, she proposes thirteen "primary forms and symmetries of isomorphology" (Anderson-Tempini, 2013).

Anderson-Tempini's isomorphological drawing practice is also used to represent the change over time of a given subject, "representing morphology as a dynamic and formative process" (Anderson-Tempini, 2018, p. 179). This practice, called isomorphogenesis "progresses from the empirical study of the morphology of static museum specimens towards a conceptual study that aims to draw morphology as dynamic" (Anderson-Tempini, 2018, p. 179). Isomorphogenesis is a "drawing practice or 'experiment'" (Anderson-Tempini, 2018, p. 179) that captures "four-dimensional shapes" (Anderson-Tempini, 2018, back cover) to explore the "potentialities of representing morphology as a dynamic and formative process" (Anderson-Tempini, 2018, p. 179). Isomorphogenesis "progresses from the empirical study of the morphology of static museum specimens towards a conceptual study that aims to draw morphology as dynamic" (Anderson-Tempini, 2018, p. 179) [6]. In short, isomorphogenesis as a drawing practice illustrates the dynamic changes of a given organism over time facilitating their deeper study.

The impact of Anderson-Tempini's isomorphology and isomorphogenesis practice extends internationally. This approach is formally recognized and "has developed as a visual counterpart for the European Research

[4] For a thorough discussion of Goethe's morphological approach see *Morphology: Questions on Method and Language* (Molder et al., 2013).

[5] For an illustration of Anderson-Tempini's isomorphologies see her illustration *Fig 1: The primary forms and symmetries of Isomorphology* (Anderson-Tempini, 2013).

[6] For an example of isomorphogenesis see "Figure 15: 'Isomorphogenesis' no.10" (Anderson-Tempini, 2018, p. 203).

Council-funded project 'A process ontology for biology', led by Professor John Dupré at the University of Exeter" (Anderson-Tempini, 2018, p. 179). Anderson-Tempini's isomorphology and isomorphogenesis methods contribute substantially to classifying natural forms and visualizing their dynamic traits and transformations through drawing.

2.7.4 Knowledge Production

To recap, KSSTP stands for Knowledge Surfacing, Synthesis, Translation, and Production. This section, Knowledge Production, concludes the literature review section dedicated to defining the terms and dynamics involved in KSSTP.

2.7.4.1 Induction, deduction, and abduction in Peirce

Within KSSTP, Sowa's understanding of Peircean analogy is closer to what I mean by Knowledge Surfacing; Adler's "syntopical reading" and Wilson's consilience are closer to what I mean by Knowledge Synthesis. Peircean abduction is closer to what I mean by Knowledge Production because it is about proposing something new. In fact, Peirce defines abduction as "the process of forming an explanatory hypothesis", the "only logical operation which introduces any new idea", and the only means to "learn anything or to understand phenomena at all" (Peirce, 1960b, p. 106).

Peirce elaborates that induction "does nothing but determine a value" and "shows that something actually is operative"; deduction "merely evolves the necessary consequences of a pure hypothesis" and "proves that something must be"; abduction "merely suggests that something may be", and "Its only justification is that from its suggestion deduction can draw a prediction which can be tested by induction" (Peirce, 1960b, p. 106). In the case of the title of this thesis, it is the *may* in the *What may be known*.

The mystery of introducing "any new idea" (Peirce, 1960b, p. 106) is captured by Peirce when he wrote: "No reason whatsoever can be given for it, as far as I can discover; and it needs no reason, since it merely offers suggestions" (Peirce, 1960b, p. 106). It would seem that curiously that the illusive Knowledge Production is vital to moving any theory forward, and yet its abduction "needs no reason" and constitutes only a proposal for the direction of further study, relying on the other forms of logical operation to constitute if it "may be" or "must be" (Peirce, 1960b, p. 106).

Wilson's borderland disciplines (Wilson, 1999, p. 12) and Adler's *Syntopicon* can work together in syntopical consilience as a means towards creating "new language" (Pangaro, 2011, p. 185). Syntopical consilience offers the possibility of Peircean abduction or introducing a "new idea" (Peirce, 1960a, p/ 106). Therefore, I propose that in KSSTP, the confluence of Knowledge Synthesis, Knowledge Translation, and Knowledge Production can be referred to as Syntopical Consilient Abduction.

2.8 Design across KSSTP

Design works across the various forms of KSSTP, surfacing, synthesizing, translating, and creating: surfacing by revealing relationships between ideas in techniques like topic modeling, synthesizing by combining ideas in techniques like Systematic Combining (Dubois and Gadde, 2002, p. 554), translating by framing ideas from one discipline in the ways that another can receive and understand (Straus et al., 2009, p. 3) and creating in generative methods like gigamapping (Sevaldson, 2011). In this section, we will cover various forms of design that relate to KSSTP within discussions of composition, spatial composition, visual forms of Knowledge Production, information design, Systems Oriented Design, Systematic Combining, Design for Sustainability Transitions, and the torus as an isomorph for visual reasoning.

To "distinguish design from Design", Sevaldson notes that B. Archer "made a distinction between design and Design with a capital D [...]. Design with a Capital D is a third area of knowledge and education equal to science and the humanities, with relations to arts and technology" (Sevaldson, 2022b, p. 91). In Archer's own words: "Design, in its most general educational sense, where it is equated with Science and the Humanities, is defined as the area of human experience, skill and understanding that reflects man's concern with the appreciation and adaptation of his surroundings in the light of his material and spiritual needs. In particular, though not exclusively, it relates with the configuration, composition, meaning, value and purpose in man-made phenomena" (Archer, 1979, p. 20). Archer, as cited by Sevaldson, thus posits Design as a distinct knowledge domain alongside science and humanities.

Sevaldson entreats: "It is urgent to develop and reinforce this perspective of Design as an equal area to science and the humanities. Design should be viewed as a unique mode of knowledge production that can be used to achieve the systemic changes needed for future systemic innovations" (Sevaldson, 2022b, p. 91). Furthermore, Sevaldson articulates: "Design is inherently systemic. Any design must relate to users, production methods, culture, aesthetics, business economy, and technology. In that sense, it is always a result of negotiation and navigation within networks of relations between large complex systems. Without putting in the effort to understand, to the best of our abilities, these networks of relations, one will not be able to produce design outs that function well in the world" (Sevaldson, 2022b, p. 91). Sevaldson posits Design as a systemic knowledge domain crucial for innovation and navigating complex interdisciplinary relational networks.

Epistemologically, I posit that Archer's Design, as opposed to lowercase-d design, is a semantic field for Wilson's consilience, in which it is possible to further integrate Science and the Humanities.

2.8.1 Composition

To define the composition, we must first consider what it means to be 'whole.' At first glance, the famous aphorism "The whole is greater than the sum of the parts" captures the core of Gestalt psychology. This statement is often attributed to Aristotle, or to Systems Thinking (Sevaldson, 2022b, p. 164)[7], but it merits clarification. To cite Gestalt psychologist Kurt Koffka in Sevaldson, "The whole is other than the sum of its parts" (Sevaldson, 2022b, p. 164)[8]. Koffka's statement is closer to the words of Aristotle, who wrote "the whole is something beside the parts" (Aristotle, 1989). To treat with composition, we need to recognize the ways wholes have properties distinct from their parts' properties.

Composition, or the interpretation of wholes and parts, is fundamental to understanding. Noam Chomsky argues that composition is foundational to language (Chomsky, 1986; Chomsky and Lightfoot, 2002), Sevaldson suggests that it is "the most important notion of design" (Sevaldson, 2022b, p. 162), and Geman et al. argue it is "fundamental to all of cognition" (Geman et al., 2002, p. 1). Furthermore, Geman et al. define composition the semantics engaged in composition as the ability "to represent entities as hierarchies of parts, with these parts themselves being meaningful entities, and being reusable in a near-infinite assortment of meaningful combinations" (Geman et al., 2002, p. 1). As Sevaldson puts it: "Composition in design can be understood as a special way of synthesis in shape and form. In art, composition rests on its own objective, and creates its own logic" (Sevaldson, 2022b, p. 167). Composition (i.e., the way we combine and interpret parts to create a whole) is fundamental to understanding language, design, and cognition.

In the converse of *composition*, Sevaldson offers additional subtlety to the discussion of *decomposition*. Sevald-

[7] For a more fulsome retracing of the lineage of thinkers that lead to Systems Thinking as a practice, see "History and State of Systems Thinking in Design" in Sevaldson (2022), p. 149-150 (Sevaldson, 2022b, p. 148-150).

[8] For a more fulsome connection between Gestalt and design and systems see "Gestalt Psychology" in Sevaldson (2022), p. 186-188 (Sevaldson, 2022b, p. 163-167).

son writes object-oriented approaches offer less emphasis on the relation between entities, which "comes as a natural consequence of their reference to language, where the relation between the words (entities) is proximal rather than a potential process or signal by its own right" (Sevaldson, 2022b, p. 169). In this thesis, I adopt an approach closer to Sevaldson's, where the relation between entities in composition is itself a signal that carries its own meaning.

2.8.2 Spatial composition

Further to visual experience in space, treatments of spatial composition exist. In Semiotics of *visual language* (1990), Saint-Martin introduces a syntax of sculptural language and its laws, including topological relations, by using the infrastructure of the virtual cube as corresponding "to the contour of the most unified geometrical forms", and having "preeminent status in the perceptual process" (Saint-Martin, 1990, p. 173-174). Proposing to work within the gestaltian cube continues to be a distinctly Euclidean perspective. While I appreciate that the constraints of point-plotting within the cube can provide a starting point, other methods of plotting points and examining their relationships exist, such as the embedding into spherical space, hyperbolic space, and custom metric space (McInnes, 2018).

Saint-Martin, however, goes on to distinguish the types of mathematics used to understand meaning-making in three-dimensional space. She recalls that in "the 1940s, the genetic epistemology of Piaget established that the first geometrical model of space used by human beings is not Euclidian geometry but topology. This spatial model of the organization of perceptual experience remains throughout human life the basic means by which one constructs his notions of reality" (Saint-Martin, 1990, p. 68).

Saint-Martin and Johanna Drucker, author of *Graphesis* (2014), imagine futures with integration of topological semantic expression. In The Semiotics of Visual Language Saint-Martin writes that she is "entrusting to a future work the development of the semantic system of topological semiotics" (Saint-Martin, 1990, p. 225) Drucker proposes that topological concepts could be useful in analyzing "textual structures" and "paratextual apparatuses", including marginal notes, footnotes, and layout features (Drucker, 2014, p. 54). She emphasizes that understanding continuity and discontinuity in text interpretation is crucial for interpreting hyperlinked environments (Drucker, 2014, p. 54). However, Drucker notes that we still need to develop a specialized 'metalanguage' to describe how graphical elements convey relationships in digital spaces and how they contribute to the text's meaning through their "structuring effects" (Drucker, 2014, p. 54). Drucker poignantly muses with the imagery of space: "Thought forms expressed in the constellationary field may be abstracted and studied for their configuration of knowledge as well as their content, and the organizing orders of graphical expression will take on their own legibility" (Drucker, 2014, p. 196). Saint-Martin and Drucker envision a future where topological concepts are integrated into semantic and textual analysis, emphasizing the need for a new language to interpret graphical relationships in digital spaces.

2.8.3 Visual Forms of Knowledge Production

Johanna Drucker might categorize the diagrams which Tversky sees as a "platform for inference" as "visual forms of knowledge production" (Drucker, 2014) distinct from visual forms of information display. In fact, Drucker defines graphesis as "the study of the visual production of knowledge" (Drucker, 2014, p. 3).

More widely than diagrams and interface, Drucker's work offers much-needed clarity in visual epistemology, or "ways of knowing that are presented and processed visually" (Drucker, 2014, p. 8). She underscores the epistemological urgency of this thesis when she writes: "Visual expressions of knowledge are integral to many disciplines in the natural sciences, but language-oriented humanities traditions have only barely engaged with visual forms of knowledge" (Drucker, 2014, p. 7). Drucker's insights in visual epistemology extend beyond diagrams and interfaces to include *visual arguments*. Tversky found that when it comes to visual arguments and visual reasoning as a whole, "well-crafted diagrams are superior to language for explaining many kinds of information—more directly, more succinctly" (Tversky and Parrish, 2022). Furthermore, visual explanations are "a check for coherence, a check for completeness, and a platform for inference" (Tversky and Parrish, 2022). In other words, well-made graphs are worth more than a thousand words, specifically because they can act as visual arguments and help us reason through complex information in ways that are more effective than using only words.

Drucker argues that information visualizations often present themselves as objective representations of data when, in fact, they are interpretative arguments made through visual means (Drucker, 2014, p. 10). Drucker points out the paradox of how visual forms of knowledge production across various media tend to conceal the visual ways arguments get constructed (Drucker, 2014, p. 10). Drucker's book aims to highlight these visual forms of knowledge production and develop a critical framework for analyzing them.

2.8.3.1 Graphical User Interface (GUI)

In a historical context when "we carry on most of our personal and professional business through interfaces", it is pertinent to single out that "no single innovation has transformed communication as radically in the last half century as the GUI", the Graphical User Interface (Drucker, 2014, p. 8). The importance of the GUI is in no small part because of its graphesis.

Drucker encouragingly describes the simultaneously technical and interpretative endeavour of graphesis as a view "into the studio laboratory of knowledge design, where we sit at the consoles of workstations meant to help engineer and imagine the creation and implementation of a diagrammatic and constellationary rhetoric, of writing in the infinitely extensible field populated by new conventions of legibility that structure and organize expression and communication" (Drucker, 2014, p. 197). Drucker then adds that "the workstation dissolves into infinite play of text and task, knowledge as performance and invention, a cognitive engine engaged with the collective life of embodied mind" (Drucker, 2014, p. 197). Drucker's description of the studio laboratory of knowledge design is a more humanistic facet of the more computer-science-oriented approach called knowledge engineering, or the use and construction of a computational knowledge-based system used for problem-solving (Wielinga et al., 1992, p. 8). Drucker's sense of graphesis as a technical and interpretative endeavour sets the stage for a more humanistic approach to knowledge design.

The "subjective display of humanistic phenomena can be applied across" domains in the following "four basic levels" of "visualizing interpretation" (Drucker, 2014, p. 135) or "visual forms knowledge production" (Drucker, 2014): "1) Modeling phenomenological experience in the making of humanities (*data* as *capta*, primary modeling, the representation of temporal and spatial experience); 2) Modeling relations among humanities documents, i.e., discourse fields (a different metric might be needed to understand dates on diplomatic documents from the spring of 1944 or 1950); 3) Modeling the representations of temporality and spatiality that are found in humanities documents (narrative is the most obvious); 4) Modeling the interpretation of any of the above (depicting or graphing the performative quality of interpretation)" (Drucker, 2014, p. 135).

2.8.3.2 Humanistic Design

The "humanist commitment to interpretation", "embracing ambiguity [...,] contradictions and the lack of fixity or singularity", and the ways that "forms of classification, taxonomy, or information organization embody ideology" (Drucker, 2014, p. 178) are not mutually exclusive to the value of synthesis across ideology and taxonomy. Wilson's borderland disciplines and Adler's *Syntopicon* are evidence of how ambiguity can coexist and even benefit from the synthetic "fixity" (i.e., artificial stability) of consilience and syntopical reading, ideological or otherwise. In fact, Drucker later revisits this comingling of "fixity" and ambiguity in the afterword of *Graphesis*: "The interpretative and the empirical need not exclude each other. So the graphic grammar of an emerging visual system inclined to present the embodied, situated, circumstantial, and fragmentary quality of knowledge will embrace specificities and particularities even as it makes possible the social mediation of communicative exchange" (Drucker, 2014, p. 196).

Drucker's *Graphesis* captures an ontological ethos for humanistic information design in which she advocates for advancing beyond the terms "set by disciplines whose fundamental beliefs are antithetical to interpretation" (Drucker, 2014, p. 178). In her vision of critical design for interpretative and humanistic interfaces, Drucker emphasizes the importance of revealing the constructedness of knowledge and facilitating interpretative activity with tolerance for "inconsistency among types of knowledge representation, classification, fluid ontologies, and navigation" (Drucker, 2014, p. 178). Drucker's work lays the foundation for the evolution of scholarly tools toward more dynamic, relational, and interpretative approaches in humanistic information design.

Drucker argues that we "are in the incunabula of information design" (Drucker, 2014, p. 176). She identifies emerging "new conventions that do not rely on book structures" (Drucker, 2014, p. 176) in information software. Drucker emphasizes that the "new condition for scholarly activity is relational and dynamic", prioritizing process over product (Drucker, 2014, p. 176). She notes that "Informational derivatives of data mining, analytics, visualization, and display are increasingly a part of a reading environment in scholarly, political, and business activity" to visualize "these networked relations, communities of scholarly exchange, argument, comment, linked references, framings, and embedded citations" (Drucker, 2014, p. 176). Drucker advocates for "an interface that is meant to expose and support the activity of interpretation, rather than to display finished forms" (Drucker, 2014, p. 179), representing a shift towards praxis in humanistic information design. Drucker envisions the dawn of humanistic information design as emphasizing dynamic and interpretative interfaces that visualize networked scholarly discourse and prioritize process over finished products.

2.8.4 Information visualization and information design

Drucker defines information graphics and information visualization as “visualizations based on abstractions of statistical data”, or “metrics expressed as graphics” (Drucker, 2014, p. 7). Sevaldson writes that information visualizations make information “accessible and understandable” (Sevaldson, 2022b, p. 186). The impact of information visualization has been great, “and in many cases, the visual serves as scientific (ostensive) proof” (Sevaldson, 2022b, p. 186). Information visualization is a valuable practice for displaying the various modes of Knowledge Activation.

Data “does not have an inherent visual form”, so visualizations are also necessarily interpretations (Drucker, 2014, p. 7). Information visualization “creates a bridge between sciences and the arts. It is often aesthetic decisions that influence the interpretation of the visualisations” (Sevaldson, 2022b, p. 186). The interpretativeness of information visualizations, and data representations more generally, are a means of bridging art and science through aesthetic decisions that shape them.

However, the limitation of information visualization is that it is “with very few exemptions, descriptive” (Sevaldson, 2022b, p. 186), and often this happens through “simplification and reduction of the complexity of the material” (Sevaldson, 2022b, p. 186).

2.8.5 Systems Oriented Design (SOD)

The complexity of science and design research as a field of Knowledge Production “demands an equally rich repertoire of interrelated methods and positions” (Sevaldson, 2010, p. 8).

As introduced earlier, one such codified repertoire is Systems-Oriented Design (SOD), an interdisciplinary methodology that combines systems thinking with design practice to tackle super-complex multi-level problems by integrating diverse information in generative rather than descriptive means (Sevaldson, 2022b, p. 27, p. 152, p. 157). SOD is a “dialect” in the larger field called Systemic Design which is distinguished by its inclination towards design practice. SOD is also sometimes called the Oslo-School of Systemic Design (Sevaldson, 2022b, p. 2)[9].

Central to SOD is the practice of gigamapping, a technique for visually representing complex systems and their interconnections (Sevaldson, 2022b, p. 26). Notably, gigamapping avoids hierarchy and orients practitioners to investigate relationships and meta-relationships like unknown unknowns (Sevaldson, 2022b, p. 55,

[9] For a more fulsome retracing of how Systemic Design emerged as a field see “Systemic Design: The Renaissance of Systems Thinking in Design” (Sevaldson, 2022b, p. 186-188).

p. 353-357). These principles speak to the utility of gigampping as a post-structuralist tool for the definition of systems and ideas. SOD integrates constructivist learning in a way that emphasizes the designer's role in shaping systems through continuous exploration, intervention, and adaptation (Sevaldson, 2022b, p. 153) [10]

In Sevaldson, we find an example of how the network graph provides a distinctly useful medium for managing the discussed epistemological ambiguity in a versatile, decentralized, interdisciplinary representation of entities and relationships, namely, Christopher Warnow's *Map of Systems Theory*(2012) (Warnow, 2012); (Sevaldson, 2022b, p. 125).

Systems Oriented Design encourages systemic designers to understand the dynamics of systems and intervene at various levels while considering the ethics, ripple effects, and consequences of their work (Sevaldson, 2022b, p. 95-96). This includes "evaluating and re-evaluating the constructed boundary when working with a system" (Sevaldson, 2022b, p. 146), or boundary critique (Midgley et al., 1998).

Here at OCAD University, Peter Jones compiled the practice of synthesis mapping based on Sevaldson's gigamapping method (Jones et al., 2017, p. 129) in and through the Strategic Innovation Lab (sLab). In fact, Jones, Shakdher and Singh employed the synthesis map method in the Knowledge Translation of Healthcare Systems (Jones et al., 2017, p. 129).

[10]For a retracing of constructivist learning theory, Sevaldson notes that it has been influenced by Lev Vygotsky, Herbert Simon, Heinz von Foerster, and Humberto Maturana (Sevaldson, 2022b, p. 153).

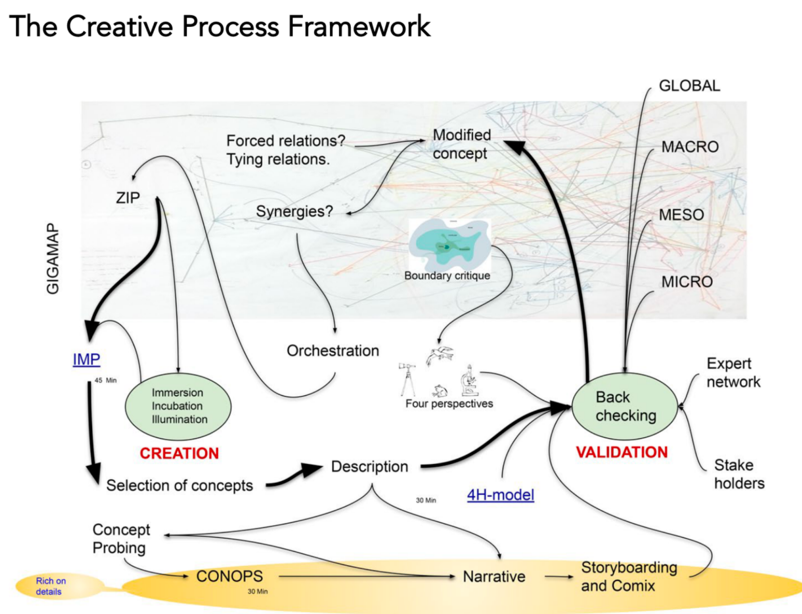

Figure 2.14: Diagram of the SOD Creative Process Framework (Sevaldson, 2022b, p. 312). Used with permission.

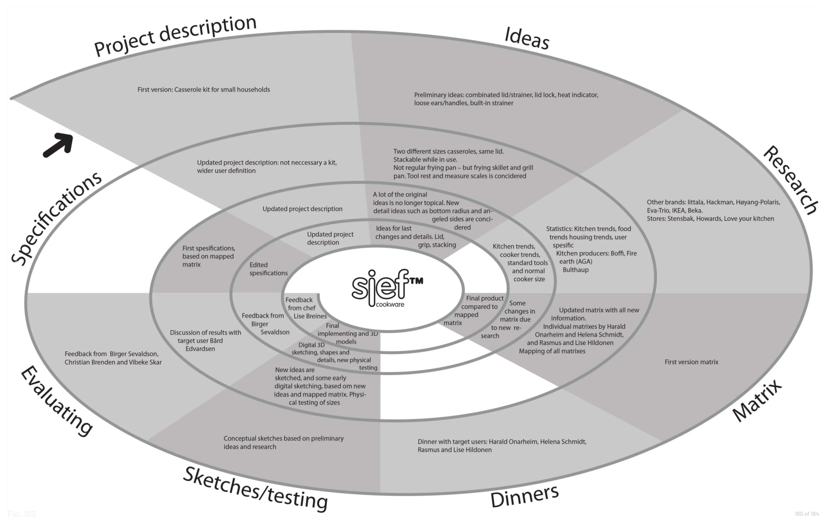

Figure 2.15: Diagram of a design process with iterations. (Sevaldson, 2022b, p. 343) (Sevaldson, 2022a). Used with permission.

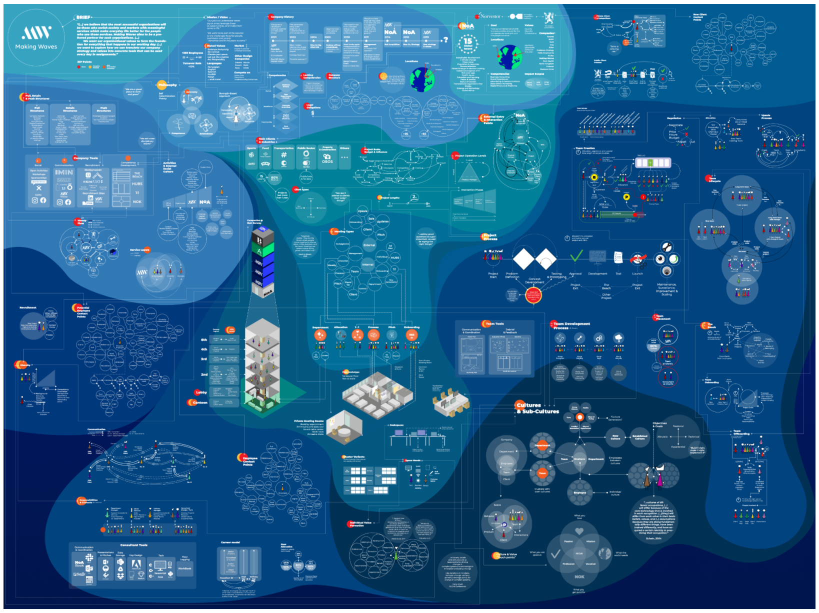

Figure 2.16: An example gigamap. Making Waves: Organizational gigamap by Angel L. Lamar Oliveras (Lamar Oliveras, 2020). Used with permission under the CC-BY-NC-ND 4.0 International License.

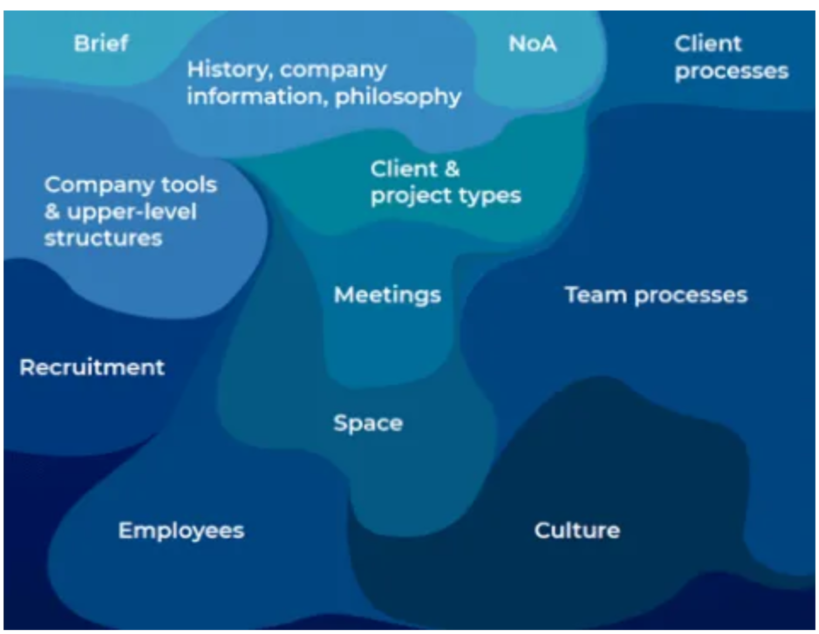

Figure 2.17: Key to Figure 2.16 (Lamar Oliveras, 2020). Used with permission under the CC-BY-NC-ND 4.0 International License.

2.8.6 Systematic Combining (SC)

If climate is everyone's problem, and climate is a system of systems, then systems approaches are everyone's problem, including designers. Robust Systemic Design approaches to sustainability are emerging, like the recent work of Svein Gunnar Kjøde, a student of Birger Sevaldson.

The systems approach to research called Systematic Combining (SC) is the central strategy for Kjøde's Entanglement of Systemic Design and Sustainability Transitions (2024). Dubois and Gadde proposed the term "systematic combining" in 2002 and described it as "a process where theoretical framework, empirical fieldwork, and case analysis evolve simultaneously, and it is particularly useful for development of new theories" (Dubois and Gadde, 2002, p. 554). They note that the "main characteristic of this approach is a continuous movement between an empirical world and a model world" (Dubois and Gadde, 2002, p. 554) "grounded in an 'abductive' logic" (Dubois and Gadde, 2002, p. 553). Systematic Combining offers a dynamic approach to theory development through the simultaneous evolution of framework, fieldwork, and analysis. The application of SC in sustainability transitions research highlights its ability to handle complex, interconnected, and emergent phenomena.

Systematic combining de-emphasizes data verification and accuracy. Instead, it leverages how "multiple sources may contribute to revealing aspects unknown to the researcher, i.e., to discover new dimensions of the research problem" (Dubois and Gadde, 2002, p. 556). "As such," Kjøde explains, "the approach arguably supports an investigation that navigates rapidly developing, interdisciplinary fields of knowledge that not only study the systemic phenomena of sustainability transitions but becomes a system of dynamic knowledge in itself" (Kjøde, 2024, p. 46). According to Sevaldson and Kjøde, systems-oriented design inquiry methods must be able to handle interrelation and contradiction of ideas (Kjøde, 2024, p. 46) (Sevaldson, 2010, p. 8). Kjøde writes that his choice to use SC in his doctoral work "responds directly to the complex, interconnected and emergent nature of the sustainability transitions field" (Kjøde, 2024, p. 45). Systematic Combining prioritizes discovering new research dimensions through multiple sources, making it well-suited for complex interdisciplinary fields like climate crisis KA, which requires handling interrelated, evolving, and contradictory ideas.

2.8.7 Design for Sustainability Transitions (DfST)

Grin et al. define Sustainability Transitions (ST) as "radical transformation towards a sustainable society" (Grin et al., 2011, p. 1) involving an axiological "quest for new value systems" (Grin et al., 2011, p. 2), "a shift to a more sustainable economy" (Grin et al., 2011, p. 1), and "long-term and complex socio-technical transitions" (Grin et al., 2011, p. 11). Design for Sustainability Transitions (DfST), also called Transition Design, is a "kind of designing that is connected to long horizons of time and visions of sustainable futures" (Irwin et al., 2015, p. 3). In short, sustainability-oriented multi-systemic interdisciplinary information processes and their societal outcomes are supported by Design for Sustainability Transitions.

Flittner et al. (2022) elaborate that DfST combines frameworks and methods from a variety of fields, like transition management, anthropology, design research, and sustainability science, towards a practice for building enduring "transitions towards more sustainable societies" (von Flittner et al., 2022, p. 160). ST and DfST are both, then, interdisciplinary, longitudinal, iterative, multi-praxis, multi-systemic, cross-sectoral theoretical work which sustains the potential for "complementary understandings" (Öztekin and Gaziulusoy, 2020, p. 197) and operationalization of social change. Furthermore, DfST engages three embedded levels of Systemic Design complexity described by Robert Young: (a)"design in context" or "design at the level of products and artefacts", (b) "designing context" or "design at the level of systems and services", and (c) "design of context" or "design at the level of policy, ideology, purposes, values and norms" (Öztekin and Gaziulusoy, 2020, p. 200).

All design must take into account ST, and in some sense, all responsible design is DfST. As such, this thesis works towards ST through KA, or STKA for short.

2.8.8 Torus isomorph as a composition for visual reasoning

The torus, with its captivating visual and mathematical properties, compellingly emerges as an isomorph across diverse disciplines and contexts. My initial encounter with the torus was through interpretations of chakra geometry whereby horn tori are used to represent cyclical energy fields in and around the human body (Singer, 2019).

In *Rudy Rucker's Infinity and the Mind (2005)*, the torus is employed to model space-time, specifically depicting an oscillating universe with circular time. Rucker's toroidal model suggests a universe that is both finite and unbounded, where time loops back onto itself in a continuous cycle as shown in Figure 2.18.

As I directed my research away from cosmology in this thesis, I continued to encounter the torus in a surprising variety of fields in ways that captured a variety of phenomena. For example, Gardner et al. use TDA of the recordings of hundreds of rat grid cells to demonstrate that "the joint activity of grid cells from an individual module resides on a toroidal manifold" (Gardner et al., 2022, p. 123), as shown in Figure 2.19. Furthermore, positions "on the torus correspond to positions of the moving animal in the environment." (Gardner et al., 2022, p. 124).

To better understand the various forms of tori I encountered, I turned to a mathematical classification of tori (Weisstein, n.d.b), which disambiguates the horn torus, ring torus, and spindle torus, as shown in Figure 2.20.

This exploration led me to contemplate the potential of plotting text graphs into a toroidal structure. The torus, as a unique and intriguing isomorph, offers a compelling framework for graphing complex nested ideas across a wide range of scales. Its topology allows for representing feedback loops, cycles, and the interconnectedness inherent in complex systems.

In the context of the climate crisis and the urgent need for consilient, syntopical information practices, the torus presents a valuable tool. Integrating insights from Tversky's work on the neuroscience of visuospatial reasoning, Anderson-Tempini's concepts of isomorphology and isomorphogenesis, and Drucker's approaches to visual Knowledge Production, the torus can facilitate new methods of data visualization and understanding.

Advancements in three-dimensional information plotting enable the production of dynamic toroidal models, particularly through platforms like UMAP (McInnes, 2018), Python, Blender and others. Combined with hyperlinked bibliometric interfaces such as Obsidian and Litmaps, these tools support the activation and navigation of large textual datasets using visuospatial graphing, which is crucial in addressing the complexities of the climate crisis.

By investigating the isomorphic properties of the torus, we can leverage its distinct interdisciplinary presence to develop innovative ways to represent and analyze interconnected systems. For example, as a metaphorical and practical framework for systemic thinking, the torus's topology embodies the cyclical and recursive nature of knowledge transformation.

In short, the torus's isomorphic, geometric, and topological versatility can serve as a means of bridging disparate academic fields in STKA.

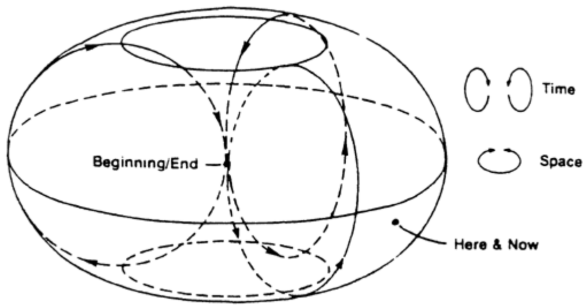

Figure 2.18: Rucker horn torus model representing "an oscillating universe with circular time" (Rucker, 2005). Used with permission.

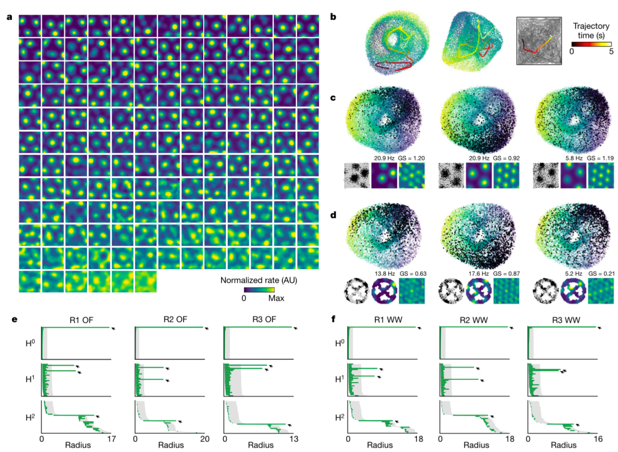

Figure 2.19: Illustration of "signatures of toroidal structure in the activity of a module of grid cells" (Gardner et al., 2022, p. 124). Used with permission.

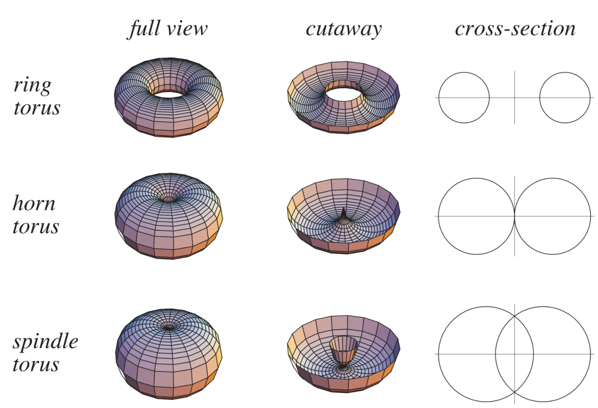

Figure 2.20: The three standard tori (Weisstein, n.d.b). This illustration shows the three types of tori: ring torus, horn torus, and spindle torus. Each type is shown as a full view, cutaway, and cross-section through the z-axis. Used with permission.

2.9 Reflection on my literature review

In this section, I discuss and critique various themes from my literature review: KA quantification, topology, Personal Knowledge Management, and Artificial Intelligence. Next, I offer an anti-oppressive critique of various terms from the literature review. Last, I discuss the research gaps I discovered.

2.9.1 Towards quantifying Knowledge Activation

In the interest of quantification and efficiency, I offer the equation $A(K)=f(Su_K,Sy_K,T_K,P_K)$, which proposes that the activation strength of knowledge K is a function of four distinct modes:

1. Surfacing (Su_K): Making implicit or dormant knowledge explicit.
2. Synthesis (Sy_K): Combining multiple pieces of knowledge to form new insights.
3. Translation (T_K): Interpreting or recontextualizing knowledge across different domains.
4. Production (P_K): Generating new knowledge from existing information.

More specifically, $A(K)=w_1Su_K+w_2Sy_K+w_3T_K+w_4P_K$, where w_i are weights representing the importance of each mode.

For in-text abbreviation of Knowledge Activation, *KA* can be used. For the longer list of distinct modes of Knowledge Activation, or Knowledge Surfacing, Synthesis, Translation, and Production, *KSSTP* can be used. For the abbreviation of individual KA modes, KSu, KSy, KT, and KP can be used.

2.9.2 Topology

The paradigmatic shift from examining geometry in symbols to considering their topology was pivotal in this thesis. I think back to many moments of wonder I have had throughout this research when I read the following passage from Goethe's *Atmosphäre:*

> *"To find yourself in the infinite,*
> *You must distinguish and then combine;*
> *Therefore my winged song thanks*
> *The man who distinguished cloud from cloud."*

(Popova, 2015, Goethe to English in Popova) (von Goethe, 1836, p. 107)

The man referred to in Goethe's poem is English meteorologist Luke Howard, who named the various kinds of clouds (cirrus, cumulus, stratus, etc.) (Howard, 1803). In my work, I will name two figures who provided pivotal information about topology: Adam Tindale and Ginestra Bianconi. My first conversation with Tindale helped me distinguish the maths of my work by introducing me to topology in the first place. Bianconi's presentation at the Santa Fe Institute introduced me to how isomorphologies can be traced across dimensions using Persistence Homology (Bianconi, 2024a) (Bianconi, 2024b). In short, to echo Goethe, their work helped me distinguish point-cloud from point-cloud and introduced me to a new language I could use to "distinguish and then combine" (Popova, 2015).

2.9.3 Personal Knowledge Management (PKM)

In our everyday navigation, people tend to revisit familiar routes and seldom venture onto different paths. This habitual behaviour extends to how we manage and access information; there are times when we find ourselves searching for knowledge we already possess but cannot readily locate. This inefficiency highlights a critical need for more effective Personal Knowledge Management (PKM) systems.

Tools like Obsidian (Li et al., 2024) have emerged to address this challenge by facilitating serendipitous discovery and cross-referencing within personal databases or "vaults" (Obsidian, n.d.a). Obsidian allows users to create a network of interconnected notes. These mirror the associative nature of human thought. While this works well for individual collections of information, it becomes unsustainably slow when scaling up to larger datasets, such as full-scale libraries or complex repositories.

In my experience, attempting to use Obsidian with a library-sized database resulted in performance issues—not due to hardware limitations but because of the way Obsidian indexes information. It is not optimized for handling the vast amounts of data present in large-scale databases. Given that libraries themselves are modest in size compared to the 'database of databases' which we collectively generate, there is a clear need for tools that can operate effectively with this higher level of abstraction.

This gap raises the question: What tools exist that operate one or two levels above current PKM systems like Obsidian? My work seeks to explore and develop methodologies and platforms that function at these high abstraction levels for information discovery and storage. I recognize that most individuals may not yet use tools like Obsidian. So, considering even higher levels of abstraction may seem premature or disconnected from the immediate needs of researchers doing climate evidence synthesis and other forms of Knowledge Activation.

PKM has the potential to address interdisciplinary challenges like the climate crisis by powering new ways to organize and navigate information. While this endeavour may appear tangential to daily problem-solving in research, it may be pivotal to finding solutions. Interdisciplinary Knowledge Activation in its various modes that has any chance of facing the global warming hyperobject hinges on human ability to interpret vast stores of information within the shortening window of opportunity.

The proposal is to empower individuals—not just information specialists—to navigate their entire discipline with the same ease as navigating files on a hard drive. Platforms that visualize the structure of knowledge within a field can help users discover new insights that are otherwise obscured by informational silos or sheer volume. Furthermore, personalized navigation maps would then be shared with researchers in other disciplines to collaborate on work and build interdisciplinary understanding.

My aim is to make accessible the paths of disciplinary interchange through which experts navigate their fields. This will facilitate the translation or transfer of knowledge, methods, and methodology between disciplines.

In line with the concepts introduced earlier in this thesis—such as Semantic Forms, Query Isomorphs, and the TCA Workspace platform—advancing PKM tools aligns with the broader goal of enhancing Knowledge Activation (KA). Integrating advanced visualization techniques and computational analysis into PKM systems supports Knowledge Surfacing, synthesis, translation, and production (KSSTP). This integration allows individuals to engage with information at multiple levels of complexity. My goal is to create a deeper understanding and more effective application of knowledge to real-world challenges.

In conclusion, while developing higher-level information technology may seem removed from immediate practical concerns, simplifying how people navigate complex knowledge repositories may be pivotal for a human response to global warming.

2.9.4 Artificial Intelligence (AI)

I conceived of TCA Workspace before I knew about Language Models and before the rapid rise of Chat GPT. By testing Large Language Models and Small Language Models, I was contending with whether or not a form of what I refer to in this thesis as a "particle accelerator of ideas" had now been made. It had. In some ways, and in many ways, it hadn't.

In my experience, LLMs have had many technical successes. Coding is an entirely new landscape of work, as is writing. However, in addition to the ecological concerns of LLM energy use, hallucinations, bias, and insight remain significant limitations of every model I have tested. I propose that low-dimensional graph information from Systemic Design methods and spatial topic models can be used to source an additional layer of calculable information for LLM training. LLM training data are rapidly becoming scarce, and this is an opportunity to source from Symbol-setting rather than just language setting.

Graph prediction can result as the expansion of the "language statistics" (Shannon, 1951, p. 1) that underlie next-token prediction. Considering the density of information that can be conveyed diagrammatically (Tverksy, Drucker, Anderson-Tempini, Sevaldson, Bánáthy, Kjøde), I propose there is great value in graph LLMs, more so if used congruently with Systemic Design, Query Isomorphs, Semantic Forms, Ontological Semantic Network Summaries, and Terroir of Text and Graphs.

2.9.5 Ability-diverse expansion of the term 'graphesis'

While I grapple with language that joins text and graph in one consolidating word, I am tempted to use Drucker's term *graphesis*, but I hesitate because I maintain that text and graphs are not exclusively visual forms of Knowledge Production. I don't believe it is Drucker's intention to exclude other senses in her scope of "visual forms of knowledge production" (Drucker, 2014); in fact, making visual representations of knowledge requires a sense of the visuospatial. However, I propose that it merits naming the diverse involvement of the senses involved in Knowledge Production. For instance, sighted people have much to learn from the spatial and physical forms of Knowledge Production used by non-sighted people. In an etymological revisiting of *graphesis*, I will here endeavour to expand this term's boundaries to be more ability-diverse [11] and closer to the term *Knowledge Production*, which can be visual and/or spatial.

Though it is likely that other non-western languages have semantic versatility that can more neatly expand the sensory container of the term *graphesis*, for the sake of linguistic proximity to Drucker's use of the term I will work with Greek etymology, dividing the term into *graph-* and *-esis*. *Graph-* comes from *grapho* (γράφω), meaning 'to write' or 'to draw' (Liddell and Scott, 1996a), and the suffix *-esis* is borrowed from Greek to signify an action

[11] *Ability-diverse* is a term used in *A Systematic Review of Ability-diverse Collaboration through Ability-based Lens in HCI* which introduces their Ability-Diverse Collaboration (ADC) framework to "create technologies which integrate abilities, and when needed possibly combine these to create not only more accessible technologies but more integrated experiences." (Xiao et al., 2024, p. 16).

or process.

I turn, then, to the Liddell-Scott-Jones (LSJ) Greek-English lexicon, or as is conventionally abbreviated, the LSJ. We might consider *morphoō* (μορφόω), or to give form or shape (Liddell and Scott, 1996b), considering my term Query Isomorph and Anderson-Tempini's term isomorphogenesis; however, giving form excludes one-and-two-dimensional representations which operate across shape *and* form, like the Sri Yantra and the Meru Chakra; furthermore, giving form also excludes more-than-three-dimensional representations like higher-dimensional graphs in TDA and LLMs. Another alternative I considered was *symbolikós* (συμβολικός), or symbolical (Liddell and Scott, 1996e); while this option is closer to Symbol-setting and not dimensionally constrained, etymologically it excludes the actions of graphing, I opt for a term that is closer to Peirce's work on the idea of 'sign.' The term *sēmainō* (σημαίνω), or to "show by a sign, indicate, point out" (Liddell and Scott, 1996c), is a more versatile starting point because its definition of making known by a sign can include visual experience, but does not necessitate it. I derive, then, that *sēmeíōsis* (σημείωσις), or "inference from a sign" (Liddell and Scott, 1996d), is a more fitting description of the work in this thesis. If graphesis is "visual forms of knowledge production" (Drucker, 2014), then semiosis is Knowledge Activation across its various modes (KSSTP), and across the interrelated senses used in understanding, including the visuospatial.

2.9.6 Anti-oppressive critique of the terms "blind spots," "black box AI," and "stakeholders"

My mission to develop clearer methods and language around Knowledge Production is inevitably co-emergent with my embodied experience. As a person of mixed ancestry including European, South American Indigenous, African, and Middle Eastern descent, living with invisible disabilities, I am driven to develop more anti-oppressive language for increased equity and solidarity. In this section, I note a few salient starting points for growth observed in my literature and contextual review. The following examples are not exclusive to these fields but are symptomatic of their prevalence and larger issues in many others. The following examples are offered as my due diligence as a member of the above social and academic communities in the practice of making our shared environments less oppressive and more informed. I do not claim that the writers referred to in this section write with oppressive terminology to intentionally perpetuate ableist colonial structures; in fact, their work is substantially anti-oppressive in other ways, as detailed in the body of this text. It is in this spirit of shared ethic and in pursuit of more inclusive language that I propose what I consider problems with the terms "blind spots", "black box AI", and "stakeholder."

2.9.6.1 "Blinds spots"

From an accessibility perspective in computational text analysis interface, I offer an observation about InfraNodus. The InfraNodus Text Analytics Panel is divided into eight tabs: AI Insights, Main Ideas, Blind Spots, Relations, Sentiment, Trends, Structure, and Stats. Note the use of the word "blind spots," which uses the disability of non-sighted people as an analogue for not knowing. Ableist terms like this must be discontinued in favour of accessibility and inclusion. I will note as a starting point that various guides for accessible language do exist (National Center on Disability and Journalism (NCDJ); ADA National Network, 2018; University of Utah). Furthermore, accessibility must be increased for computational text analysis interfaces and all others. For those interested in pursuing examples of inclusive design, I encourage you to see the work coming out of OCAD University from its Inclusive Design (ID) and Design for Health (DH) graduate programs under Graduate Program Director Dr. Michelle Wyndham-West and the Perceptual Artifacts Lab (PAL) under Dr. Peter Coppin.

2.9.6.2 "Black box AI"

Many writers refer to opaque and noninterpretable AI as "black box AI" (Garrett and Rudin, 2023). In *Interpretable algorithmic forensics* (2023), Garrett and Rudin work to resist the ways AI compounds racial oppression. However, their use of black as a pejorative works in favour of the very oppression they intend to resist. Using the black to mean dangerous (Browne, 2015, p. 38, 138, 158) in the context of the noninterpretability of AI contributes to the historical and ongoing exclusion of black people from self-determination in the technology used to oppress them. (McIlwain, 2020, p. 244-245). Furthermore, calling noninterpretable AI a "black box" acts against Afrofuturism and the wider umbrella of the Black Speculative Art Movement (Anderson, 2016, p. 233) in a time when white nationalism is on the rise and black empowerment, futuring, and hope are particularly critical. The ongoing work required to reinforce the equitable use of algorithms (Noble, 2018) requires dismantling terms that embed racial bias like "black box AI." I propose that we use terms like 'opaque AI' instead.

2.9.6.3 "Stakeholder"

From the perspective of decolonizing and Indigenous resurgence, I offer an observation about my broader literature review in Information Studies, Cybernetics, and Systemic Design.

The term "stakeholder," in its currently widespread sense, refers to a person who can affect, can be affected by, and has a claim to a group or organization's activities. The Canadian province of British Columbia hosts a webpage guide to "Terminology in Indigenous content". In it, they write that "stakeholder" "is a common corporate term for partners that has negative connotations to many Indigenous Peoples. When land acquisition was happening, this term referred to the allotment of land to settlers. Settlers were given wooden stakes to claim their plot of land prior to any treaty or land negotiations with Indigenous Peoples. It's more appropriate to refer to Indigenous Peoples as partners rather than stakeholders. Indigenous Peoples are not stakeholders; they're Aboriginal rights holders whose rights are protected under the Constitution of Canada" (Province of British Columbia, 2024).

During this study I found the uncritical use of the word "stakeholder" to be widespread in academic writing and even in the daily speech of University officials whose work is otherwise very pro-Indigenous. In my literature review, I found the word "stakeholder" was especially used in publications among disciplines which interact with corporate environments, including Information Studies, Cybernetics, and Systemic Design. As a participant in these academic communities, I see it as my ongoing responsibility to critique its use.

I found that the word "stakeholder" is notably missing from the work of Antionette D. Carroll and Creative Reaction Labs in the *Equity-Centered Community Design Field Guide* (Creative Reaction Lab, 2018). Furthermore, the reader who is also allied to decolonizing and Indigenous resurgence might consider the following resources about pivoting away from anti-Indigenous language (Reed, 2022; Phipps, 2022; Gettel-Gilmartin, 2023).

I chose the source of the above-quoted definition of the word "stakeholder" in solidarity with brave Indigenous communities leading decolonial discussions while living in the post-apocalyptic aftermath of genocide. The brave resistance of Indigenous communities endures while being displaced from their sacred lands by colonizing settlers who continue to destroy the earth with pipelines while enshrining their actions within aggressively imperial names like 'British Columbia.'

While I am adjoining myself to proposed starting points for an anticolonial, anti-racist, anti-ableist move away from the terms "blind spots", "black box AI", and "stakeholders", I am not proposing that the critique of oppressive terms *requires* making suggestions for improvement. I underscore this point in solidarity with the many oppressed people for whom the labour of educating their oppressors compounds the weight of injustice. I recall the words of Theodor W. Adorno: "One continually finds the word critique, if it is tolerated at all, accompanied by the word constructive. The insinuation is that only someone can practice critique who can propose something better than what is being criticized. By making the positive a condition for it, critique is tamed from the very beginning and loses its vehemence" (Adorno, 1998, p. 287).

2.9.7 Research gap

My literature and contextual review identified research gaps, which are implementational, practical, and theoretical.

First, I will address the gap I identified in implementation. While three-dimensional modes of information visualization exist, the range of forms utilized seems to be limited in number and implementation complexity. First, I did not observe cone diagrams (Taylor, 1990; Bezold and Hancock, 1993; Hancock and Bezold, 1994) that were developed into large network graphs. Second, I observed cylindrical network graph composition (Volkart, 2018), but not applied to categorizing information. Third, spheres, or forms organized around a central origin vertex, have been developed as tools for topic category visualization, but with no options to query for relationships between ideas using a visual graphlet interface (Sunter, 2023; Nodus Labs, 2024; Weichart, 2023). Fourth, I observed the use of some spatial graphlets to visualize text, but I found no option for searching for similar graphlets (Ortiz, 2024). I could not find any forms that used tori, series of cones, or complex geometries to reveal semantic relationships.

Second, there is a gap in practical knowledge where research findings do not seem to be finding practical application. Theoretical questions exist regarding the spatial semiotic representation (Saint-Martin, 1990), interdisciplinary symbolic representations of knowledge (Anderson-Tempini, 2018), text interface development (Drucker, 2014), ontological graphs (Sowa, 2000, p. 4), interdisciplinary topic mapping (Adler et al., 1952b), conceptual unification of theoretical models (Wilson, 1999), and the visual implementations of Systematic Combining (Kjøde, 2024). While these practices are independently advanced and advancing, it would seem using them in conjunction with three-dimensional topic model network graphs, climatically or otherwise, is not currently used to chart deeper relationships between ideas across academic disciplines. In short, I was not able to find literature that aims to face the interdisciplinary complexity of the climate hyperobject by using human visuospatial reasoning in spatial interfaces for computational methods.

Third, I observed a theoretical and literature gap between spatial network graph models and my observations of their diversity. Bertin proposes three-dimensional information visualization forms (Bertin, 2011, p. 270) and

Saint-Martin proposes her perspective on three-dimensional arrangement (Saint-Martin, 1990), yet the range of spatial topic model network graph composition types they propose seems to exclude substantial diversity of forms as I detailed in the implementation gap. Furthermore, it would seem there is an absence of taxonomies that address the semantic value of distinct composition forms for making information visualizations in three-dimensional space, whether static or changing in movement. Therefore, I propose such a taxonomy, illustrated by examining spatial topic model network graphs. My taxonomy of Semantic Forms is foundational to my proposal for the development of CATG in digital scholarship, Systemic Design, Sustainability Transitions, and other disciplines.

3

Secondary methodologies and methods

3.1 Research-creation methodology

I used research-creation as a secondary methodology in this thesis to support my literature review. Canada's Social Sciences and Humanities Research Council defines research-creation as "an approach to research that combines creative and academic research practices, and supports the development of knowledge and innovation through artistic expression, scholarly investigation, and experimentation" (Government of Canada, 2021). My art and design "creation process is situated within the research activity and produces critically informed work in a variety of media (art forms)" (Government of Canada, 2021).

Research-creation is most often associated with artistic production in the context of the university, but, as Natalie Loveless asserts, "its real potential rests in its demand for an inter-or transdisciplinary perspective that, while marshalling the insights of emerging and developing fine arts research methodologies, exceeds the fine arts proper. 11" (Loveless, 2019, p. 6-7). The research-creation methodology supports my mixed methods by allowing for the combination of art, design, and research in ways that challenge conventional separations of knowledge. Research-creation provides a framework for exploring and developing new forms of visual epistemology and diagrammatic reasoning while contributing to my work's transdisciplinary nature. and

By working interdisciplinarily with research-creation, I risk "the revelation of incompetence possible when the skills of one discipline prove insufficient in another context" (Loveless, 2019, p. 45). Yet, I do not think that not working at the boundary of ignorance is an option in any form of research. My ignorance of topology and topic modeling at the outset of my research can be an asset. My thesis is also a user case-study of folks from similar disciplinary backgrounds to mine for developing knowledge work platforms. As Shoshona Felman asserts, the "truly revolutionary insight—the truly revolutionary pedagogy discovered by Freud—consists in showing the ways in which ignorance itself can teach us something, become itself instructive" (Felman, 1987, p. 79) (Loveless, 2019, p. 38). As a Brand/UX designer and photographer, the novelty of the fields I encountered by research-creating this thesis adds an additional layer of value to this document.

I propose that the origin of perspective in art before being codified into mathematical terms in DeCartes' rectangular coordinate system, as retraced by Panofsky (Panofsky, 1991, p. 57-58), is an example of research-creation. If the art of perspective can precede the math of perspective, the convergence of various disciplines through research-creation is of immense value and urgency in the context of sustainability transitions and other global problems that require interdisciplinary convergence. Loveless vibrantly frames research-creation itself as a matter of perspective, asserting that it "mobilizes forms that anamorphically shatter single-point perspective, failing to cohere fully into art or scholarship, instead nurturing driven curiosity as its lure and guide: the desires articulating the eruptions of the drive(s) that animate each of us in unpredictable, but nonetheless accountable, directions. It demands the production of new, unruly, driven stories within the university as not only a bastion of privilege, but a site of intense transformative pedagogical power" (Loveless, 2019, p. 105). Despite the divisive misinformation about climate urgency being 'a matter of perspective', we may, in fact, lean on the history of perspective itself as an example of joining efforts across disciplines.

3.1.1 Chapman and Sawchuk

My work embodies the principles of research-creation as defined by Chapman and Sawchuk (Chapman and Sawchuk, 2012), integrating creative practice with academic research to generate new knowledge. My research aligns with three out of their four main categories: research-for-creation, research-from-creation, creative presentations of research, and creation-as-research. However, this thesis works primarily on research-creation as research-for-creation and research-from-creation.

First, research-for-creation has been a foundational aspect of my work. My literature review of geometry, topology, information visualization, and computational text analysis provided the theoretical underpinnings necessary to develop Semantic Forms and Query Isomorphs. My exploration of mathematical concepts like Topological Data Analysis (TDA) and Persistent Homology informed the production of new visualization methods. Philosophical frameworks from Kant and Foucault, along with existing visualization techniques like Bertin's taxonomy of network graphs (Bertin, 2011, p. 52, 270), inspired me to innovate forms such as the horn torus Semantic Form.

Second, in research-from-creation, the act of devising network graph composition forms led to theoretical insights for me. Making models of Semantic Forms and Query Isomorphs revealed to me how semantic forces influence the spatial organization of ideas in text graphs and how these forces might be operationalized through algorithms and interfaces. The creation of Ontological Semantic Network Summaries (OSNS) allowed me to theorize about visualizing ontological positions in texts as a way for researchers to choose sources and databases for their work better. Similarly, Terroir of Text and Graphs (TTG) emerged as a theoretical product of my making process, leading me to new perspectives on Knowledge Translation based on how ecological context and language influence each other.

Overall, my thesis seeks to advance theoretical knowledge through creative practice, generate new insights from the act of creation, communicate research findings creatively, and position creation itself as a form of research. By integrating creation and research, I offer a set of contributions to both academic scholarship and creative practice, emphasizing the value of research-creation in addressing complex global challenges like the climate crisis.

3.2 Critical Systems Thinking Methodology

I used the Critical Systems Thinking Methodology in parallel with research-creation to support my literature review. Considering the interdisciplinary and multi-technological nature of design and information in addressing complex global challenges like the climate crisis, my thesis employs a diverse set of methods in alignment with Critical Systems Thinking (CST). CST, as proposed by Midgley, emphasizes two dimensions of criticality: power relations and methodological pluralism (Sevaldson, 2022b, p. 143). My thesis aligns with both by proposing computational tools that can be used to resist the abuse of power (Castaño-Suárez, 2023c, 2024, 2023a,b) and by complementing systems analysis with research-creation and mixed methods literature review.

3.2.1 Pluralism of methodology and method

My research seeks to embrace methodological pluralism by integrating mixed qualitative and quantitative methods, as discussed in my mixed methods literature review.

My methods were also plural and complementary and aligned with CST's emphasis on non-reductionist investigation of connections and relations (Sevaldson, 2022b, p. 144); (Midgley, 2000). By combining philosophical, computational, and multi-mathematical approaches, my research seeks to build methods for uncovering insights to better catalyze climate resilience.

In brief, my thesis uses CST as a methodological framework for interdisciplinary research by addressing power relations and embracing pluralism of method and methodology, supporting justice-oriented methods for solutions to global challenges.

3.3 Research design for mixed methods

I approached my work with mixed methods as a response to the diverse needs of the climate crisis. In their editorial *Evidence synthesis for accelerated learning on climate solutions Berrang-Ford et. al* write: "In order to comprehensively learn from the available evidence on climate solutions, it is, therefore, vital to mirror the methodological diversity in primary evidence by promoting the application of the full breadth of qualitative and mixed methods evidence synthesis methodologies" (Berrang-Ford et al., 2020, p. 3).

My mixed methods seek to be integrative, in keeping with the mission to align otherwise diversified approaches. The separation of knowledge/s is exactly what I am working against through methods of integration. For this reason, my thesis moves between phases of literature review, contextual review, making, and reflection.

I categorize my thesis as a work of anticipatory design instead of using more sense-exclusionary terms like "design foresight." My ongoing efforts to use inclusive language extend across disciplines. My thesis is interdisciplinary in that I am informing disciplines with each other. Further, my work is also transdisciplinary in that the subject matter, tools, and anticipatory design move the study of art and design into math and computer science.

3.4 Methods

The following methods in my research were specifically qualitative. First, my survey of symbols and information visualizations was achieved by collecting and cataloguing photographs, screenshots, and digital copies into categories. My categorization of these selected content was based on the specimen's originality and complexity. For information visualizations I categorized specimens by composition type.

In doing so, I analyzed information visualizations for their geometric compositions, and increased their dimensionality from two dimensions to three so as to be more capable of analyzing larger topic model network graphs. The increase in dimension allows for a more fulsome utilization of the neuroscience of the visuospatial as per Tversky's research, but also provides a very practical function in network graphs since larger graphs have vectors that tend to cross over each other, obfuscating the clarity necessary for pattern-finding. Beyond geometric analysis I endeavoured in a literature review of topology to better capture the means of analyzing network graph representations in my models. Such means include Topological Data Analysis (TDA) using Persistence Homology (PH). In my analysis of practices that seek to manage complexity, I arrived at the field of Systemic Design and its toolkit of designerly approaches (Sevaldson, 2011; Jones and Bowes, 2016; Sevaldson, 2022b; Kjøde, 2024).

3.5 Sampling strategy

I collected figures according to their originality of format, complexity represented in the visualization, and the symbolic quality of the composition. In other words, I considered whether the composition of the visualization could read as its own stand-alone unit. After a more general sampling according to the categories above, I selected a smaller number of the most diverse information visualizations based on their composition.

3.6 Analytical approaches

Overall, I surveyed information visualization compositions and the semantic affordances of their basic geometries using inductive, deductive, and both approaches. I produced a taxonomy of two-dimensional shapes and three-dimensional forms that act as morphological categories for most information visualizations, whether network graphs or otherwise.

3.6.1 Composition analysis of information visualizations, graphs, and symbols.

I analyzed information visualization figures, network graph and otherwise, through inductive, deductive and abductive approaches.

3.6.1.1 Inductive, bottom-up analysis of deriving categories from specific examples.

I derived observations from a collection of figures by categorizing them as images on one large virtual canvas, namely Affinity Designer. This inductive approach allowed me to narrow down images for more detailed consideration by dividing them into categories.

In addition to the conventional text interpretation in a literature review, this deductive analytical approach to a sampling of figures involved contextualization and interpretation. A benefit of this approach to sampling symbols and information visualizations was identifying and interpreting figures that I considered highly unique. Examples of this interpretive approach follow: first, the pivotal example in my research was interpreting the Sri Yantra alongside its three-dimensional counterpart, the Meru Chakra (Bühnemann, 2003, p. 31), as image, symbol, and graph; second, was the interpretation of a network graph 'whole' as a unit made of smaller graphlets, which was foundational to arriving at Topological Capta Analysis (TCA) as a means of activating texts by tracking network graphlet isomorphologies; third, as a diversification of network graph 'wholes', texts like Manuel Lima's classification of information visualizations as trees or circles (Lima, 2014, 2017) lent themselves as corroboration for the value of a geometric approach to information visualization composition analysis, network graph or otherwise.

3.6.1.2 Deductive, top-down derivation of specific examples from larger categories

I analyzed top-down observation of composition forms in taxonomies of information visualization. Consulting the work of subject-matter experts who categorize information visualizations was of central importance. Notably, Anna Vital's infographic *How to think visually* (Vital, 2018) acted as both an introduction and touchpoint to my work of examining the range of visually epistemological options available for information visualizations.

3.6.1.3 Algorithmically-assisted sampling that was both top-down and bottom-up

In my third approach for sampling figures, using Pinterest was inductive and deductive by feeding into its image-recommendation algorithm. My inductive process was the selecting and classifying images from the wide range of samples initially populated by Pinterest, while it had limited information about my image collecting. By saving certain types of images from certain categories, I then deductively co-created the parameters for new sets of images, which starts the process over again. As a member of the OCAD U Digital Futures graduate program, which has trained many game designers and theorists, this algorithmic feedback loop added a ludic serendipity to part of my research practice.

3.6.2 Meta-systematic combining

In this thesis, composition is both object of study and method. I accomplish this through an expansion of Systematic Combining (SC).

As discussed previously, Kjøde employs the valuable SC method in his work to visualize the entanglement of systems in Sustainability Transitions (ST) for several reasons:

1. SC facilitates simultaneous evolution of "theoretical framework, empirical fieldwork, and case analysis" (Dubois and Gadde, 2002, p. 554).

2. SC emphasizes a "continuous movement between an empirical world and a model world" (Dubois and Gadde, 2002, p.554) using "abductive logic" (Dubois and Gadde, 2002, p.553).

3. SC prioritizes discovering new research dimensions over data verification, combining frameworks from multiple sources to reveal unknown aspects (Dubois and Gadde, 2002, p.552).

4. SC is suitable for "rapidly developing, interdisciplinary fields" that become "a system of dynamic knowledge" (Kjøde, 2024, p. 46). It can handle interrelated or contradicting ideas (Kjøde, 2024, p. 46) (Sevaldson, 2010, p. 8), making it appropriate for the "complex, interconnected and emergent nature of the sustainability transitions field" (Kjøde, 2024, p. 45).

In appreciating the value of SC, I propose an expansion of this method in an effort to develop new methods to bolster its theoretical impact on Knowledge Activation. I propose that meta-systematic combining (MSC) is a geometric and topological analysis and combination of composition types which can work with a computational analysis of texts and graphs (CATG).

Due to the same pressing urgency of complexity management, my expansion of the SC approach integrates not only the graphical representation of systems but also the analysis and combination of their compositions. My aim in this thesis is "designing the designing" (Pangaro, 2011, p. 156) of complexity management operationalized as the development of new platforms for the composition-informed Computational Analysis of Texts and Graphs (CATG).

3.7 Ethical considerations

The use of technology in this thesis does not preclude the rapid and radical reduction of technology use as a means to return to more traditional land-based living; in fact, I actively work towards it in my life as someone in the midst of re-encountering my own Indigenous ancestry. I strive to benefit from colonially extractive technology as little as possible and to spend time honouring the land as much as possible. It is to this end that I position my investigation as a search for increased efficacy of information systems and the equitably sustainable research that they support. Considering the ecological cost of AI, I limit LLM use to lower-carbon options like local AI models and text-only outputs whenever possible.

While my work is distinctly visual and builds on affordances of visual processing, which benefits some kinds of accessibility, I recognize that focusing only on visual accessibility is insufficient. In a later section, I critique some of the ableist language used by sources in the literature and contextual review.

In my appreciation for Sevaldson's ethics of Systemic Design and SOD, I turn to key moments in his Designing Complexity (2022) that capture values which also guide my work. Designers must consider the ethical consequences of their work. We must always work within sustainability parameters to limit, or hopefully stop, the ways we contribute to and accelerate over-consumption. It is ethically impossible to be a designer today without balancing the production of commercial advantage and climate impact. The geometric value of a circular composition heuristic notwithstanding, designing with a holistic circular economy in mind implies "that the designer takes responsibility for the whole process, all material systems, the life cycle and the recycling" (Sevaldson, 2022b, p. 36). Every person in a given project must keep in mind the people 'not in the room', the "people who are deprived of expressing their interests, like children, seniors with dementia, or refugees; it could also be future generations, other species, or people who are affected by the effects that are only visible to the expert" (Sevaldson, 2022b, p. 97).

Design can be wielded to be catastrophically destructive. Sevaldson warns that doing the "wrong thing in an excellent way results in great devastation" (Sevaldson, 2022b, p. 87). To illustrate this point, Sevaldson offers the famous example of Nazi art. Nazi art can be argued to be bad design or low quality art, but its political efficiency is evident (Sevaldson, 2022b, p. 87).

The value of Systemic Design tools notwithstanding, the balance of ideals and lived experience demands important choices from us. As Sevaldson writes, "understanding the social systems open [sic.] up a way to involve and engage that might bridge the gap between desire and sustainability, between refinement and solidarity, between individual needs and the social, as well as between doing the right thing and making profits. The interesting thing is that this way may open up new possibilities. By recreating and reconnecting these contradictions, new ways of acting within and changing the social system might appear" (Sevaldson, 2022b, p. 42-43).

Overall, I seek to activate knowledge and texts for innovation, and for the ways KA can power anti-oppression, social justice, eco-justice, and environmental sustainability. Sevaldson notes that Béla Heinrich Bánáthy "is known for placing an empty chair in the middle of conversations, representing future generation" (Sevaldson, 2022b, p. 97). In the spirit of keeping space open for the voices of the 'other,' I invite responses to my work that help me do this better.

4

Preliminary making

4.1 Torus anatomy

In this section, I begin by defining the parts of a torus. The distance from the centre of the torus to the centre of the torus's body, also called the torus tube, is the Major Radius (R). The radius of the tube itself is the Minor Radius (r), which is measured from the centre of the tube to its outer surface. The Major Diameter (D or 2R) is the distance between torus centre lines. The Minor Diameter (d or 2r) is the diameter of the torus tube. The Outer Diameter is the total width of the torus at its widest and is equal to the sum of the Major Diameter (D) and the Minor Diameter (d) (D+d). The Inner Diameter of the torus is the diameter of the torus hole, and it is equal to subtracting the Minor Diameter from the Major Diameter (D-d).

In Figure 4.1, I illustrate a top view of the two tori from Figure 2.20 relevant to this thesis, the ring torus and the horn torus. Note that the horn torus dimples to a single point, while the ring torus has an opening in its doughnut-like form. This key difference means that the horn torus is illustrated with no Inner Diameter, Major and Minor Radii of equal length, Major and Minor Diameters also of equal length, and no change to the Major Diameter.

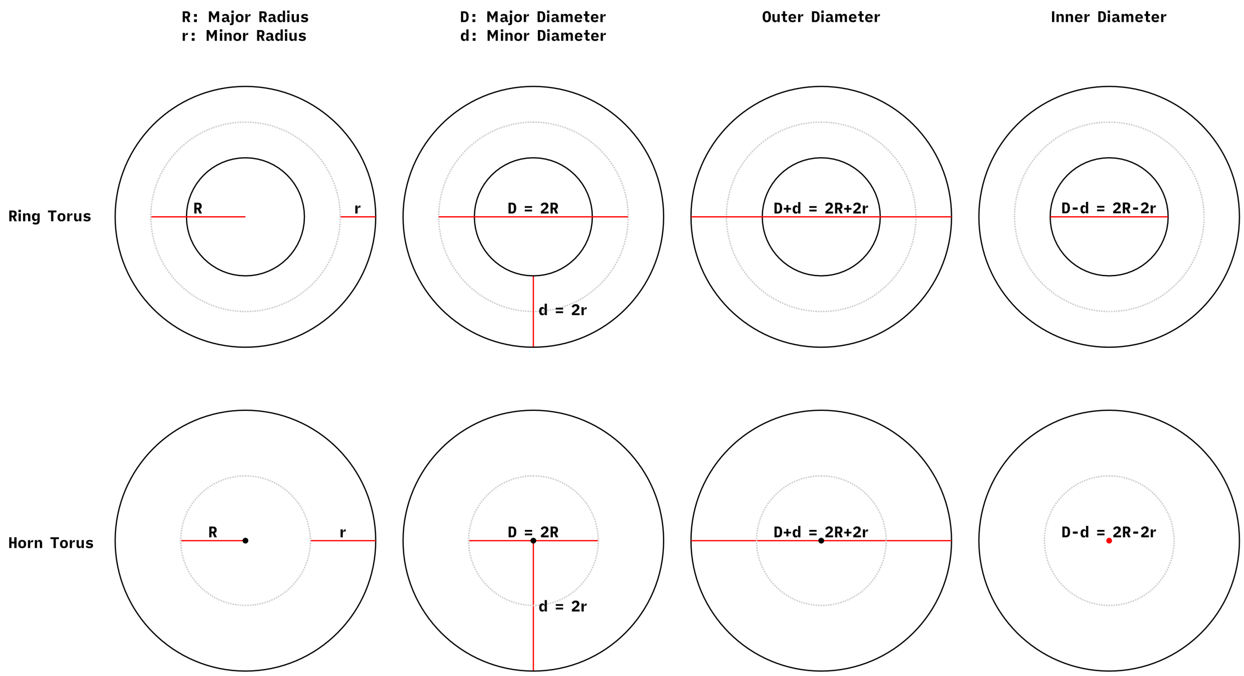

Figure 4.1: Anatomy of the ring and horn tori.

4.2 Thought experiments featuring text analysis point plot composition using the horn torus

4.2.1 Horn torus as integration and disintegration

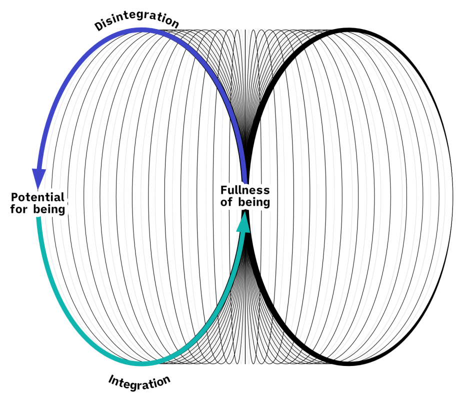

Figure 4.2: Visualization of the Horn Torus Semantic Form as a flow of re-creation. This model traces the paths of integration from chaos into a fullness of being, then back out to potential for being, or complete dis-integration.

Considering the semantic complexity afforded by Rucker's torus space-time model, I sought to use the horn torus as an information visualization to examine the boundary between what is and what might be before what is; in a sense, a contemplation of ontology and metaphysics. At the centre of Figure 4.2, I placed "fullness of being" as a recurring origin point. Out from this central point arcs the movement through disintegration to potential for being. From here, the trajectory arcs trace through integration back to fullness of being, and so on. The resulting composition calls back to the trumpet form of a flower as the top hemisphere of the torus and calls back to roots pulling nutrients from the soil, or raw matter, at the bottom of the torus.

As a more theologically person-centred contemplation of this boundary exercise for ontology and metaphysics, I plotted what Ignatius called "consolation and desolation" (Loyola, 1522, 1548, 1914) in Figure 4.3. In this graph, I replaced disintegration and integration with desolation and consolation, respectively.

Figure 4.3: Horn torus sculpture as Semantic Form information physicalization of consolation and desolation. *Left*: Horn Torus Semantic Form. *Right*: *Schrodinger's Theology* (2022), made of foraged Kentucky Coffee Tree branches and unbleached cotton thread.

4.2.2 Futuring database query with the horn torus

Considering the semantic and semiotic range of the horn torus, I considered how it might be applied to information composition for multiple texts in a larger database. In Figure 4.4, I imagined how a cloud of horn tori might model a database as a heatmap for a researcher's query, pointing to which texts are most relevant for them.

The horn torus's negative space at the top and bottom of itself is in the form of two trumpet shapes. If a series of horn tori were attached to each other across their top and bottom openings, they would form a sequence of double cones, resembling the popular double diamond shape used by the British Design Council (British Design Council). The similarity in the form could allow for a similar approach to modeling information from a given database in sequences of divergence and convergence; and, perhaps, also sequences of induction and deduction.

Furthermore, the cone composition appears in significant information visualizations, including Taylor's cones of plausibility (Taylor, 1990, p. 14), Bezold and Hancock's futures cone (Bezold and Hancock, 1993, p. 73), and Grant et al.'s meta-analysis funnel plot in their typology of literature reviews (Grant and Booth, 2009, p. 94-95).

In Figure 4.5, I propose an example of how isomorphologies in a text network graph can be revealed with Horn Torus Semantic Forms across multiple graphs: (a) the heatmap format would allow for quick identification of the zones most relevant to a Query Isomorph. (b) Heatmaps would also identify through-lines across graphs.

Point clouds reveal relationships between points through proximity, distance, and movement, but I was curious about the potential of other forms of visualizing points in space. Network graphs also use individual points but include the addition of lines connecting said points. To examine how information visualization could be applied to large groups of texts, I turned to the emerging space of Personal Knowledge Management (PKM) and platforms like Obsidian, which visualized databases as network graphs.

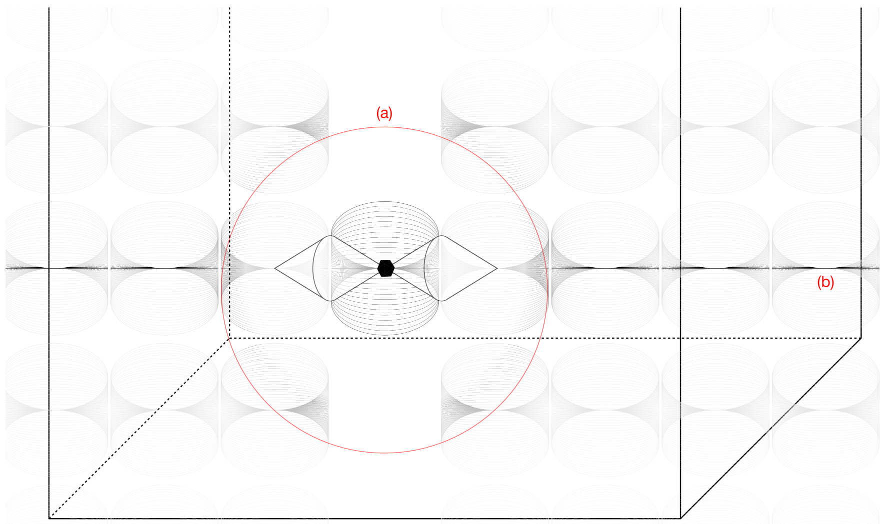

Figure 4.4: Field of horn tori as point plot heatmap with negative space as a sequence of double cones.

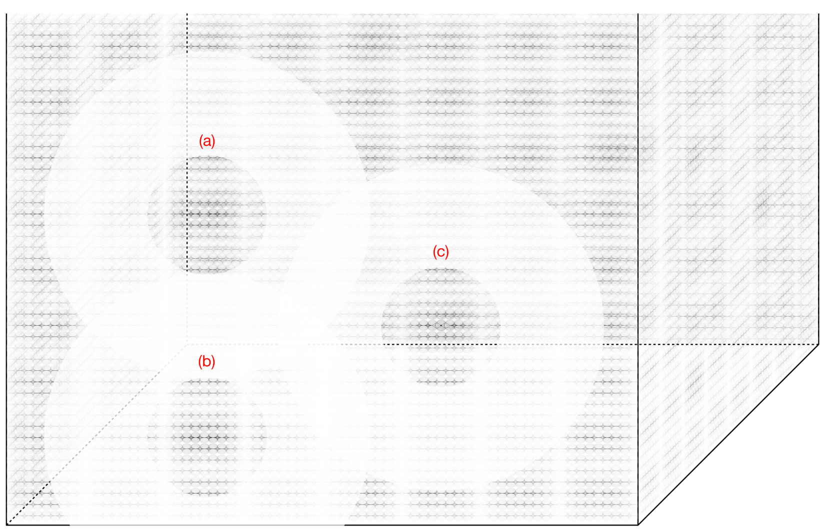

Figure 4.5: Larger field of horn tori as point plot heatmap.

4.3 Experiment to test computational information management of a hyperlinked research database

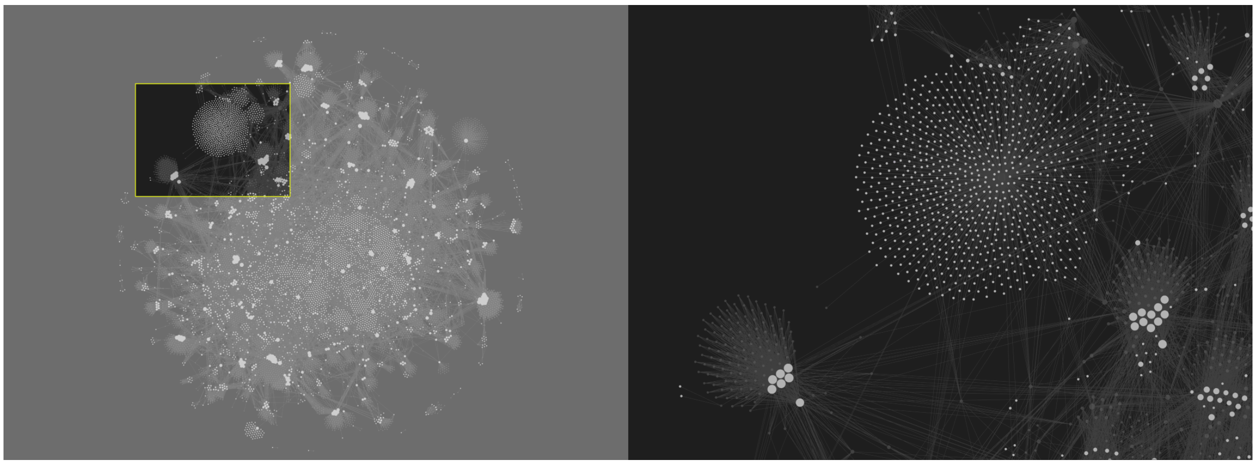

Figure 4.6: Obsidian network graph of my research database and detail.

To test the production of network graphs in PKM, I began my work with Obsidian, a markdown language platform that allows users to hyperlink across text files (Obsidian, n.d.b). Obsidian user databases are called vaults, individual text files are called pages, bulleted lines of text are called blocks, and hyperlinks are called links. Users of Obsidian's predecessor Roam Research (Research, n.d.) or other similar platforms like Logseq (Logseq, n.d.) may be familiar with some of the terminology and Markdown language formatting (Gruber, 2004; Swartz, 2011).

I set up my workflow for collecting sources and linking them following courses by Danny Hatcher (Hatcher, n.d.)) and Lisa-Marie Cabrelli (Cabrelli, n.d.). I consulted with Jay L. Colbert (Colbert, 2022) to set up synchronization of my Obsidian and Logseq databases.

As part of my survey of similar platforms, I tested Logseq, which had an attractive default mode for outlining text using collapsable lists of nested bullet points. I built an index of the names of every page generated in my Logseq database by creating an alphabetized list of page names in an automatically updating list. I modified the string query code by Logseq discussion forum user starryvechsh (starryvechsh, 2022). I created a page with queries for pages with names beginning with each letter of the alphabet, for pages beginning with each Arabic numeral and for pages beginning with any of Adler's syntopical terms. For example, this is my Markdown code for the letter 'a':

```
#+BEGIN_QUERY
{
  :title ”Pages that start with a”
  :query [
    :find (pull ?p [*])
    :where [
      [?p :block/name ?name]
      [(clojure.string/starts-with? ?name ”a”)]
    ]
  ]
}
#+END_QUERY
```

Logseq's convenient collapsible lists of bullet points allowed me to create a page that indexes all blocks in my database that start with any given letter. I also added a section to query for any string of characters starting with a given number. As an exercise in information categorization and to expand on Adler's Syntopicon (Adler et al., 1952a), I also created an index using Adler's 102 Great Ideas. The full-length code for my index is available in my GitHub Repository for this thesis, and also linked to in section A.2.

4.4 Experiment to test topic modeling between semantic fields for interdisciplinary Knowledge Translation

As a person raised Roman Catholic working towards climate crisis mitigation, I made topic models to better understand the relationships between the papal encyclical *Laudato si'* (Bergoglio, 2015) and the *Synthesis Report of the IPCC Sixth Assessment Report* (Calvin et al., 2023).

Using the platform InfraNodus (Paranyushkin, 2019; Paranyushkin et al., n.d.), I generated a topic model that graphed the intersecting themes of these two influential documents from different semantic fields in pursuit of Knowledge Translation between them. The result included ten names for groups of high-level ideas among the intersected graph: (1) development equity, (2) environmental justice, (3) climate emissions, (4) disaster risk, (5) community development, (6) religious ethics, (7) global emissions, (8) climate resilience, (9) climate action, and (10) sustainable energy. InfraNodus notes in a tool-tip within the interface that its High-Level Ideas were generated using GPT-4.

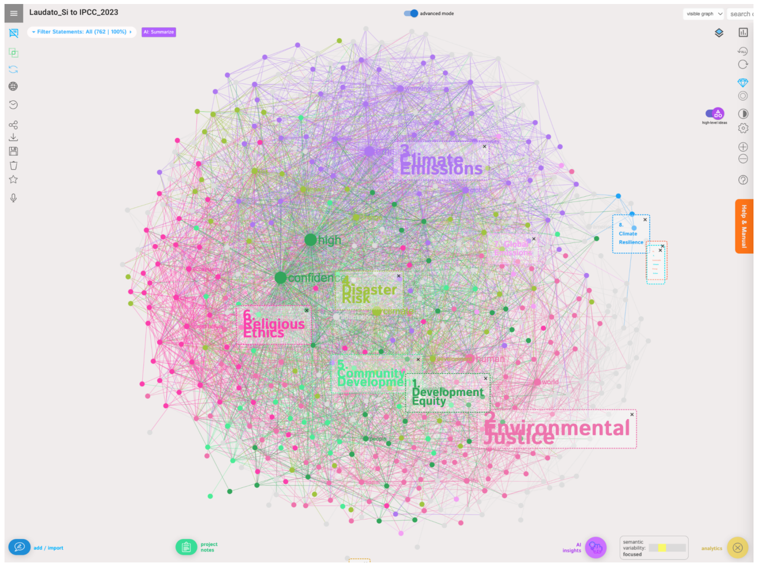

Figure 4.7: InfraNodus topic model relating two texts. Graph of intersecting themes in *Laudato si'* (Bergoglio, 2015) and the *Synthesis Report of the IPCC Sixth Assessment Report* (Calvin et al., 2023). Ten high-level ideas are identified here by InfraNodus and labelled in bright colours as (1) development equity, (2) environmental justice, (3) climate emissions, (4) disaster risk, (5) community development, (6) religious ethics, (7) global emissions, (8) climate resilience, (9) climate action, and (10) sustainable energy. Used with permission (Paranyushkin et al., n.d.).

I found that there are concepts present in the *Synthesis Report of the IPCC Sixth Assessment Report* but missing in *Laudato si'*, and vice versa. I was concerned that 'adaptation' and 'mitigation' were not a part of *Laudato si'*. Conversely, the *Synthesis Report of the IPCC Sixth Assessment Report* did not include the terms 'god' and 'church,' which is unsurprising considering it is not a theological document.

InfraNodus also provided a list of entry points to develop each text, which it calls *conceptual gateways*. In addition to the previous missing concepts to develop *Laudato si'*, this topic model recommended developing the ideas of 'infrastructure' and 'warming.'

While neither document is a complete representation of climate science or theology, I found the results of topic modeling across disciplines was a promising proof of concept for the development of graph-based computational semantic revelation techniques.

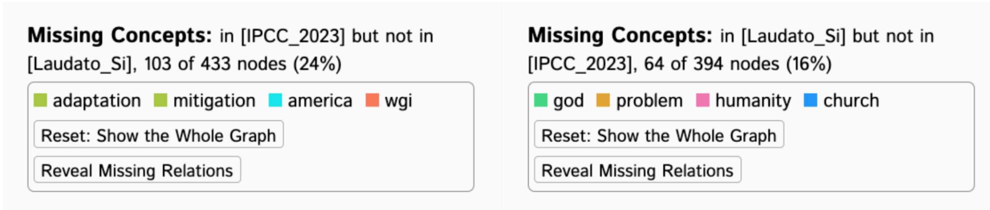

Figure 4.8: Missing Concepts listed within the Blind Spots tab in the Text Analytics Panels of InfraNodus. Comparison of missing concepts. *Left*: concepts in the Synthesis Report of the *IPCC Sixth Assessment Report* but missing from *Laudato si'*. *Right*: concepts in *Laudato si'* but missing from the Synthesis Report of the *IPCC Sixth Assessment Report*. Used with permission. (Paranyushkin et al., n.d.).

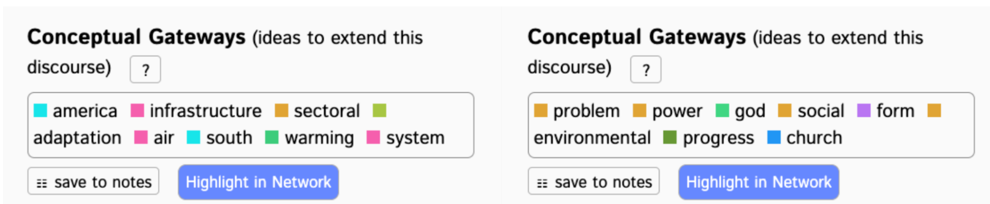

Figure 4.9: Conceptual Gateways listed within the Blind Spots tab in the Text Analytics Panels of InfraNodus. Comparison of conceptual gateways as "ideas to extend this discourse" (Paranyushkin et al., n.d.). *Left*: gateways for *Laudato si'*. *Right*: gateways for the *Synthesis Report of the IPCC Sixth Assessment Report*. Used with permission.

4.5 Experiment to test more ecological local AI

> "*The ecology of the vast symbolic world has to be supported by a material infrastructure of sustainability and responsibility, and turning our back on the real is no way to guarantee the virtual*" (Drucker, 2014, p. 196).

Since my thesis works to apply the "studio laboratory of knowledge design" (Drucker, 2014, p. 197) and "knowledge engineering" (Wielinga et al., 1992, p. 8) behind Sustainability Transitions Knowledge Activation, it is foundational to approach this work while managing its ecological cost. AI, in particular, has a large and growing cost that is "widening disparity in how different regions and communities are affected" (Ren and Wierman, 2024).

Considering the environmental costs of using AI, I moved to test topic modeling using Small Language Models that can run on my local workstation. Computer scientist Rahul Nayak proposes one such solution to create what he refers to as graphs of concepts using Mistral 7B, named after its comparably small seven billion parameters (Nayak, 2023).

Software engineer Juan Sulca and I successfully used Nayak's method to create a navigable and searchable graph of concepts of *Laudato si'*. However, further development would be required to create a comparison graph such as the one generated by InfraNodus.

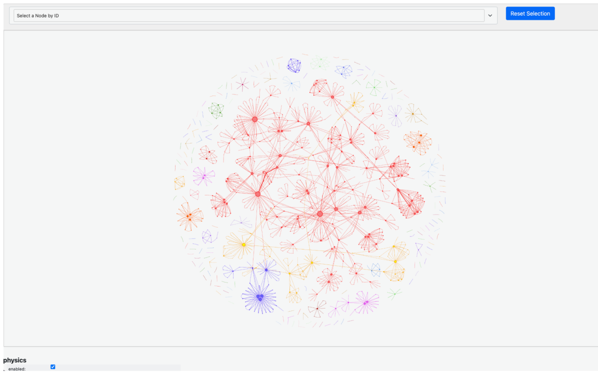

Figure 4.10: Overview of the *Laudato si'* graph of concepts. Topic model made using Rahul Nayak's Mistral 7B method (Nayak, 2023).

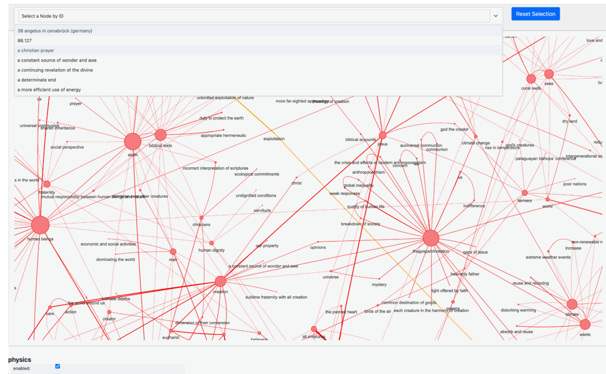

Figure 4.11: Detailed view of the *Laudato si'* graph of concepts. Topic model made using Rahul Nayak's Mistral 7B method (Nayak, 2023).

4.6 Observations about information practices in the University

A number of political and economic factors actively detract from climate mitigation. For example, hyper-specialization is convenient for the current predominantly empire-driven capitalist extractivist economy; hyper-specialization makes humans monocrops for convenient harvesting through overwork, which keeps large populations subjugated as politically docile consumers. It seems to me that it is convenient to keep researchers underinformed about solutions from other fields that support climate crisis mitigation. This means solutions can be bought and sold to maintain control of populations. Specialization is required to achieve proficiency and make an impact in any field, but isolation-reinforced hyper-specialization does not have to be the norm.

As the earth careens toward catastrophe, resistance will inevitably ensue, and oppressors will have the prerogative to control populations by harsher means. In the imperfect container of the University, people have historically had, and still may have, some leverage to resist the ideological and technological limitations that work against climate justice and resilience.

Discussing my research has taught me that many organizations, including universities, struggle to best use available information to facilitate researcher grouping, which significantly restricts funding for many deserving initiatives. In my pursuit of building better tools for connecting ideas, I also aim to connect the people who have them. Doing both makes it more likely that we will reveal solutions for climate crisis mitigation that may exist in the information we already have.

5

From theory and method to visuospatial models and back

5.1 From theory to visuospatial models

The following contributions are ways visuospatial models encapsulate theories from my literature review as contributions 1, 2, and 7: Semantic Forms, Query Isomorphs, and TCA Workspace, respectively.

5.1.1 Contribution 1. Semantic Forms

C1 *Semantic Forms*, a taxonomy of three-dimensional topic model compositions for HITL CATG, HATG, or both.

5.1.1.1 Vedic entry point to visuospatial epistemology

A key outcome of my survey of symbols was arriving at two- and three-dimensional representations. Studying the Sri Yantra and the Meru Chakra together catalyzed a significant shift in my work, expanding it from visual to visuospatial epistemology of information visualization and network graphs. This occurred in two steps.

First, I read the Sri Yantra as a network graph, which extended its significance in my work beyond its more conventional appreciation as a representation of spiritual qualities to the more etymologically encompassing range of the word *yantra* which includes the practical and mechanical attributes of an 'instrument' or 'machine' (Bühnemann, 2003, p. 28). The numerous overlapping triangles of the Sri Yantra evoked a sense of movement for me, like moving network graphs of nodes and edges.

Second, I encountered the Meru Chakra in relationship to the Sri Yantra as interdimensional 2D-3D representations of each other. I propose that signify meaning in both their individual complexity and in the way they hold space for meaning across dimensions. This tension across dimensions catalyzed my ongoing fascination with visuospatial epistemology and the various ways we convey meaning using visuospatial signs (Midgley et al., 1998; Dubois and Gadde, 2002; Drucker, 2014; Tversky and Parrish, 2022; Sevaldson, 2022b; Anderson-Tempini, 2018).

5.1.1.2 Defining Semantic Forms

My proposal of Semantic Forms in this thesis does not include comprehensive technical specifications for how to algorithmically build them. Instead, I focus on what researchers might do with Semantic Forms if and when they are developed. I make the assumption that it is possible for Semantic Forms to work with vector embeddings and network graphs. I also conjecture that rich TCA graphs can be used to train Language Models by parsing visuospatial forms of knowledge activation.

The sense of visuospatial affords humans a higher bandwidth for information processing than just two-dimensional representation (Tversky and Parrish, 2022), which could hold a key for managing the complexity of the climate crisis, or at the very least engaging with it with more agency. This section, however, is about the visuospatial models I made and not about their application to climate.

As an interface, Semantic Forms are dimensionally versatile three-dimensional visuospatial point cloud compositions that can be dimensionally reduced to produce two-dimensional information representations. As a computational tool using Topological Capta Analysis on high-dimensional graphs, dimensional reductions would occur across a much wider range of dimensions.

In the following section, I describe the geometric fundamentals I derived from surveying two-dimensional information visualization composition; then, as a means of Meta-Systematic Combining (MSC), I added a third dimension. I called the two-dimensional compositions I derive *Semantic Shapes*, and the three-dimensional compositions I derive *Semantic Forms*. I will write geometric shapes and forms in lowercase, like "circle" and "sphere"; I will write the shape identifiers names of my Semantic Shapes and Semantic Forms in uppercase, like "Circle Semantic Shape" and "Sphere Semantic Form."

5.1.1.3 Topology in Semantic Forms

Filtration can be used to assess hierarchical structure in weighted networks (Giusti et al., 2016, p. 11). Therefore, filtration can facilitate Query Isomorph queries across Semantic Forms with a rigorous inspection process of all nodes and edges in a network, allowing the identification and analysis of network isomorphologies across a variety of network formations, nested and hierarchical or not.

While filtration is necessary for managing higher-dimensional graphs or graphs with a high density of nodes, I offer a complimentary analogy of magnetic form types. These magnetic form types would affect the distribution of nodes and edges in space in distinct arrangements. The Cone Semantic Form, for example, could distribute topic model graph nodes to reveal the divergence or convergence of ideas in a given text.

The value of investigating Semantic Shapes and Semantic Forms was supported for me in more contemporary topological literature about network weighting. The torus and the disc are closely related to the forms uniquely suited to manage Global Topological Synchronization (GTS). [1] We are one step closer to higher-dimensional topic models in which the physical representations of node relationships represent and reveal more complex semantic relationships like syntopical consiliences.

[1] According to Wang et al., two weighted simplicial complexes, the Weighted Triangulated Torus and the Weighted Waffle "can sustain global synchronization of edge signals" (Wang et al., 2024, p. 9).

5.1.1.4 Magnetic approach to node groups using weighted graphs

Building onto the current practices of network graph filtering and labelling[2] nodes using the semantic value of shapes or forms. I propose Semantic Forms as a new approach for revealing semantic relationships in text graphs. One way this would be achieved is by quantifying Peircean modes of reasoning as a means of node clustering. The Semantic Forms, then, would act as 'magnetic' fields which influence the placement of nodes and edges in a topic model graph. Depending on the researcher's aims, these semantic forces would act as an organizing principle that influences all graph nodes or a filtered few. Semantic Forms are, in a sense, semantic forces captured as geometric patterns; they are not prescriptive but are meant to be used to arrange nodes in space to reveal characteristics and patterns within a set of topics. By arranging nodes rather than filtering out potentially valuable contextual nodes, Sematic Forms would alter node visibility and proximity to emphasize more relevant nodes and node relationships.

Weighting a network with the characteristics of Peircean induction, deduction, and abduction would imbue network relationships with useful information for clustering nodes in the virtual semantic field using Semantic Forms. For example, Ontological Semantic Network Summaries (OSNS) can be used to determine the semantic (1) impact and (2) 'direction' catalyzed by a given term. For example, in the literature of Aristotle, the practice of categorization would (1) be quantified as having a very high impact; (2) its direction would be (2.1) inductive, as a practice for moving from specific observations to general, or syntopically consilient, conclusions, (2.2) deductive, as a prescription for ontological analysis (e.g. the Tree of Porphyry as semantic network of ontology), (2.3) abductive, defined in a Peircean way, as a means of innovating an explanation in compliment to inductive and deductive reasoning (Peirce, 1960b, p. 106). For example, in the study of cognition, categorization is both (a) a phenomenon that can be observed as being comprised of specific characteristics and (b) a means of studying a given subject.

5.1.1.5 Semantic Shapes: two-dimensional geometric network graph

Parting from the assumption that dots and lines are the necessary representation of one-dimensional relationships, I developed a list of two-dimensional shapes which summarize node-radiality compositions used in the

[2] While existing approaches emphasize filtration for managing a large number of nodes (Kovács et al., 2024), and self-organizing bundling for emphasizing node relationships to increase their visibility (Holten and Van Wijk, 2009, p. 1), the literature considered for this thesis did not find any approaches that considered organizing network graph.

semantic organization of network graph information visualizations[3], or what I am naming *Semantic Shape*. The rectangle Semantic Shape can be used to illustrate grids, the triangle Semantic Shape can be used to illustrate hierarchical relationships or contingencies, and the Circle Semantic Shape can represent a multidirectional array of triangular Semantic Shapes.

The limited number of individual relationships a node can have in a rectangle Semantic Shape benefits applications like algorithmic quantitative analysis in spreadsheets. However, qualitative analysis benefits from the larger range and variable number of nested node relationships possible in the triangle and Circle Semantic Shape. My focus in the following work favours the triangle and Circle Semantic Shape and their role in categorizing compositions for node graph information visualization.

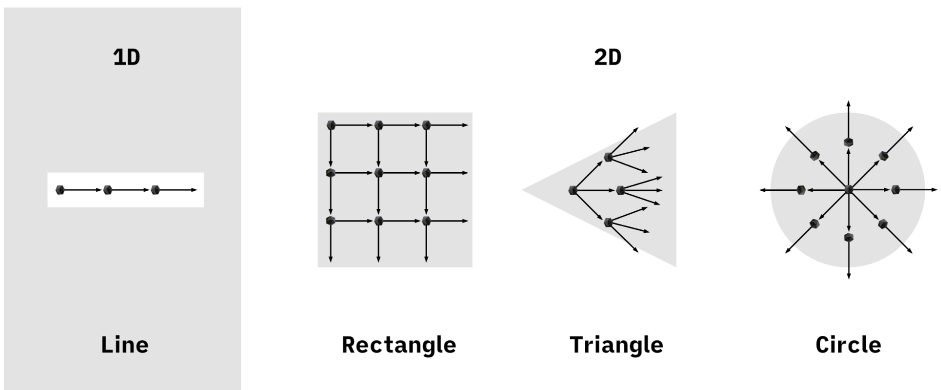

Figure 5.1: Network graphs as Semantic Shapes. *Left*: the one-dimensional network graph line. *Right*: Semantic Shape, two-dimensional network graph radiality compositions, the Rectangle, Triangle, and Circle.

[3]Rendgen et al.'s *History of Information Graphics* (Rendgen et al., 2019) provide a rich source matter for analyzing information visualization composition. Anna Vital's infographic of infographics *How to think visually using visual analogies* (Vital, 2018) and *The Data Visualisation Catalogue* by Severino Ribecca (Ribecca, 2017) provide categorizations of information visualization compositions types. I found that individual units of information, dots or otherwise, were laid out away from each other in varying radiality configurations with distinct semantic affordances.

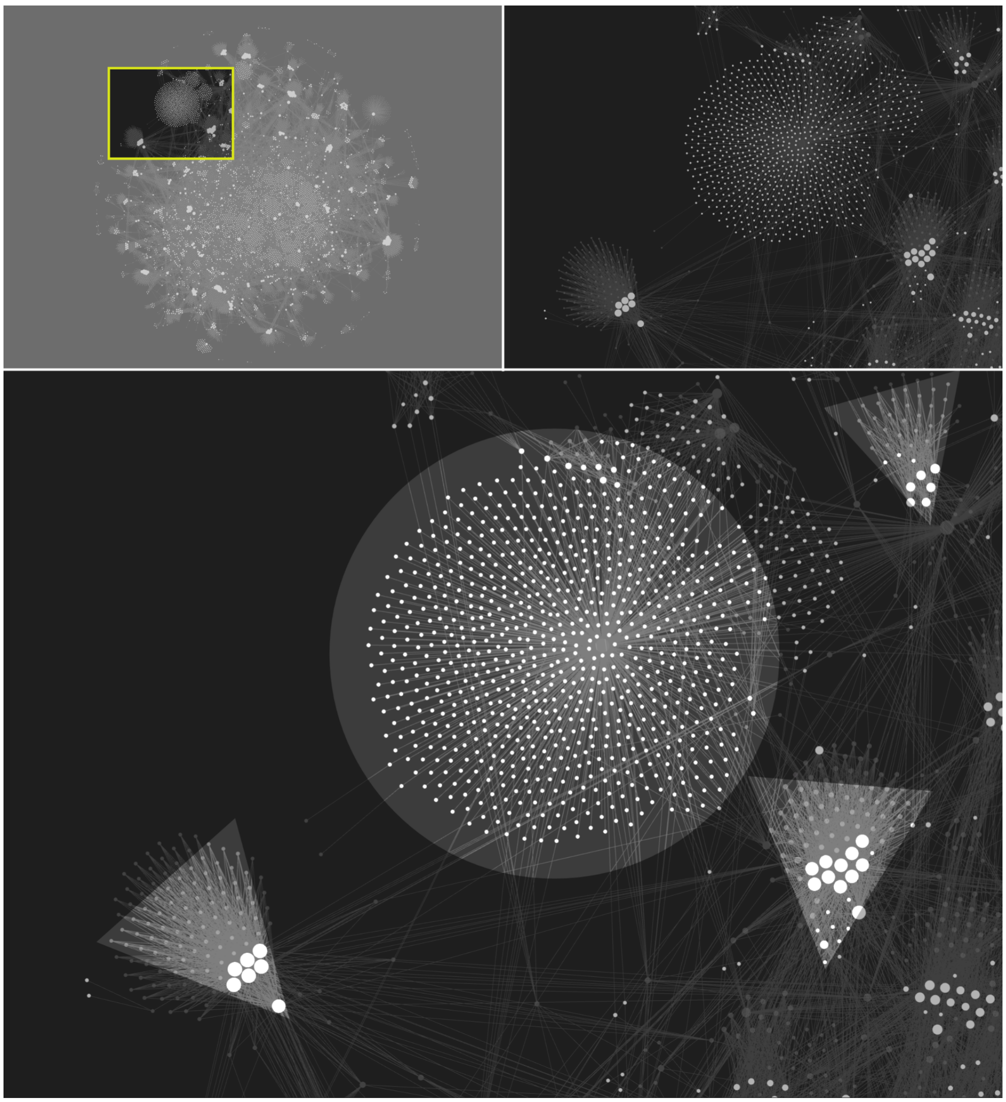

Figure 5.2: Example of Circle and Triangle Semantic Shape nested in a larger Circle Semantic Shape network graph. *Top left*: Obsidian graph view of my research database. *Top right*: Zoomed view of region marked with yellow-green box. *Bottom*: Labelled Semantic Shape on clusters of network nodes.

5.1.1.6 Semantic Forms: three-dimensional composition types in network graphs

Moving from one-dimensional network graph lines to two-dimensional network graphs, Semantic Shape laid the groundwork for adding a third dimension to my network graph models and a resulting list of *Semantic Forms*. I approached this exercise as both a deconstruction of complex forms and a combination of Semantic Shape.

Deconstruction of complex forms

Calling back to my preceding work involving visualizations of Vedic principles, namely the chakras, perhaps the most pivotal point of my journey from theology into network graphs was through Vedic religious imagery. In particular, two interrelated forms were the object of my delight and fascination: the Sri Yantra and the Meru Chakra. To show my accountability as I strive to honour the religious significance of the Sri Yantra and the Meru Chakra, I have been guided in the study of Vedic spirituality and practice by a number of educators, especially Dr. Monisha Bhatia. However, my work in this thesis with the Sri Yantra and the Meru Chakra will emphasize their visuospatial, rather than their cosmological, attributes.

Encountering that a two-dimensional graph of lines like the Sri Yantra could interrelate with a three-dimensional visualization like the Meru Chakra encouraged me to consider the opportunities available in dimensional addition to flat graphs.

By averaging out the different steps, or elevations, of the Meru Chakra, which has "the form of a mountain" (Bühnemann, 2003, p. 31), the cone form is evident in its composition. The Sri Yantra itself is composed around a central point and its sets of triangles are outlined by a circle. I arrived at the geometric curiosity of a graph of lines that could be represented as both a circle and a cone, the former being more typical of an information visualization composition and the latter being novel for me as a method for the semantic representation of individual elements in a graph.

Upon reflecting on the shape of the horn torus, its two horn-shaped negative-space dimples are shaped like cones. Motivated by this geometric curiosity, I considered how other simple forms could be understood as parts of the horn torus. Following this line of reasoning, I arrived at the cylinder as the horn torus's body, which is also the body of a ring torus. Here, I call back to my preamble work, where I illustrated how a series of horn tori form double cones. At this point, it was easy to envision a horn torus without its double-dimple as a network of nodes organized around a central point or a sphere. Through this deconstruction process, in order of arrival, I list here six Semantic Forms: the Horn Torus, the Cone, the Ring Torus, the Cylinder, the Double-Cone, and the Sphere.

Combination of Semantic Shapes

Through the combination of Semantic Shapes, conversely, to the previously explained process of deconstruction, I arrived at the same six Semantic Forms. I illustrate how in Figure 5.3. I begin with the PKM graphs from Obsidian and Logseq, which are disc-like Circle Semantic Shapes of nodes. I considered a simple dimensional addition to the Circle, which was to add linear extrusion along a perpendicular axis, creating a Cylinder. I added another form of circular complexity to the Cylinder by circling it in on itself into a Ring Torus. Next, I combined the Triangle and the Circle Semantic Shapes to arrive at the Cone and the Double Cone. Next, I consider the perpendicular placement of two Circle Semantic Shapes intersecting at their centres by which I arrive at the Sphere. Last, I consider that the Ring Torus can be narrowed to shrink its inner radius to a single point, which makes a Horn Torus.

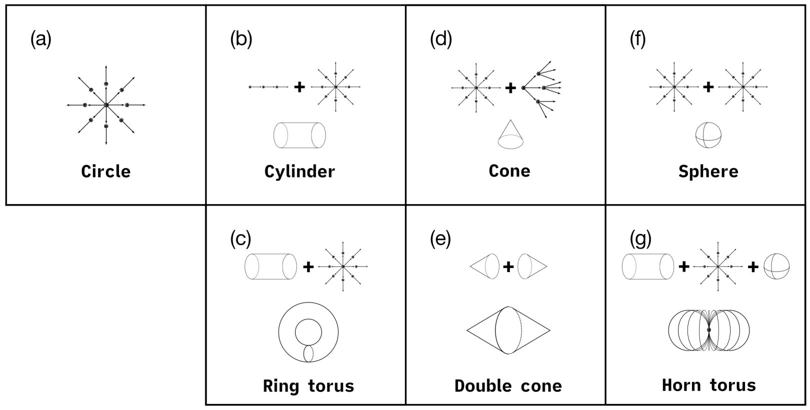

Figure 5.3: Semantic Forms derived from the Circle Semantic Shape and other Semantic Forms. Systematic Combining was used as dimensional addition to move from two-dimensional to three-dimensional network graph compositions.

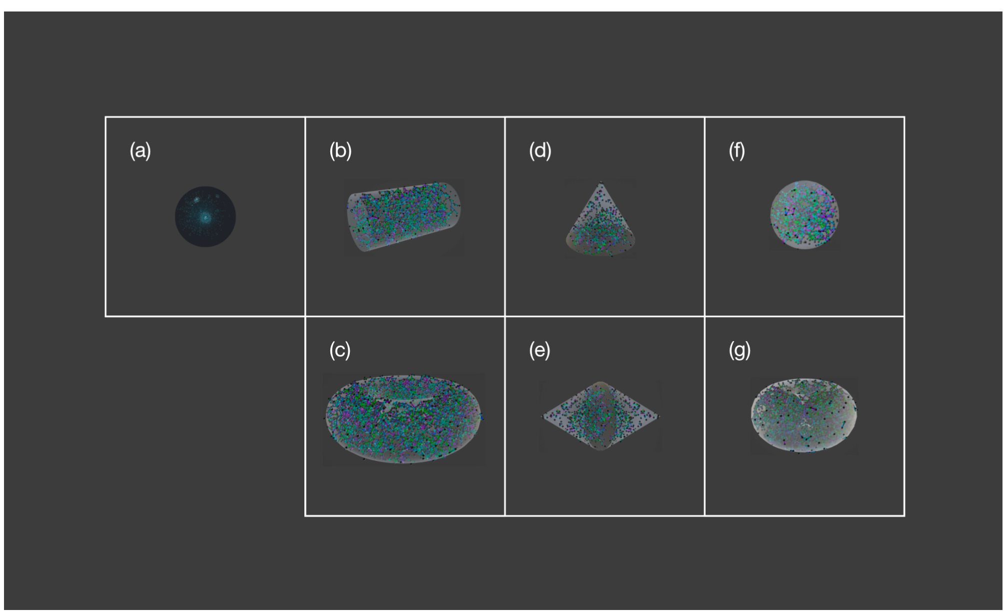

Figure 5.4: Knowledge graph disc and six Semantic Forms: (a) Circle Semantic Shape knowledge graph, b) Cylinder Semantic Form, (c) Ring Torus Semantic Form, (d) Cone Semantic Form, (e) Double-Cone Semantic Form, (f) Sphere Semantic Form, and (g) Horn Torus Semantic Form. The top row includes more basic forms, and the bottom row includes more geometrically complex ones.

The Semantic Forms are means of three-dimensional topic model node clustering in a semantic field of terms, which reveal relationships like (1) ontological hierarchy of Peircean reasoning modes in which a singular term expresses a general principle and diverse instances of that general principle, (2) cyclicality, and (3) other modes of semantic relationship interpretation in the visuospatial. As a means of capturing hierarchical semantic systems, Semantic Forms have the capacity to nest other Semantic Forms within themselves. In the following section, I illustrate the Semantic Form Cone, Sphere, Cylinder, Cone, Double-Cone, Ring Torus, and Horn Torus.

The Cone Semantic Form is perhaps the most direct illustration of this principle because its form physically turns to a single point. The Sphere Semantic Form encompasses a higher number of radii, which accommodates multiple Cones converging to a single point or a series of nested convergence points. Figure 5.27,*The Ontological Semantic Network Summary of the Syntopicon's Great Ideas onto the Tree of Porphyry*, is an example of a dimensionally reduced Cone Semantic Form of consilience-oriented information categorization. Figure 5.27 demonstrates that Sowa's sense of philosophical-computational ontology and Adler's interdisciplinary term-indexing (Adler et al., 1952a) can be understood as a single system through Aristotelian categorization and Porphyrian semantic network graphing (Sowa, 2000, p. 4).

The Cylinder Semantic Form provides an extruded space of the flat circular graph and traces individual nodes or graphlets across a third variable along a z-axis, such as time.

The Ring Torus Semantic Form accommodates the cone as a structure that feeds back to itself in a cycle.

The Horn Torus Semantic Form accommodates multiple cycles that exhibit transformation and feeding back into themselves by emerging from a point, changing, and then returning to that same re-origin point. The horn torus has the distinct ability to nest two cone-like structures in its negative space as an opportunity to capture or reveal additional semantic relationships. For instance, a moving Horn Torus Semantic Form network graph, which is used to topic model a text and identify a re-origin point, can also capture the deductive and inductive changes in relationships between ideas in that text or between this given text and other texts by using the horn torus negative-space horn dimples as Cone Semantic Forms. The Cone Semantic Form can be used on its own to model the deductive and inductive reasoning in a text or texts, of course.

Horn Torus Semantic Form models can be adapted from static representations to moving models that capture the shifts of reasoning in a given text over time, considering its iterations, a set of texts that build on each other, or the representation of popular opinion on a given subject over time. Moving horn toroidal models can, in turn, also be overlaid with each other to compare similar or dissimilar arguments and their corresponding isomorphic

Query Isomorph structures.

Moving Semantic Forms

To render the three-dimensional network graphs of these six Semantic Forms, I used Blender to create moving network graph point clouds using Manuel Casasola Merkle's plexus effect node programming tutorial (Casasola Merkle, 2022).

The resulting models captured my idea for a topic modeling interface that uses three-dimensional network graph Semantic Forms with more clarity. The information visualization encoding of Semantic Forms as interface would label categorical and sequential differences between groups of related ideas using nodes colours. Ideas that can be listed across categories would be identified using edges with colours that gradiate between origin the two different node colours. Moving nodes would represent changes in a database over time including occasions when ideas displace or replace other ideas.

As moving network graph representations of computational text analysis, my Semantic Forms exemplify how Anderson-Tempini's isomorphogenesis [4] is echoed in Drucker: "We will use the interpretative force of graphical rhetoric as a gesture language of intellectual life, as a way of shaping our communication using the variable dimensions of time and space in ways that print could only hint at, recording as it did the layered, palimpsestic traces of individual and collaborative activities on the enduring substrate of its material surfaces" (Drucker, 2014, p. 197). My moving Semantic Form models capture the way in which new information changes the shape of a visuospatial topic model. For a link to view my moving Semantic Forms, see the Appendix section A.1.

Geometric analysis

Upon further geometric investigation of my Semantic Forms, I found that they are closely related to surfaces of revolution, meaning surfaces "generated by rotating a two-dimensional curve about an axis" (Weisstein, n.d.a). Note the similarities to the Semantic Forms in the following examples: "Examples of surfaces of revolution include the apple surface [similar to the horn torus], cone (excluding the base), conical frustum (excluding the ends), cylinder (excluding the ends), Darwin-de Sitter spheroid, Gabriel's horn, hyperboloid, lemon surface [similar to the double cone], oblate spheroid, paraboloid, prolate spheroid, pseudosphere, sphere, spheroid, and torus (and its generalization, the toroid)" (Weisstein, n.d.a).

When considering the combination of Semantic Shapes, I was more concerned about how new forms of spa-

[4] Isomorphogenesis is described in more detail subsubsection 2.7.3.1. As a brief reminder, Anderson-Tempini's term isomorphogenesis refers to the extension of her isomorphology practice used for "representing morphology as a dynamic and formative process" (Anderson-Tempini, 2018, p. 179).

tial network graphs would plot *into* the Semantic Forms, so I did not originally consider the Semantic Forms' surfaces as their own classifications.

I suspect considering Semantic Forms in relation to surfaces of rotation will lead me to new forms for network graph plotting. To begin the differentiation of the Semantic Forms' volume and surface for the next steps of their geometric analysis, I list the Semantic Forms' volume and surface equations in Cartesian coordinates as a starting point in Appendix section A.4, though spherical coordinates may be more suited for further analysis of surfaces that form around a central point of rotation.

Tidiness of the Semantic Form models

While I am observing the geometry of such compositions and providing examples that neatly showcase their shapes and forms, I am not claiming to advocate for node-by-node retrofitting to fit these models, which would be a disservice to the data. Finding patterns in data is difficult in two dimensions, let alone any dimensions above it. In future work, I will investigate mathematical approaches for identifying Semantic Form patterns in large network models of computationally modeled data. The focus of this work is to identify the semantic value of an array of shapes and forms so as to establish which patterns to look for. The finding of these patterns in real data is for another work.

By making Semantic Forms, I sought to define the ways geometric form can be given topological versatility in the ways large groups of nodes reveal group semantic relationships, similar to Global Topological Synchronization (Wang et al., 2024; Bianconi, 2024b). In the following section, I aim to focus on the smaller network chunks within these more macroscopic murmurations.

5.2 Contribution 2: Query Isomorphs

C2 *Query Isomorphs* as a means of Topological Capta Analysis (TCA) in HITL CATG using small graph chunks.

5.2.1 Defining the Query Isomorph

I propose Query Isomorphs or isomorphic directed graphlets as two-and-three-dimensional query objects and query interfaces. Query Isomorphs differ from Sowa's query, conceptual, and canonical graphs in their dimensional versatility. I propose that Query Isomorphs can be used in conjunction with Topological Capta Analysis.

TCA supports models and queries across any number of dimensions, and certainly within the visible three dimensions, including moving Semantic Form graphs. [5] Their vector search is an example of how querying vectors enables "efficient and accurate similarity-based querying" and "clustering algorithms to gain valuable insights from massive datasets" as a means to "model data in a more semantically meaningful manner, enabling a deeper understanding of the connections between different entities" In this study, I did not engage with TerminusDB graphs because they are opaquely high-dimensional and do not reveal their graph analysis process within the visible three dimensions. (TerminusDB, 2023).

Canonical graphs (Sowa, 2013, p. 53) are related to my Query Isomorphs in that they can help recognize patterns of meaning across different texts and contexts to facilitate faster KSSTP. Query Isomorphs differ from canonical graphs (Sowa, 2013, p. 53), as well as query graphs (Sowa, 1984, p. 313) and conceptual graphs (Sowa, 2013, p. 53). Query Isomorphs are *dimensionally versatile* elements queriable with TDA and TCA. Query Isomorphs can themselves be dimensionally versatile query *interface* in one, two, or three dimensions (with or without movement). I arrived at the idea of isomorphological query graphlets independently from Sowa, but considering my work stands in his legacy, I choose to include the word 'Query' in Query Isomorph in honour of his query graphs.

Isomorphology has a wider application than Anderson-Tempini (Anderson-Tempini, 2018)'s practice which includes chemistry. The way molecules of a given element or elements maintain repeatable configurations of atom-bond relationships is also called isomorphology. I considered naming Query Isomorphs 'datacules' for this reason. However, in this thesis, I align my graphlet thought experiment with Drucker's humanistic design. Drucker asserts that "*data are capta*, taken not given, constructed as an interpretation of the phenomenal world, not inherent in it." (Drucker, 2014, p. 128). I propose that isomorphology reveals what Drucker refers to as the "constructedness of data as capta" (Drucker, 2014, p. 128). Considering the versatility of isomorphology across disciplines, I chose it as one of the key identifiers of my neologism. This is the 'Isomorph' in Query Isomorph.

5.2.2 Semantic Field S and Sample s

Words do not exist in isolation: this applies to their linguistic relationships and graphical representations. To provide an example of the way Query Isomorph term nodes relate to Semantic Forms I set some parameters.

[5] As a point to refer to more contemporary applications of querying using graphs, it is worth noting developments that use AI. TerminusDB's platform is evidence of semantic isomorphology.

Specifically, I set a semantic field, which is "a set of words which cover a particular semantic domain and bear structured relations with each other" (Jurafsky and James H., 2024, p. 107).

To arrive at this list, I uploaded my thesis as a PDF to ChatGPT 4o and parsed its keywords with the following prompt sequence:

1. "Categorize and list the key words in this document."
2. "Write these as a list separated by commas, ranked by their relevance in the text"

I imported this list of 756 Comma Separated Values (CSV) to Microsoft Excel. Next, I reduced the number of terms on this list by removing redundant and less relevant words. I arrived at a list of 310 terms which I called Semantic Field *S*. This list is included in Appendix section A.11.

Sample *s* is a list of nineteen ideas which I arbitrarily selected from Semantic Field *S* for having high importance in my thesis. In Table 5.1, I list the terms from Sample *s* along with the date of their earliest recorded use in my research database and a note of where the idea was first recorded. I use the word 'idea' here and not 'term' because some terms have changed over time. For example, I first named 'Query Isomorph' 'datacule' as mentioned previously. The idea of isomorphic representations of ideas endures across the change from the term 'datacule' to the term 'Query Isomorph.' In a sense, this is an example of the textual isomorphogenesis of ideas about the visuospatial isomorphogenesis of ideas.

As I drafted the graphs of Query Isomorph *i* that you will encounter in this section, I arrived at the term *Computational Graphesis* as a through-line for this thesis. It seemed fitting as a term that encompasses the practice of applying computational methods like TCA to a wide array of "visual forms of knowledge production" (Drucker, 2014), what Drucker calls *graphesis*. However, the term *graphesis* did not encompass the framework I developed. To recap subsection 2.9.5, I critique Drucker's *graphesis* for overemphasizing sight.

Seeking to build on Drucker's term by including Tversky's neuroscience of the visuospatial (Tversky and Parrish, 2022), I return to Drucker's Greek etymology of *graphesis*. I then derive *semiosis* as more fitting for the sensorially decentralizing and diversifying scope of my *visuospatial* forms of Knowledge Production. More specifically, I defined my use of the term semiosis in this thesis as Knowledge Activation across its various modes (KSSTP), and across the interrelated senses used in understanding, including the visuospatial. For my updated through-line term, I arrived at the term *Computational Semiosis*, which you will notice features prominently in Table 5.1 and the graphs that follow it.

#	Sample *s* term	Earliest use on record	Note
1	Symbol-making	2022 Jan and earlier	Prior studies: note-taking methods experimentation
2	Sri Yantra	2022 Jan and earlier	Prior studies: theology
3	Network Graphs	2022 Jan and earlier	Prior studies: note-taking methods
4	Meru Chakra	2022 Jan and earlier	Prior studies: theology
5	Personal Knowledge Management (PKM)	2022 Jan 12	Obsidian: first vault
6	Torus	2022 Mar 17	Images: RSF Torus Yin-Yang
7	Graphesis	2022 May 01	Images: Drucker (2014) first read
8	Isomorphology	2022 Jun 21	Images: Anderson-Tempini (2018) first read
9	Topology	2022 Nov 22	Logseq: Adam Tindale meeting notes
10	Spatial Information Visualization Composition (SIVC)	2022 Nov 30	Logseq: Saint-Martin (1990) first read
11	Semantic Forms	2023 Jul 31	Physical notebooks: first sketches of Semantic Forms
12	Query Isomorphs	2023 Aug 06	Physical notebooks: first sketches of the Query Isomorph, then called 'Datacules'
13	Topic Models	2023 Jul 11	Zotero: InfraNodus added
14	Gigamapping	2023 Sep 28	Zotero: Sevaldson (2022) added
15	Systematic Combining	2024 Apr 17	Zotero: Kjøde (2024) added
16	Persistence Homology (PH)	2024 Jun 10	Watched Bianconi's talk at the IDEAS Research Centre
17	Global Topological Synchronization (GTS)	2024 Jul 15	Wang et al. added to Zotero
18	Computational Semiosis	2024 Oct 15	New term: expansion of Computational Graphesis
19	TCA	2024 Oct 30	New term: information-oriented differentiation from TDA

Table 5.1: Sample *s* terms chronology.

5.2.2.1 Visualization style for the Query Isomorph

At this point in the document, I will begin using three-dimensional objects made with Blender. I decided to keep the dark grey background typical of the Blender platform in alignment with Drucker's sense of humanist post-structuralist design, which reveals the "constructedness of knowledge" (Drucker, 2014, p. 178) in visuospatial forms of "knowledge production" (Drucker, 2014). I used the shape of a Blender icosphere as the form of each node signal spatial interface for Query Isomorphs.

To design my figures I draw from *Spectrum*, Adobe's design system, and its guide, *Color for data visualization* (Adobe, 2022). I use its categorical colour palette to represent differences between ideas that operate in different semantic lanes. For example, I use categorical colour distinctions to differentiate between words more closely associated with Semantic Forms, as opposed to the words more closely associated with Query Isomorphs.

I use the Adobe *Spectrum* sequential colour palette (Adobe, 2022) to represent ideas that are incrementally different along a semantic spectrum. For example, the gradiating difference between the highly summative/less numerous terms like "Computational Semiosis", and less summative/more numerous terms like "Isomorphology" and "Topic models".

I chose the colour of the edges in my moving Semantic Form network graphs to gradiate across the indigo-teal-green continuum in general alignment with the Adobe Spectrum Viridis sequential colour palette. The use of gradient, instead of block hues, represents the subtle semantic gradiation between related ideas that I would use in the topic model of a complex text.

When iterating my graphs, the more complex illustrations include three sequential colours and three or more categorical colours. In practice, these more complex figures required a lighter colour for the lightest sequential figures. I tested a colour from the same Adobe Spectrum *Color for data visualization* (Adobe, 2022), specifically the middle colour of its diverging colour palettes, `#FFFFE0` (Light yellow).

In practical application, Light yellow was difficult to distinguish from white annotations, such as axis lines. I tested options for colour options darker than Light yellow colour slightly while keeping it substantially lighter than Light green, and arrived at `#FFF7C7` (Lemon chiffon).

As a result, my figure illustration style guide consisted of four categorical colours and three sequential colours. The categorical colours are: `#0FB5AE` (Seafoam 600), `#F68511` (Orange 600), `#DE3D82` (Magenta 800), `#7E84FA` (similar to Indigo 700). For simplicity of description of the illustrations that follow, I will refer to these as the categorical figure colours Teal, Orange, Magenta, and Purple. The sequential figure colours are: #FFF7C7 (Lemon chiffon)), #D2E21B (Pear), and #7AD151 (Atlantis) to designate high, middle, and low summativeness respectively. I will refer to these as the sequential figure colours: Light yellow, Light green, and Green. [6]

I ensured that the colours I chose for my design system adhere to the Adobe Color Blind Safe color checker (Adobe, 2024). I confirmed that the contrast ratio is higher than the minimum required 3:1 ratio for all colours using WCAG 2.2 Technique G183 (World Wide Web Consortium (W3C) Web Accessibility Initiative (WAI) Accessibility Guidelines Working Group (AG WG) Participants et al., 2024).

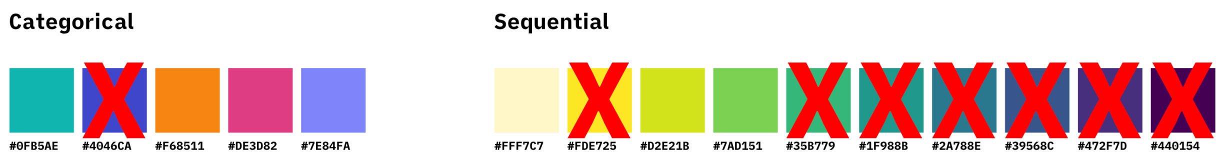

Figure 5.5: Illustration colours considered from the Adobe Spectrum design system *Color for data visualization* (Adobe, 2022).

Figure 5.6: Illustration colours chosen from the Adobe Spectrum design system *Color for data visualization* (Adobe, 2022).

Illustrating Sample *s* as network nodes

I applied my visualization style to Figure 5.7 visualizing each idea as a node paired with a text label. I have arbitrarily designated each node-label pairing as a high-summative node, mid-summative node, or a low-summative node; these three categories were labelled as Light yellow, Light green, or green respectively, as per my chosen set of sequential figure colours. On the left, I list all nineteen ideas from Sample *s*, and on the right, I list the nodes I will use in illustrations of Query Isomorph *i*. Neologisms have a tilde beside them (~), and Contributions have an asterisk beside them (*). Note that the names I gave my contributions are also neologisms, so they have both an asterisk (*) and a tilde (~) shown as *~.

[6] Categorical figure colours were not assigned word names by Adobe in *Spectrum* (Adobe, 2022) in addition to their hexcodes, so I included the name provided by the Colblindor Color Name & Hue tool (Flück, 2021).

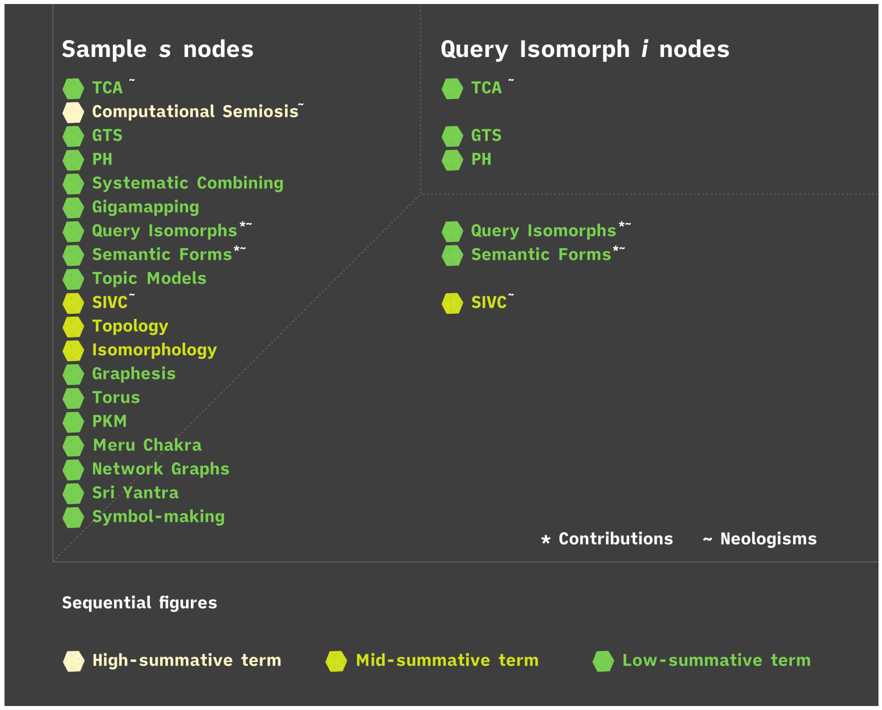

Figure 5.7: Sample *s* ideas list and Query Isomorph *i* ideas list.

Timelines of Sample s terms

Figure 5.8 illustrates when each idea was first included in my research database on a linear timeline. The purpose of including this timeline is to visualize how much time passed between the inclusion of each idea in Sample *s*. This figure also introduces some key design components for illustrations of my example Query Isomorph, which follows later in this section. Note that terms are paired with a node, which will be instrumental in illustrating spatial node relationships. Also note that nodes and text are labelled with sequential figure colours for high-summative, mid-summative and low-summative term nodes. This illustration also includes the date and origin note from Table 5.1. Some Semantic Forms are arranged using rectilinear timelines, like the Cylinder.

Not all Semantic Forms use rectilinear time representations like the Cylinder. The Ring Torus uses a time *circle*, for instance. To accommodate the passing of time represented as ellipses, I transposed Figure 5.8, the Linear Timeline of terms of Sample *s*, onto the circumference of a circle.

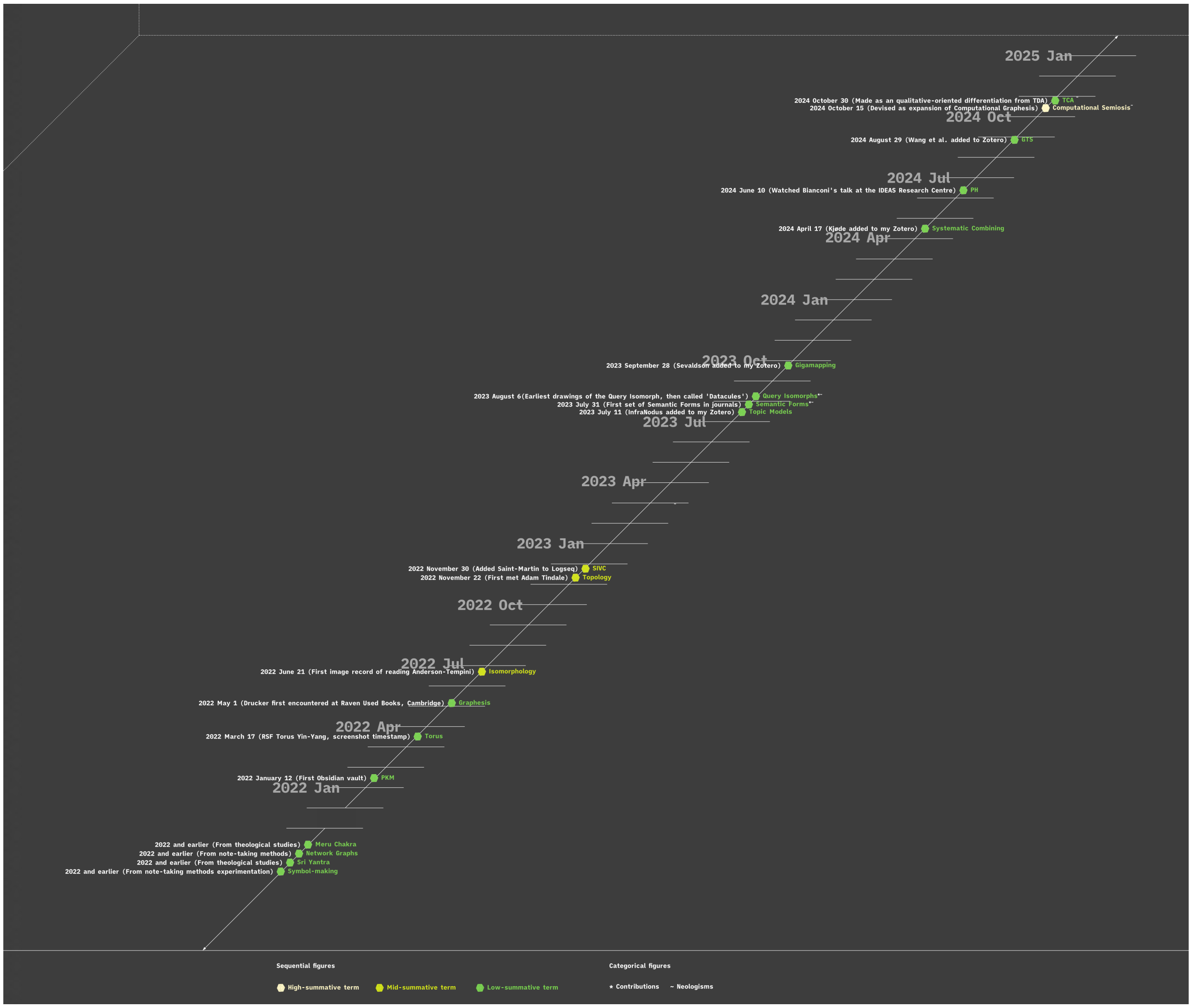

Figure 5.8: Sample *s* ideas on a rectilinear timeline.

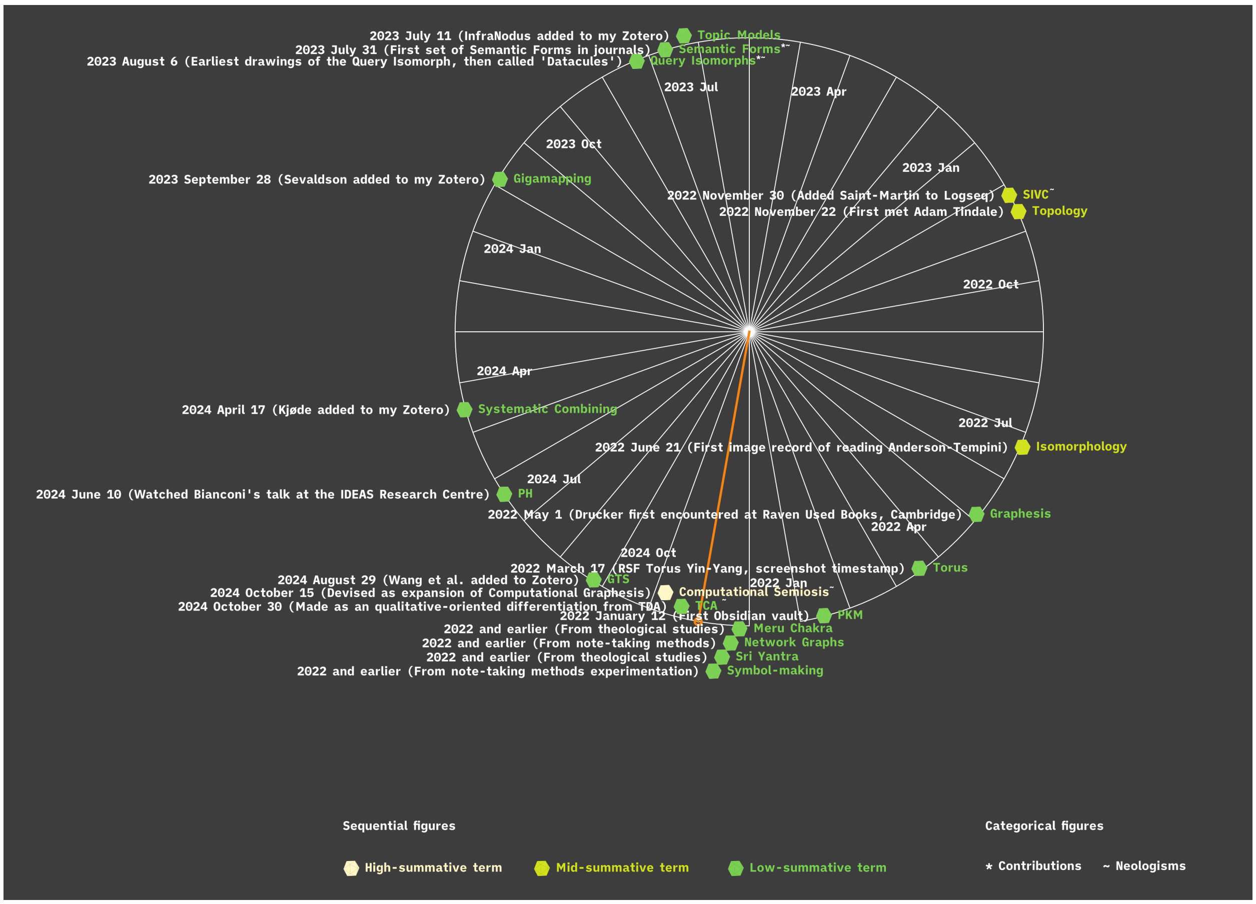

Figure 5.9: Sample *s* ideas on a timeline transposed onto a circle.

5.2.3 Experiments in Visuospatialization: Query Isomorph *i* in Semantic Forms

5.2.3.1 Introducing Query Isomorph *i*

***i* as a name**

The name 'i' may seem to point to the popular prefix used to signify individual customizability of many iProducts, but it was named primarily for other reasons. The scholastic practice of incipit identified works by their first few opening words (Smith, 2001, p. 3) [7]. The 'textiti' in Query Isomorph textiti, is an incipit of the word 'Isomorph' by using the first letter of its name. Second, as a play on scale using miniature symbolic representation, the letter 'i' seems to depict a small person with a body and a head, whimsically calling attention to the ways text-and ideas- are a space that we move through and with; third, and by extension, the 'i' is autobiographical in that, like any work, this thesis is in a sense a self-portrait of its maker. Fourth, the letter 'i' uses one point and one line, the first and first-dimensional building blocks of all network graphs in all dimensions. To articulate this point further in topological terms, because I propose the Query Isomorph as a tool in Topological Capta Analysis, the point of the 'i' represents the 0-dimensional simplex, or the point, and the bar of the 'i' represents the 1-dimensional simplex, or the line segment (Maletić et al., 2011, p. 3).

Two-dimensional and three-dimensional Query Isomorph configurations

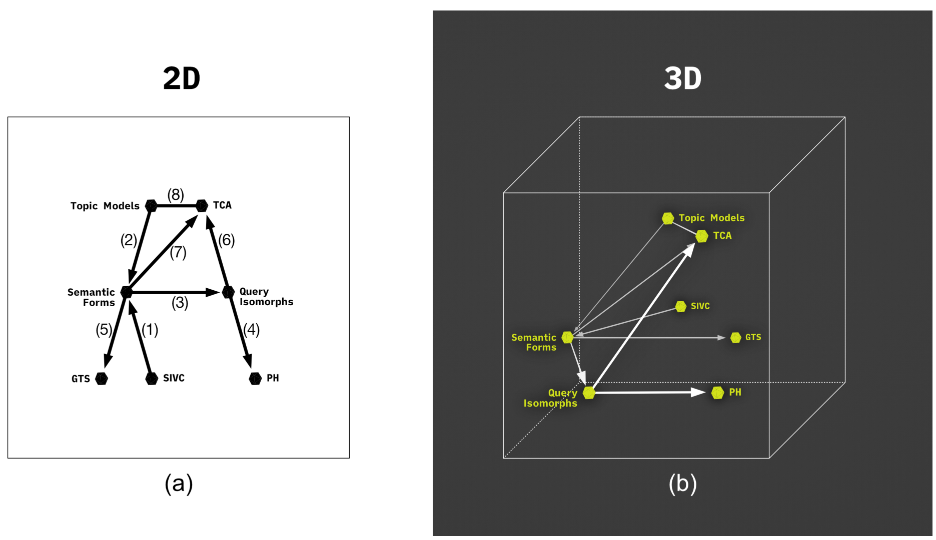

Figure 5.10: Query Isomorph *i* in 2D and 3D.

[7] For a thorough introduction of the incipit, its medieval use, and its ideological significance, see the introduction of *Book of the Incipit : Beginnings in the Fourteenth Century* (Smith, 2001, p. 3).

Figure 5.10 is a depiction of how a researcher might query this thesis using Query Isomorph *i* in two-dimensional and three-dimensional directed graphlet formats. Figure 5.10 (a) has eight numbered Query Isomorph graph edges; 1-5 are directed edges which align with the order of ideas in Sample *s*; Note that 4, 5, and 6 indicate that Query Isomorphs lead me to Persistence Homology (PH), which facilitates 5 as a connection from Semantic Forms to Global Topological Synchronization (GTS)- both 4 and 5 are required to move to TCA, which I arrive to through Query Isomorphs first in 6 because I arrive to the topological ideas of PH via Query Isomorphs, and not through Semantic Forms in 7; 8 represents is an example of an undirected Query Isomorph edge in use, meaning the fictional researcher using Query Isomorph *i* in this example is not looking for a particular derivation sequence between these two ideas, Topic Models and TCA in this case.

In Figure 5.10 (a), I depict Query Isomorph *i* in two dimensions. In (b), I depict Query Isomorph *i* in three dimensions, which affords a wider range of node placement. Verticality is used as a method to encode hierarchy into the query. For example, by placing a node higher than another, a researcher using this interface would be querying for how TCA acts as a category for Semantic Forms and Query Isomorphs. The depth of the visuospatial input view affords more space for additional cues for hierarchy and sequence through node placement.

Many people do not read from left to right, so if I were to code this 3D input method, I would make sure to include an option for the TCA Workspace user to adapt their interface to align with a right-left sequential heuristic. For example, a feature that automatically populates directed Query Isomorph edges between nodes depending on their placement along the horizontal axis would adapt to the person's settings of derivation starting from the left or from the right. To be clear, however, the Query Isomorph edge direction would be customizable and not dependent on the node's position along a horizontal axis only, as I expect will be required for many different query configurations.

I conjecture that the benefits of inputting a query of this level of specificity with a directed query graphlet like the Query Isomorph *i* instead of the above natural language query equivalent can save some time. In my experience, queries are often iterated upon to fine-tune desired information and altered when insightful correlations are encountered. It is in this sense that the dimensionally versatile Query Isomorph, as input methods shown in Figure 5.10 (a) and (b), offer value to the TCA Workspace interface by facilitating query iterations through the semiotic affordances of node position and edge direction.

The option to represent Semantic Shapes in three-dimensional space

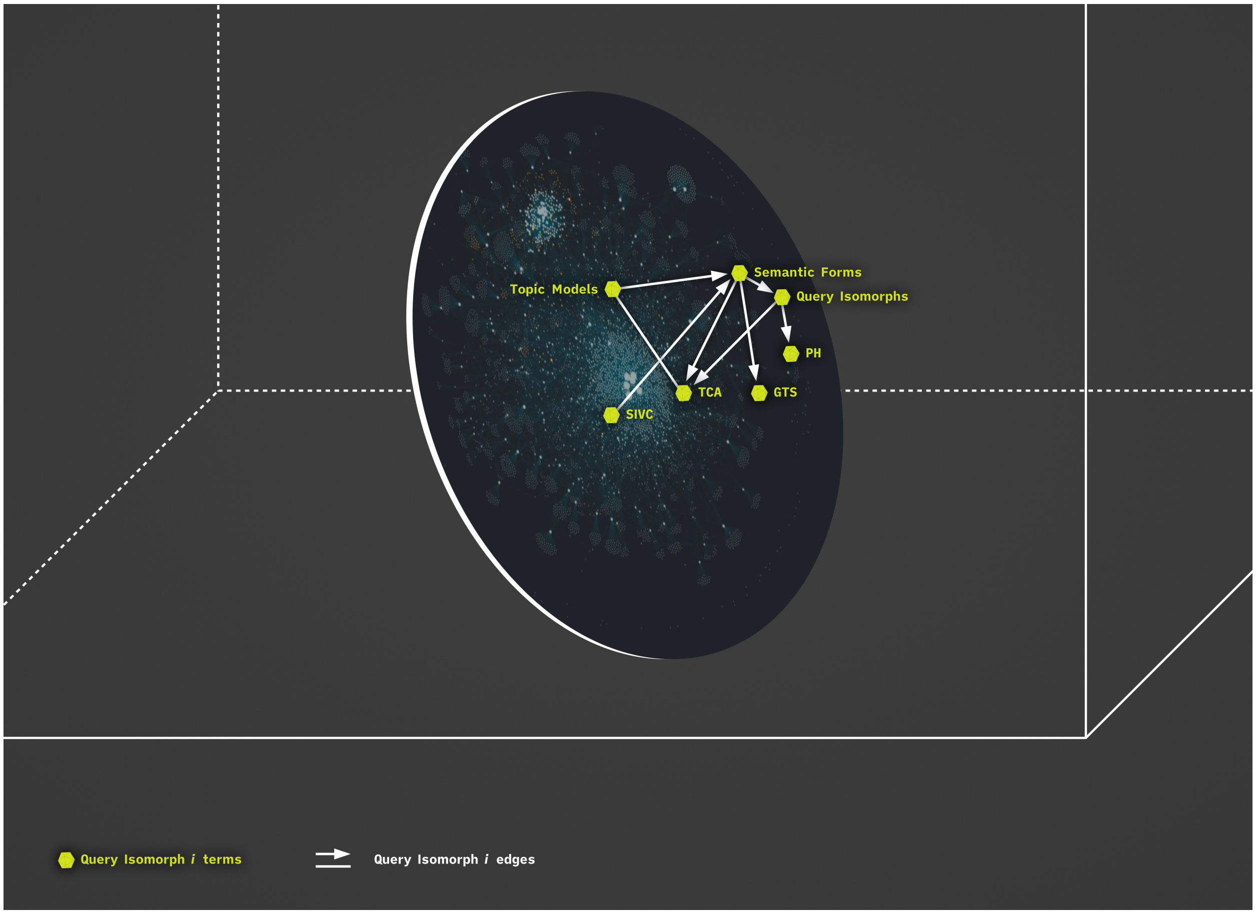

Figure 5.11: Query Isomorph *i* on a Circle Semantic Shape Logseq network graph.

I propose that representing the flat Semantic Shapes in three-dimensional space will be valuable. For example, one occasion I expect will be the placement of Query Isomorphs in their 3D input configuration alongside the larger graph from which they are pulled. Since I propose that TCA Workspace can extend the capabilities of PKM platforms, I illustrate here an example of Query Isomorph *i* superimposed onto my Logseq graph. Furthermore, I expect the dimensional versatility of TCA Workspace to include many more applications of models that use both 2D and 3D information visuospatializations.

5.2.3.2 Query Isomorph *i* in six Semantic Forms

To begin this series of experiments in Computational Semiosis and information visuospatialization, I will illustrate Query Isomorph *i* as it would appear in TCA Workspace if it were coded.

By representing Query Isomorph *i* in the following six Semantic Forms, I illustrate the ways the Query Isomorph would be rearranged and warped when placed within the 'magnetic' field of each Semantic Form's semantic force. I made Sample *s* about this thesis to make it easier for the reader to understand how Query Isomorphs and Semantic Forms could be applied to a text by starting from the text we are already discussing.

Each of the following illustrations of Query Isomorph *i* in a Semantic Form was rendered by overlaying node-label pairings onto screenshots of my visuospatial Blender Semantic Form models.

As a continuation of Figure 5.3 and Figure 5.4, I will present my Semantic Forms as pairings. Each coupling includes a simpler Semantic Form followed by one that is more complex. The Semantic Form pairings that follow are Cylinder with Ring Torus, Cone with Double Cone, and Sphere with Horn Torus.

Query Isomorph *i* in the Cylinder and Ring Torus Semantic Forms

Cylinder Semantic Form

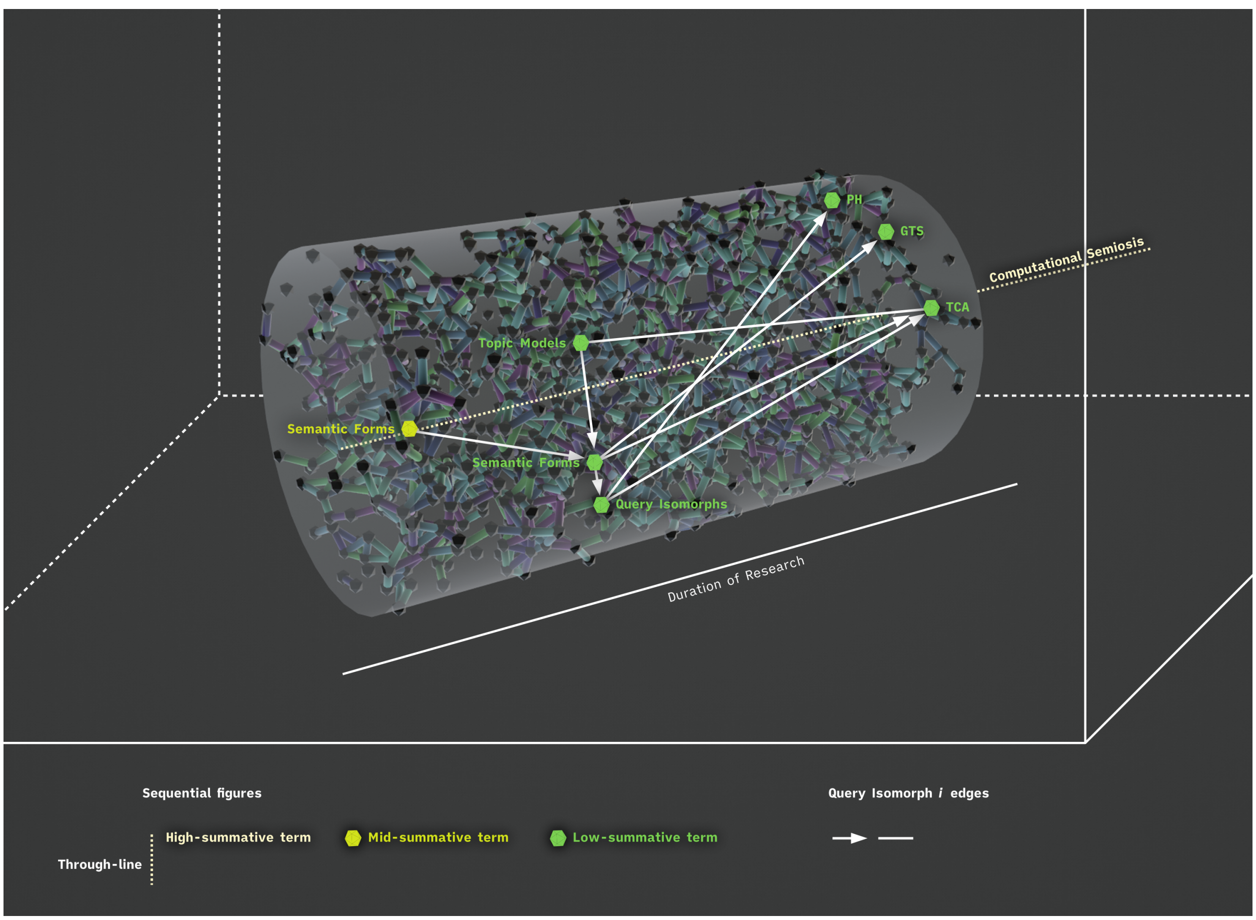

Figure 5.12: Cylinder Semantic Form about Query Isomorph *i*.

The Figure 5.12 Cylinder Semantic Form represents the duration of my research. To assist in placing each idea node accurately along the central axis line that runs through the core of the Cylinder's barrel, I overlaid the timeline from Figure 5.8 onto the image of the Cylinder Semantic Form. However, also note that nodes closer to the rotational axis line of the cylinder are more general or summative terms. For example, Spatial Information Visualization Composition (SIVC) is a more general idea than Query Isomorphs. Graphs in PKM platforms Obsidian and Logseq tend to place more densely connected terms in the middle of the graph. Since I am representing a series of PKM graphs as the Cylinder Semantic Form, I am adhering to the principle that more densely connected terms, in this case, more general terms, are placed toward the middle of the two-dimensional graph. Conversely, less summative terms, like Persistence Homology (PH), are represented as less densely connected and, as such, placed closer to the periphery of the Cylinder Semantic Form.

One of the through-lines of my thesis document is Computational Semiosis, which is labelled in Figure 5.12 as a light yellow dashed line through the middle of the Cylinder barrel. The metaphor of a "through-line" can be made visuospatial with TCA as a means to add clarity to a topic model. The through-line acts as a semantic analogue in a Topological Data Analysis Principal Curve, which passes through the "middle" of a data cloud. (Kegl et al., p. 1), or mean/average line.

Ring Torus Semantic Form

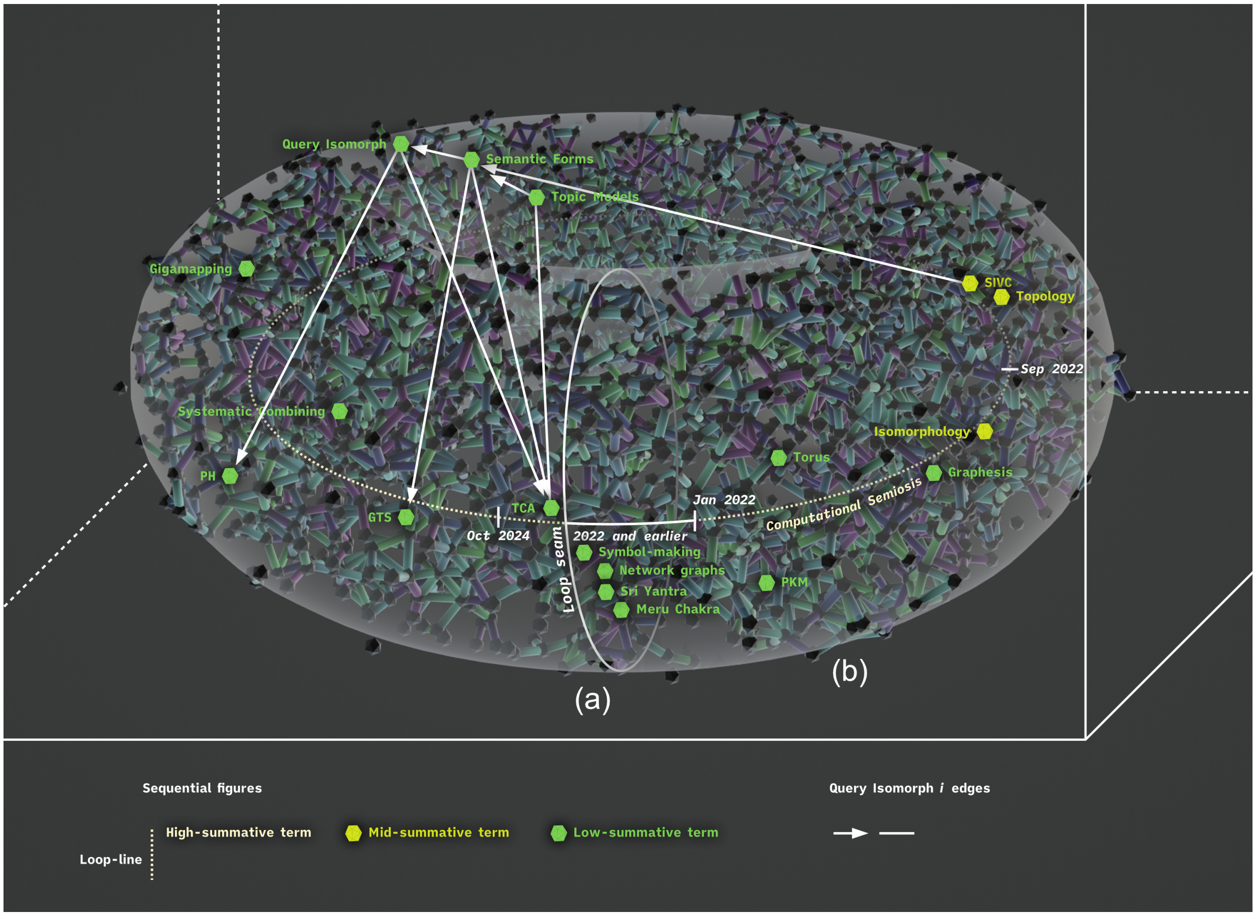

Figure 5.13: Ring Torus Semantic Form about Query Isomorph *i* with rectilinear edges. (a) is the the Loop seam, and (b) is the Loop-line.

I visualized the warp of input Query Isomorph *i* in the output Ring Torus Semantic Form in two ways: In Figure 5.13 I illustrated Query Isomorph edges using rectilinear edges to emphasize the derivation of each Query Isomorph *i* node. In Figure 5.14, I illustrated the Query Isomorph edges using long arcs that align with the curvature of the Ring Torus. This second style of edges emphasizes the sequence of each Query Isomorph *i* node along the elliptical timeline. I anticipate that toggling between both options will be valuable in the Ring Torus Semantic Form, the Horn Torus Semantic Form, and any future Semantic Forms that involve curved plotting.

Figure 5.13 a) indicates the Loop Seam between the earliest dates and the latest dates along the timeline circle. Dates from Sample *s* that were dated as "2022 and earlier" are labelled in a time segment to the right of the Loop Seam and left of "Jan 2022". In the case of the Ring Torus Semantic Form, the through-line circles back into itself in what I am calling a Loop-line, indicated in Figure 5.13 b). The Loop-line represents a theme or themes that are both strongly present in a TCA database within a given time range and are expected to be perpetuated if existing semantic patterns continue.

A computational method to query for topics that act as through-lines about a Query Isomorph in a Ring Torus Semantic Form would accelerate the analysis of texts and text groups. Similar functionality using OpenAI's GPT-4 to name the relationship between nodes on a graph is already technologically possible, as shown earlier in a discussion about InfraNodus. To apply the Ring Torus Semantic Form, a researcher querying for through-lines using a ring-torus Semantic Form diagram could use this model to identify which topics in a given text most facilitate the continuation of a given thematic cycle.

To determine accurate node placement within the Ring Torus Semantic Form, I overlaid Figure 5.9 as a guide. Specifically, I warped Figure 5.9 so that its circumference matched the core line running through the Ring Torus in Figure 5.13. I then moved each node manually along the radii lines of the superimposed and warped Figure 5.9 either closer to the inner radius or outer radius of the ring torus, depending on my arbitrary measurement of how summative each term is. This technique aligns with the way PKM graphs position nodes by placing more highly connected nodes toward the middle.

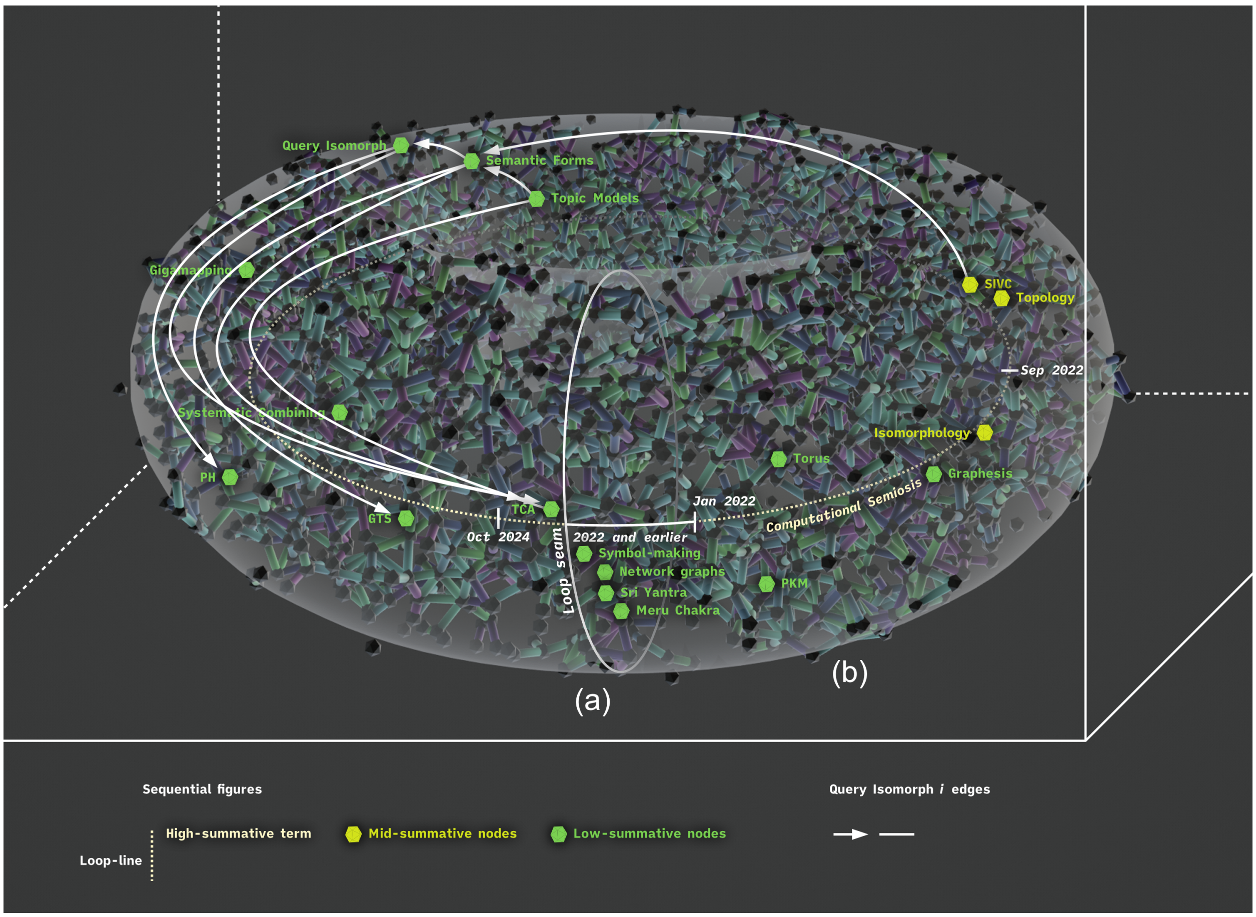

Figure 5.14: Ring Torus Semantic Form about Query Isomorph *i* with arced edges. (a) is the the Loop seam, and (b) is the Loop-line.

Query Isomorph *i* in the Cone and Double Cone Semantic Forms

Cone Semantic Form

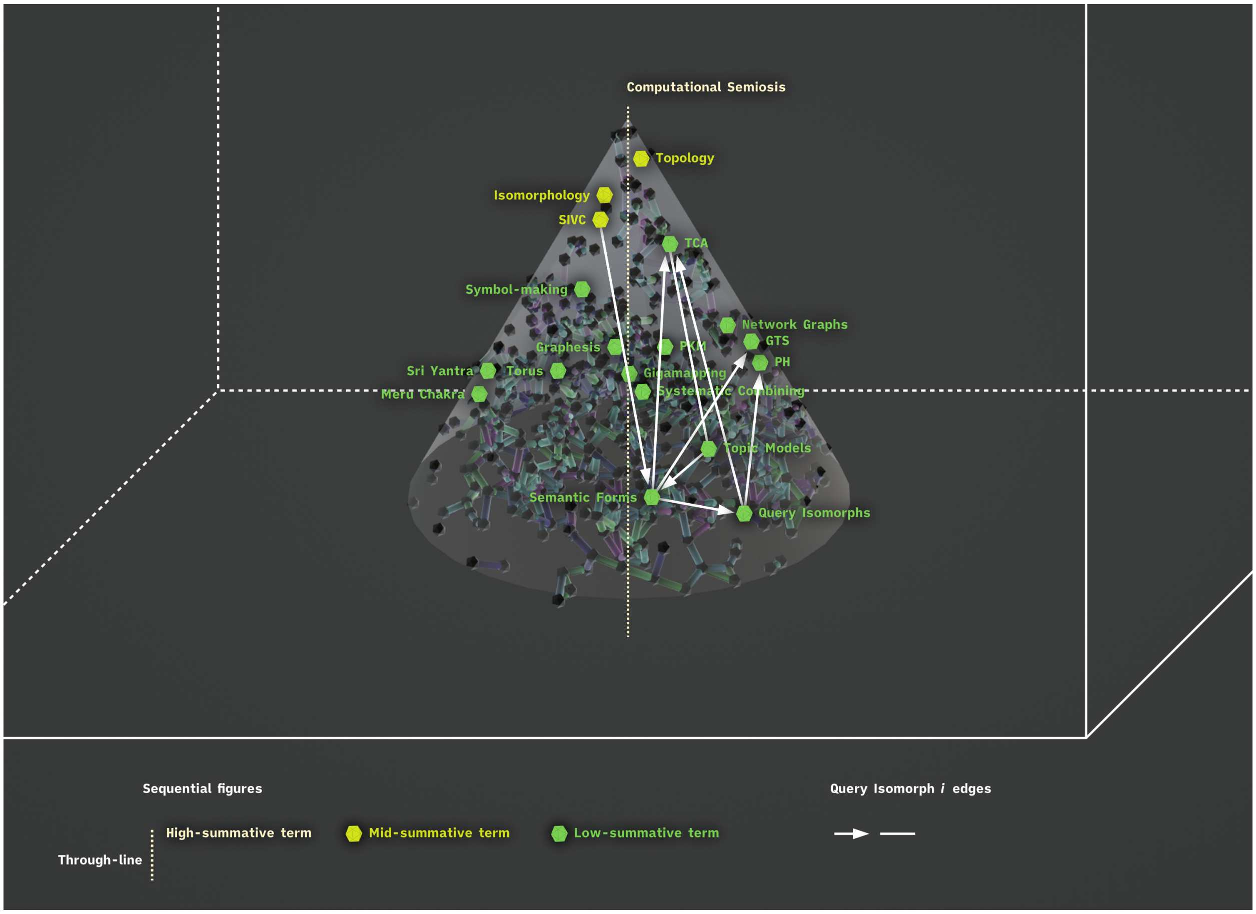

Figure 5.15: Cone Semantic Form about Query Isomorph *i*.

The Cone Semantic Form warps input Query Isomorph *i* vertically and horizontally by arranging nodes into a hierarchy of summativeness. This differs from the Cylinder and Ring Torus Semantic Forms because node placement in this Cone Semantic Form does not emphasize when a given concept was added to a TCA database.

The Cone Semantic Form extra clarity by doubly encoding the highly summative nodes closer to the Cone's peak, followed by mid-summative nodes and low-summative nodes in sequence toward the Cone base. Query Isomorph *i* is labelled by connecting its nodes with white edges.

The summative arrangement of the Cone Semantic Form works similarly to the Ontological Semantic Network Summaries in that the terms which are fewer in number towards the top point are the most summative and have the most subsequent terms derived from them.

Double Cone Semantic Form

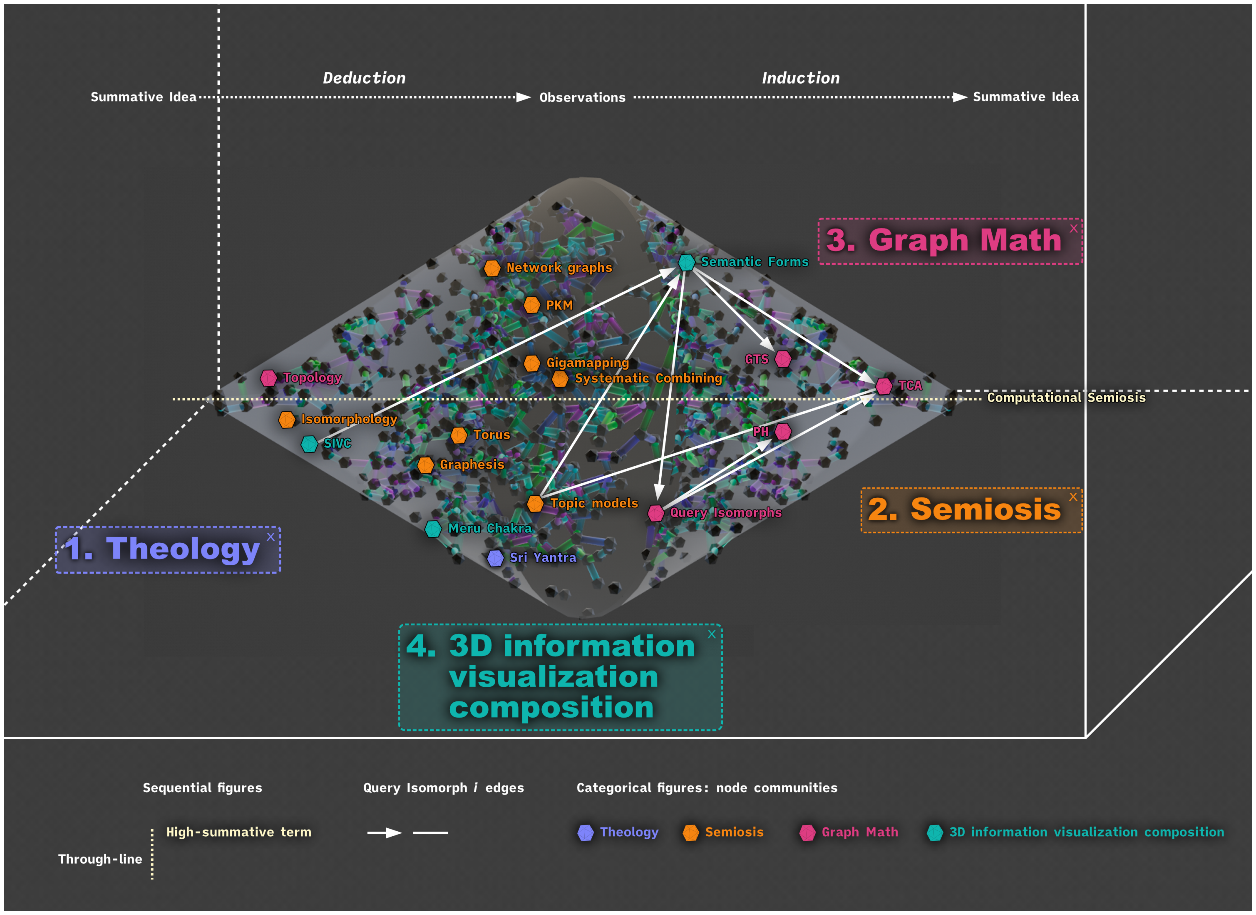

Figure 5.16: Double Cone Semantic Form about Query Isomorph *i*.

The Double Cone Semantic Form in Figure 5.16 represents the divergence of nodes in the process of deduction and then, conversely, the convergence that occurs with induction. My Double Cone Semantic Form for visuospatializing semantic divergence and convergence follows and builds on important precedents. As traced by Sevaldson, Pappus's (290-350) discussion of analysis and synthesis (Hinitikka and Remes, 1974, p. 7) was foundational to later visual expression like Bánáthy's model *The dynamics of divergence and convergence* (Bánáthy, 1996, p. 75) and the British Design Council's Double Diamond framework (Design Council, n.d.). However, my Double Cone Semantic Form differ from these precedents as a dimensionally versatile TCA tool that visuospatializes semantic divergence and convergence for HATG and HITL CATG, compared to the specifically two-dimensional HATG models by Bánáthy and the British Design Council.

In Figure 5.16 I label node communities in the style of InfraNodus (Paranyushkin, 2019; Paranyushkin et al., n.d.) [8] Theology nodes are labelled in Purple, Semiosis terms are labelled in Orange, 3D information visualization composition terms are labelled in Teal, and Graph Math terms are labelled in Magenta.

Query Isomorph *i* in the Sphere and Horn Torus Semantic Forms

Sphere Semantic Form

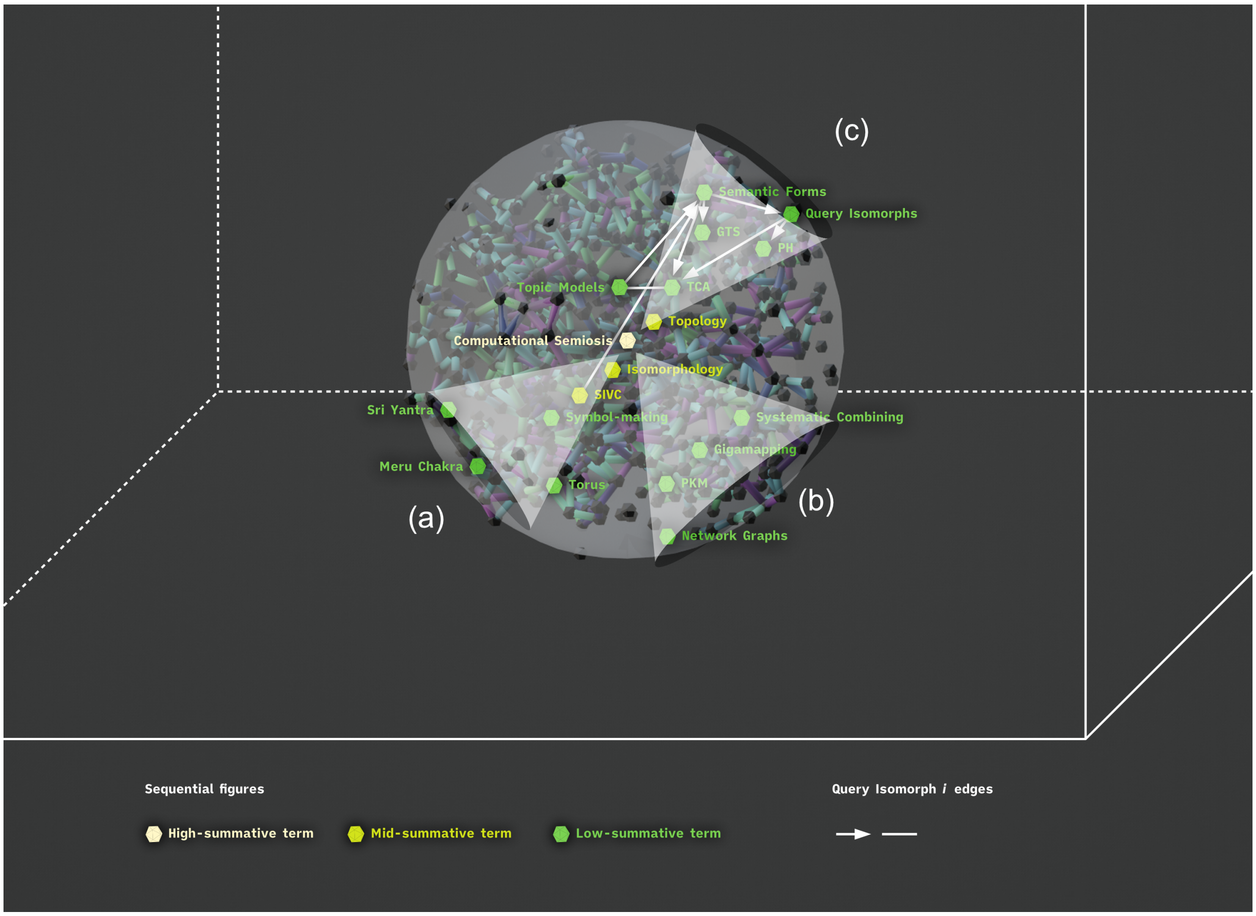

Figure 5.17: Sphere Semantic Form about Query Isomorph *i*. This Sphere Semantic Form contains three Cone Semantic Forms: (a) which is about Spatial Information Visualization Composition and Isomorphology, (b) which is about text graph methods of visuospatial knowledge production, and (c) which is about Topology.

The Sphere Semantic Form is similar to the Cone Semantic Form in that it represents hierarchical relationships between nodes. However, while the Cone Semantic Form can represent various hierarchies within itself, it predominantly represents one hierarchy. The Sphere Semantic Form effectively represents multiple cone semantic forms, increasing the number of hierarchies that can be represented.

Figure 5.17 illustrates how the high-summative node Computational Semiosis is shared by three Cone Seman-

[8] InfraNodus uses the Louvain community detection algorithm proposed by Blondel et al. (Blondel et al., 2008; Paranyushkin, 2022).

tic Forms: (a) which is about Spatial Information Visualization Composition and Isomorphology, (b) which is about text graph methods of visuospatial knowledge production, and (c) which is about Topology.

I present the Sphere Semantic Form with nested Cone Semantic Forms to illustrate an additional notation method for grouping nodes that does not depend on colour encoding like in Figure 5.16, which increases the researcher's ease of interpretation and avoids opportunities for accessibility issues related to colour blindness. In the same way that the Circle Semantic Shape can contain and overlap with Triangle and Circle Semantic Shapes, like in the Obsidian knowledge graph in Figure 5.2, the Sphere Semantic Form can nest and overlap with Cone and Sphere Semantic Forms. The number of nodes that can be organized in nested hierarchies of Semantic Forms is substantially more than the nodes that can be represented in a Circle Semantic Shape due to their dimensional difference. I expect that testing user experience of reading node hierarchies in Semantic Forms versus Semantic Shapes will reveal results consistent with Ware and Mitchell's *Visualizing graphs in three dimensions* (Ware and Mitchell, 2008, p. 10) in which users will be able to benefit significantly from a three-dimensional interface for dense graphs.

Horn Torus Semantic Form

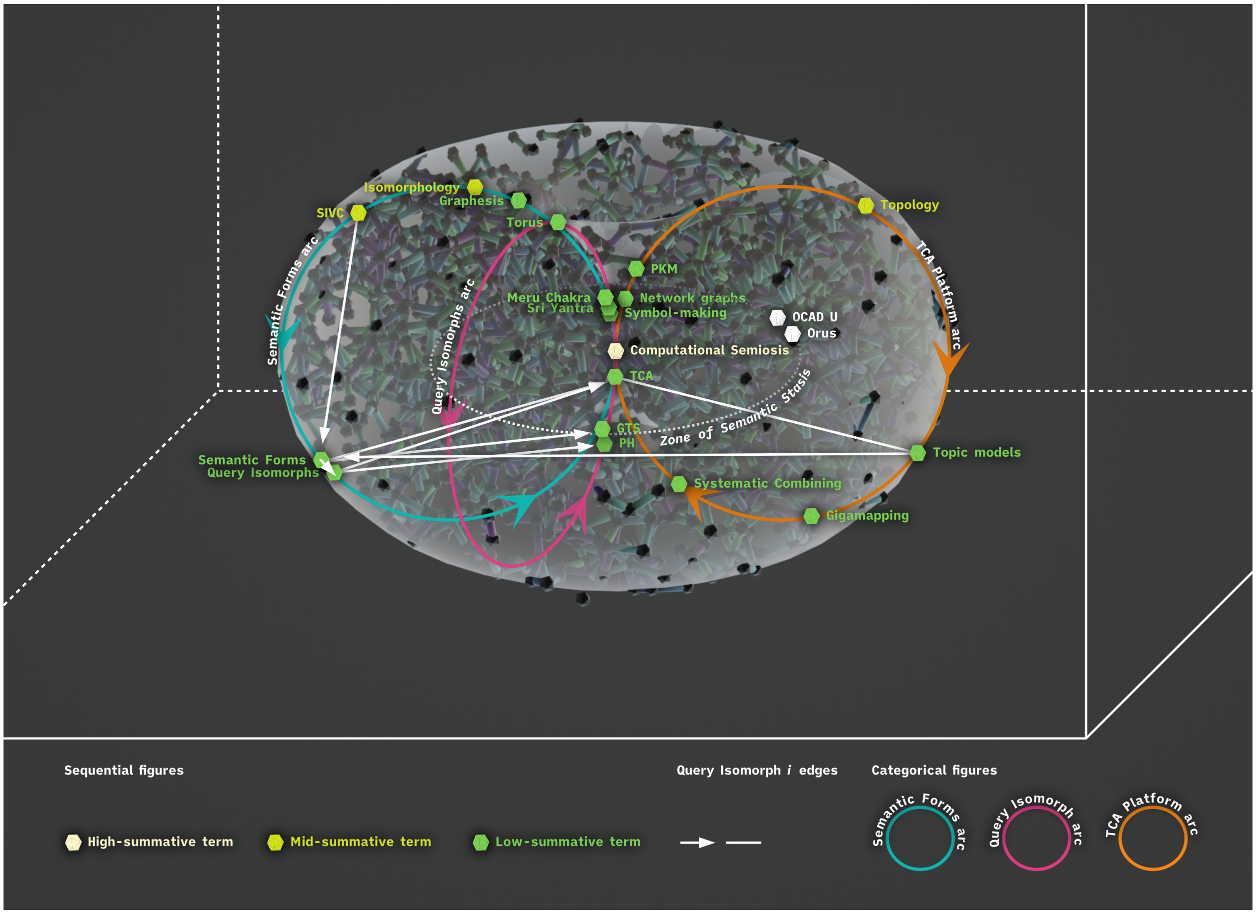

Figure 5.18: Horn Torus Semantic Form about Query Isomorph *i*.

The Horn Torus Semantic Form is similar to the Ring Torus and Cylinder Semantic Forms in that it represents a series of Circle Semantic Shapes like Rolodex (Mellby, 2021) of Obsidian or Logseq graphs in one continuous space as the tube of its body. However, the inner radius of the Ring Torus narrows to a single highly-summative point in the centre of the Horn Torus Semantic Form, making two Cone Semantic Forms which diverge away from each other as negative space outside the Horn Torus. Furthermore, the Loop-line of the Ring Torus Semantic Form is a Zone of Semantic Stasis in the Horn Torus Semantic Form, where ideas are the most consistent and unchanging.

I oriented my model Horn Torus Semantic Form to dimple above and below to evoke trees. The core of the torus represents the trunk which branches up and out, whose leaves fall and transform into the soil, whose nutrients are taken up by the tree's roots–represented by the bottom horn torus dimple. These nutrients are taken back into the tree to the trunk re-origin point in an ongoing cycle of blossoming transformation representative of ideas' flux.

I depict these Horn Torus Semantic Form trajectories of transformation as arcs emerging and returning to their re-origin point. Similarly to the Ring Torus, I used Figure 5.9 to accurately place term nodes from semantic field *S* with chronological precision onto their respective arcs. The re-origin point, Computational Semiosis, is in the high-summative sequential figure colour Light yellow. I depicted the transformation trajectory arcs by labelling them in categorical figure colours: the Semantic Forms arc in Teal, the Query Isomorph arc in Magenta, and the TCA Platform arc in Orange. My transformation trajectory arcs follow the circumference of the torus tube like Rucker's vertical arc orbits representing time in his horn torus model of space-time (Rucker, 2005). However, my transformation trajectory arcs blossom upward and out from the horn torus's centre.

The Horn Torus Semantic Form differs from the Sphere Semantic Form because it does not nest a variety of Cone Semforms within it at different angles. In fact, the two Cone Semantic Forms at the poles of the Horn Torus Semantic Form represent Gestaltian geometric liminality and interbeing (Nhất Hạnh, 2008, p. 80) (Deleuze and Guattari, 2007, p.25) of Semantic Form in which the Cone Semantic Form and the Ring Torus Semantic Form are exactly at the brink of being their own forms, being each other, and being a whole that "is other than the sum of its parts." (Sevaldson, 2022b, Koffka in Sevaldson, p. 163). This thesis is, in many ways, a celebration of the strange and wonderful qualities of the horn torus as a spatial information visualization composition, particularly as a network graph isomorph.

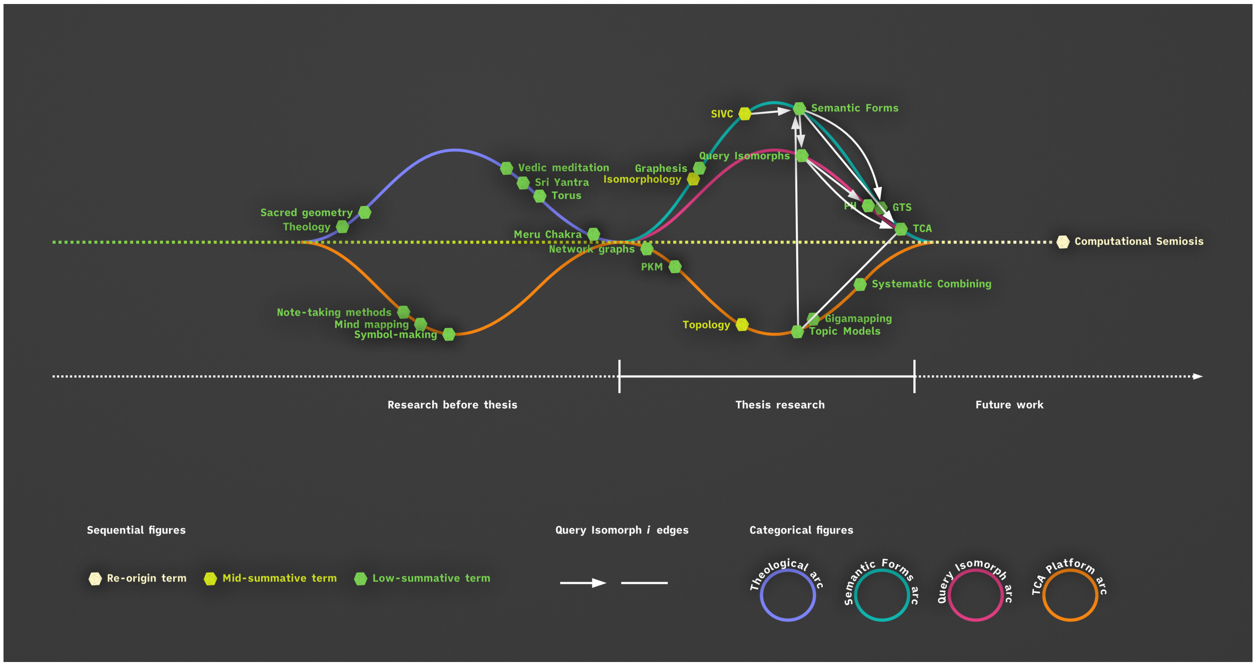

Figure 5.19: Horn Torus Semantic Form about Query Isomorph *i* dimensionally reduced to 2D.

In Figure 5.19 I illustrate two sequences of Horn Torus Semantic Form re-origination in a dimensional *reduction* of Figure 5.18. On the left, I represent the research before my graduate work at OCAD U in a cycle of divergence and convergence. To the right, I represent my thesis research at OCAD U, which leads to future work. I represent Query Isomorph *i* by connecting its nodes with white colour edges. The three transformation trajectory arcs from Figure 5.18 are included, but left of the bracket for Thesis research, I added arcs to represent a rough timeline of encountering key formative ideas that preceded my work at OCAD U. First, I added a Theological arc, which includes the terms Theology, Sacred geometry, Vedic meditation, Sri Yantra, and Torus. Note here that the Torus is included earlier in this representation because my fascination with it began with artistic representations of chakras as horn tori. Also, note that the Meru Chakra is placed directly before the beginning of my thesis research arcs and directly before Network graphs. I labelled the Theology arc Purple, the Semantic Forms arc Teal, and the Query Isomorphs arc Magenta because I arrived at a study of network graphs through my fascination with the Meru Chakra. Since the development of Semantic Forms and Query Isomorphs are distinct extensions and disambiguations of a theological principle, I used colour to represent how the Teal Semantic Forms arc and the Magenta Query Isomorphs arc are the separation of blue and red primary colours that make up Purple. Second, the TCA Platform arc extends backward into a short origin story, including Note-taking methods, Mind mapping (Buzan, 2005), and Symbol-making. Both arcs and additions left of my Thesis research arcs represent a rough timeline, as I mentioned. I spread each idea along the timeline according to my estimated age when I encountered each idea. The nodes furthest left on the timeline represent the earliest ideas that influenced this research, and the nodes closest to the beginning of my thesis research arcs represent the ideas that were most influential right before beginning my degree at OCAD U.

5.3 Contribution 7. TCA Workspace, for living webs of thought

C7 *TCA Workspace*, a proposal for a collaborative HITL CATG + HATG platform to:

(a) house all my thesis contributions (*Semantic Forms*, *Query Isomorphs*, *OSNS*, *Symbol-setting*, *TTG*, and *TCA Researcher Grouping*).

(b) facilitate their combined use with Systemic Design methods for visuospatial reasoning encountered through my literature review, such as gigamapping (Sevaldson, 2011), (Sevaldson, 2022b, p. 26) and Systematic Combining (Dubois and Gadde, 2002, p. 554), (Kjøde, 2024).

TCA Workspace is my proposal for a software platform which will accelerate the computational analysis of texts and graphs with Semantic Forms, Query Isomorphs, Symbol-setting, Ontological Semantic Network Graphs, and Terroir of Text and Graphs (TTG) as independent tools or as combined approaches. The 'space' in TCA Workspace invokes the dimensionality of 'place' but invokes the colliding of electromagnetic particles in nested holarchies of complexity, from the atoms that are our words to the ontologies that are our visible universes. In this sense, TCA Workspace is a particle accelerator of ideas that activates living webs of thought.

In TCA Workspace researchers would examine isomorphogenic molecular dynamics simulations of 'datacules', formed of spatial network graphs of entities and relationships in Query Isomorphs and Semantic Forms. Researchers would be able to identify and observe the semantic forces at play in text and graphs, using the rich visuospatial analogues available from the consilient fields of physics, chemistry, and computational analysis from the highly consilient field of mathematics by using Topological Capta Analysis. Doing so is a means of identifying richer meta-patterns in the visuospatial forms of knowledge production we use and developing new language for Sustainability Transitions, syntopically consilient or perhaps beyond it.

The following sections invite the consideration of how current approaches to graphs and text are aligned with and can be expanded by the TCA Workspace toolkit.

5.3.1 Dimensional addition in Systems Oriented Design

Considering the Meta-Systematic Combining approach I used in this thesis for arriving at Semantic Forms through dimensional addition of Semantic Shape, I propose dimensional addition to Sevaldson's gigamaps (Sevaldson, 2011, 2022b) as a feature of TCA Workspace that can work concurrently with Semantic Forms and Query Isomorphs. As introduced in Figure 5.11 with the spatial TCA Workspace representation of the Circle Semantic Shape PKM graph with an overlay of Query Isomorph nodes, I do not intend to represent information in only two-dimensions or three-dimensions in TCA Workspace; instead, I think both can be valuable together in the same render. To illustrate the dimensional versatility of the interface of TCA Workspace, I present two examples of visuospatial gigamaps: Figure 5.20 my Horn Torus Semantic Form gigamap and Figure 5.21 my Cone Semantic Form gigamap.

5.3.1.1 Gigamaps with Semantic Forms

Horn Torus Semantic Form gigamap

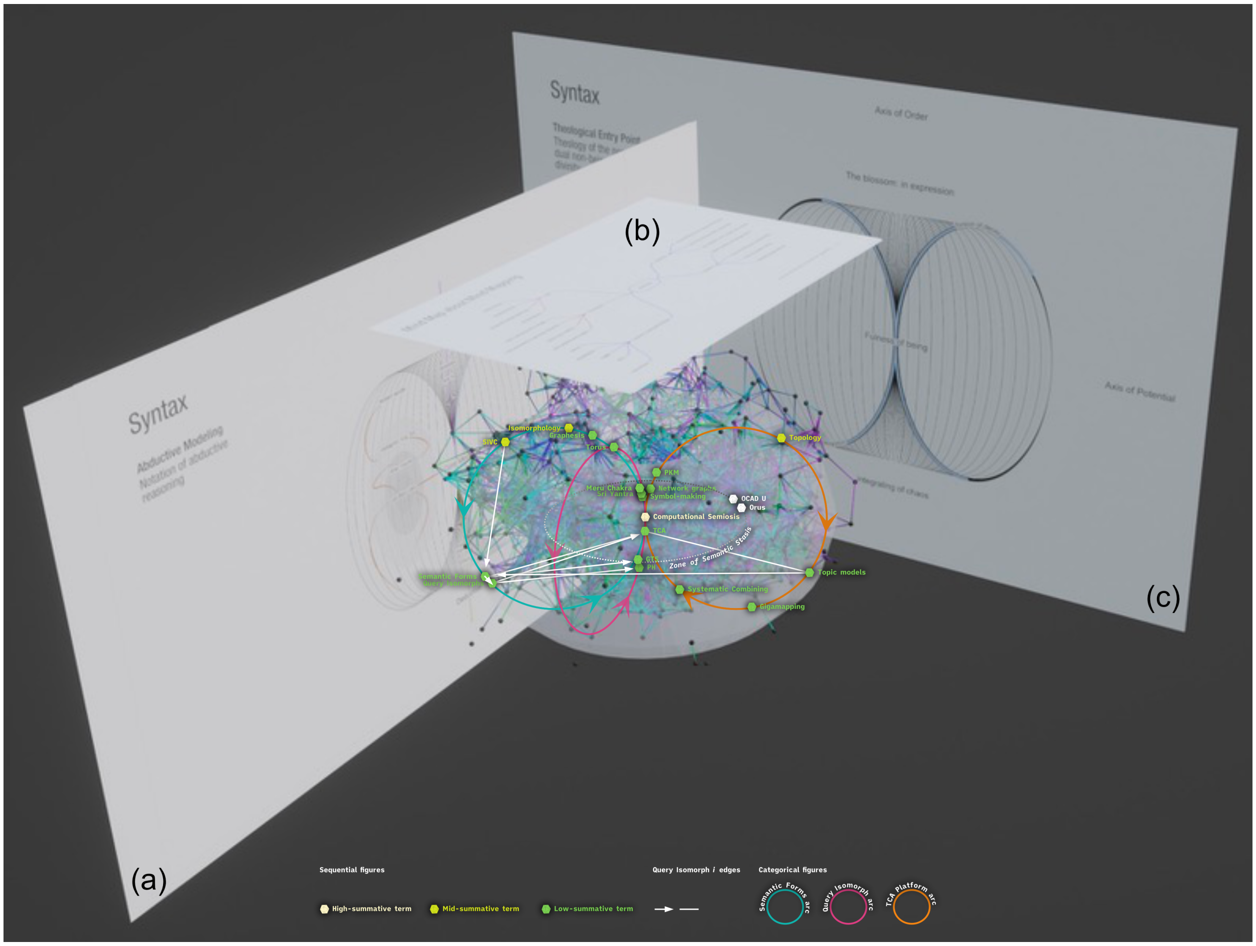

Figure 5.20: Horn Torus Semantic Form gigamap. The network graph is dimensionally reduced in three angles into two-dimensional panes: (a) and (b) reveal the Disintegration and Integration arcs from Figure 4.2 that organize the semantic relationships of divergence and convergence from Figure 5.18. (c) depicts the Horn Torus Semantic Form from its top view as a Mind Map (Buzan, 2005).

First, in Figure 5.20, the Horn Torus Semantic Form gigamap, I depict a conceptual gigamap with a Horn Torus Semantic Form network graph along with dimensionally reduced two-dimensional panes. In (a) and (b), I depict panes which reveal the Disintegration and Integration arcs from Figure 4.2 that organize the semantic relationships of divergence and convergence from Figure 5.18. In (c), I depict the Horn Torus Semantic Form from its top view in the shape of a Mind Map (Buzan, 2005) to show how that the Horn Torus Semantic Form can be dimensionally reduced into a Circle Semantic Shape. Angles for panes (a), (b), and (c) were chosen for simplicity of introduction. The angles of a two-dimensional reduction of a given Semantic Form could be positioned in as many angles as there are vantage points. In fact, the diversification of dimensional reduction angles can empower

HITL CATG by summarizing the most influential vantage points perpendicular to point cloud mean/average lines. HATG from various angles would also permit a researcher to examine a spatial network graph using non-computational pattern-finding abilities.

Cone Semantic Form gigamap

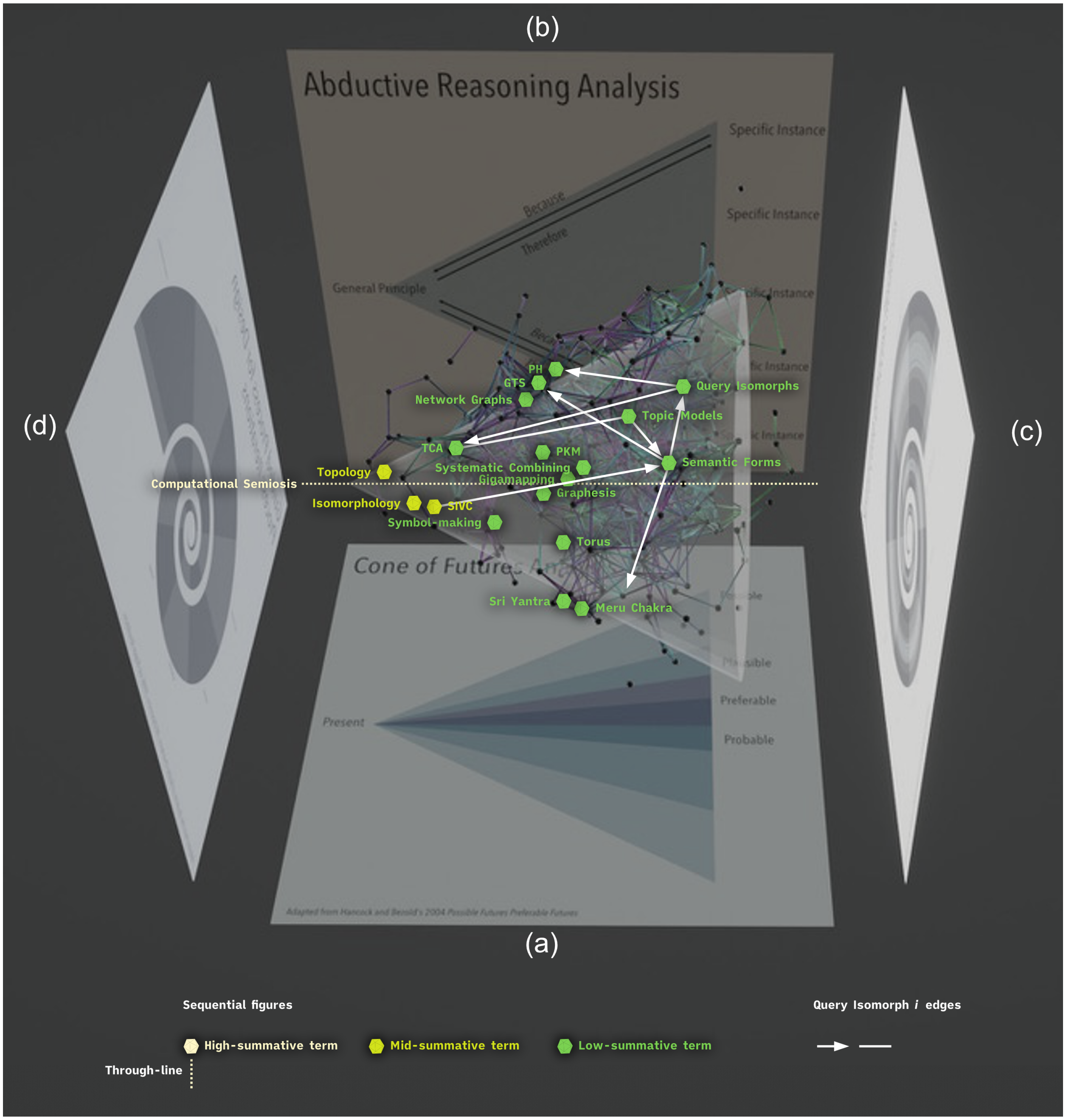

Figure 5.21: Cone Semantic Form gigamap about Query Isomorph *i*. The network graph is dimensionally reduced in four angles into two-dimensional panes: (a) in a Cone of Plausibility (Bezold and Hancock, 1993), (b) as an inductive and deductive reasoning analysis, (c) as a Horn of Futures model, and (d) as an adaptation of "Diagram of a design process with iterations" (Sevaldson, 2022b, p. 343) (Sevaldson, 2022a).

Second, I depict a conceptual gigamap with a Cone Semantic Form network graph dimensionally reduced in four angles: (a) in a Cone of Plausibility (Bezold and Hancock, 1993), (b) as an inductive and deductive reasoning analysis, (c) as a Horn of Futures model, and (d) as an adaptation of "Diagram of a design process with iterations" (Sevaldson, 2022b, p. 343) (Sevaldson, 2022a), similarly to Figure 5.20, these angles are not prescriptive to the practice of Cone Semantic Form gigamapping.

5.3.1.2 Semantic Forms in Systematic Combining.

Systematic Combining (SC) is a form of Knowledge Production that combines diagrams into larger, more integrated, and capacious models. The driving urgency of my work is Sustainability Transitions, so I examine the doctoral thesis and Systematic Combinations of Svein Gunnar Kjøde, *Entanglement of Systemic Design and Sustainability Transitions* (Kjøde, 2024), as a case study for the existing use of Spatial Information Visualization Composition (SIVC) in Design for Sustainability Transitions. Identifying the current use of SIVC is valuable to me because it demonstrates areas that would benefit from the key functions of TCA Workspace, such as Semantic Forms and Query Isomorphs.

I found that Kjøde included or made SIVCs using three geometric forms, which are among my six Semantic Forms, represented in Figure 5.22, Figure 5.23, Figure 5.24. First, the sphere, which organizes the ideas in Figure 5.22 the "Floke programme and quadruple helix for stakeholder inclusion" (Kjøde, 2024, p. 125). Second, the cone, which organizes the ideas in Figure 5.23, Kjøde's "Relating systemic design practice to socio-technical systems theory and the MLP" (Kjøde, 2024, p. 123). Third, the cylinder which organizes the ideas in Figure 5.24, Kjøde's "Praxeological framework for DfST relating to systematic transition initiatives" (Kjøde, 2024, p. 144). The first two figures have a more self-evident similarity to my Semantic Forms. The third figure, Figure 5.24, is a four-lobed visualization with the words "Systemic Praxeology of DfST" in its centre. This four-lobed figure is indicated to occupy the one-dimensional "Systemic Practice", which is labelled as a colourful double-directional arrow pointing from the bottom left to the top right. "Systemic Practice" is labelled as one 'slice' of a cylindrical spiral labelled with a single-directional arrow and the words "Transition Initiative(s)." To apply my terminology as a summation, Kjøde's four-lobed "Systemic Praxeology of DfST" is a two-dimensional Circle Semantic Shape in a Cylinder Semantic Form, similar to the composition of Figure 5.12 which represents a cylinder of PKM graphs.

To relate my work to Kjøde's, I include a fourth figure, Figure 5.25, which represents how nodes in Sample *s* and Query Isomorph *i* would be positioned in relation to "Systemic Praxeology of DfST" (Kjøde, 2024, p. 144). Note that I maintain the layout of placing terms with higher summativeness toward the figure's centre like in my Circle Semantic Shape.

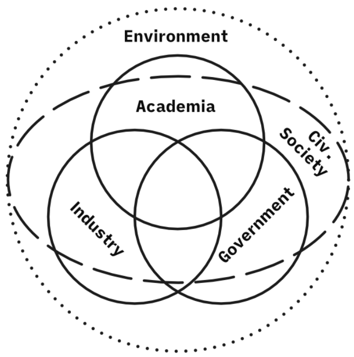

Figure 5.22: Spherical SIVC in DfST. This figure is based on the "Floke programme and quadruple helix for stakeholder inclusion" in Kjøde (Kjøde, 2024, p. 125)

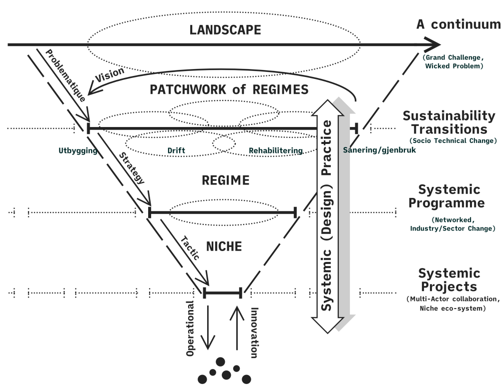

Figure 5.23: Conical SIVC in DfST. This figure is based on Kjøde's "Relating systemic design practice to socio-technical systems theory and the MLP" (Kjøde, 2024, p. 123). This figure includes Norwegian terms left of "Sustainability Transitions" to indicate the "patchwork of regimes" in overlapping aspects of "Socio Technical Change": utbygging, drift, rehabilitering, sanering, and gjenbruk: Utbygging refers to the initial "development" (Cambridge University Press, e); Drift refers to the ongoing operations and management (Cambridge University Press, a); Rehabilitering refers to the "rehabilitation" or restoration and upgrading of existing structures (Cambridge University Press, c); Sanering refers to "clearing" or sanitation (Cambridge University Press, d); Gjenbruk refers to reusing or recycling (Cambridge University Press, b).

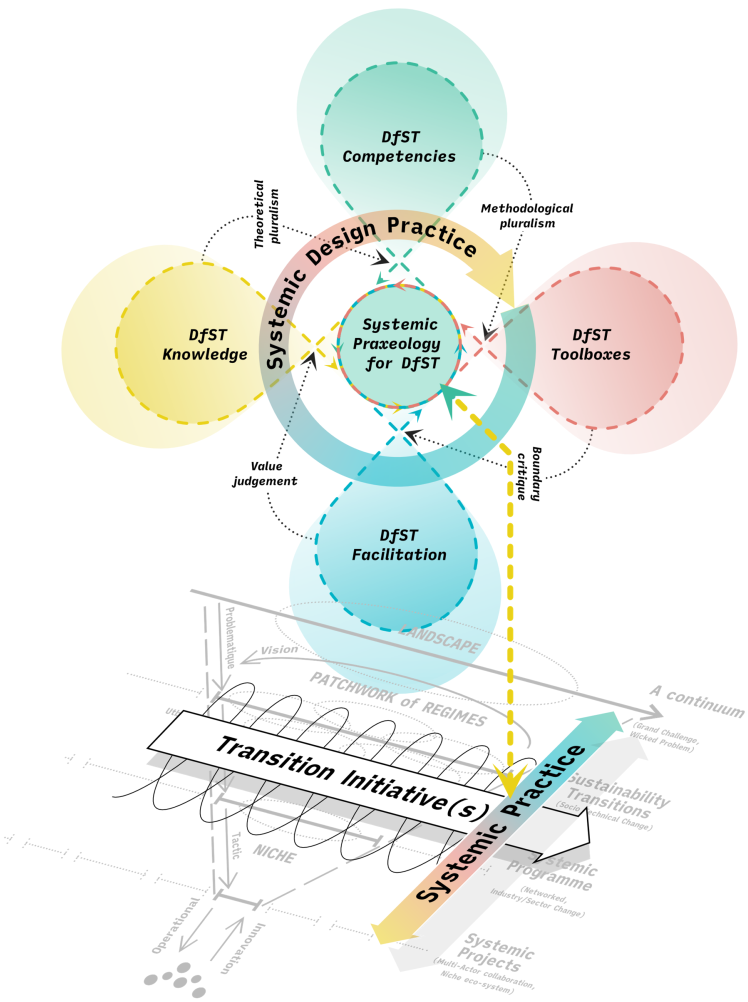

Figure 5.24: Cylindrical SIVC in DfST. This figure is based on Kjøde's "Praxeological framework for DfST relating to systematic transition initiatives" (Kjøde, 2024, p. 144).

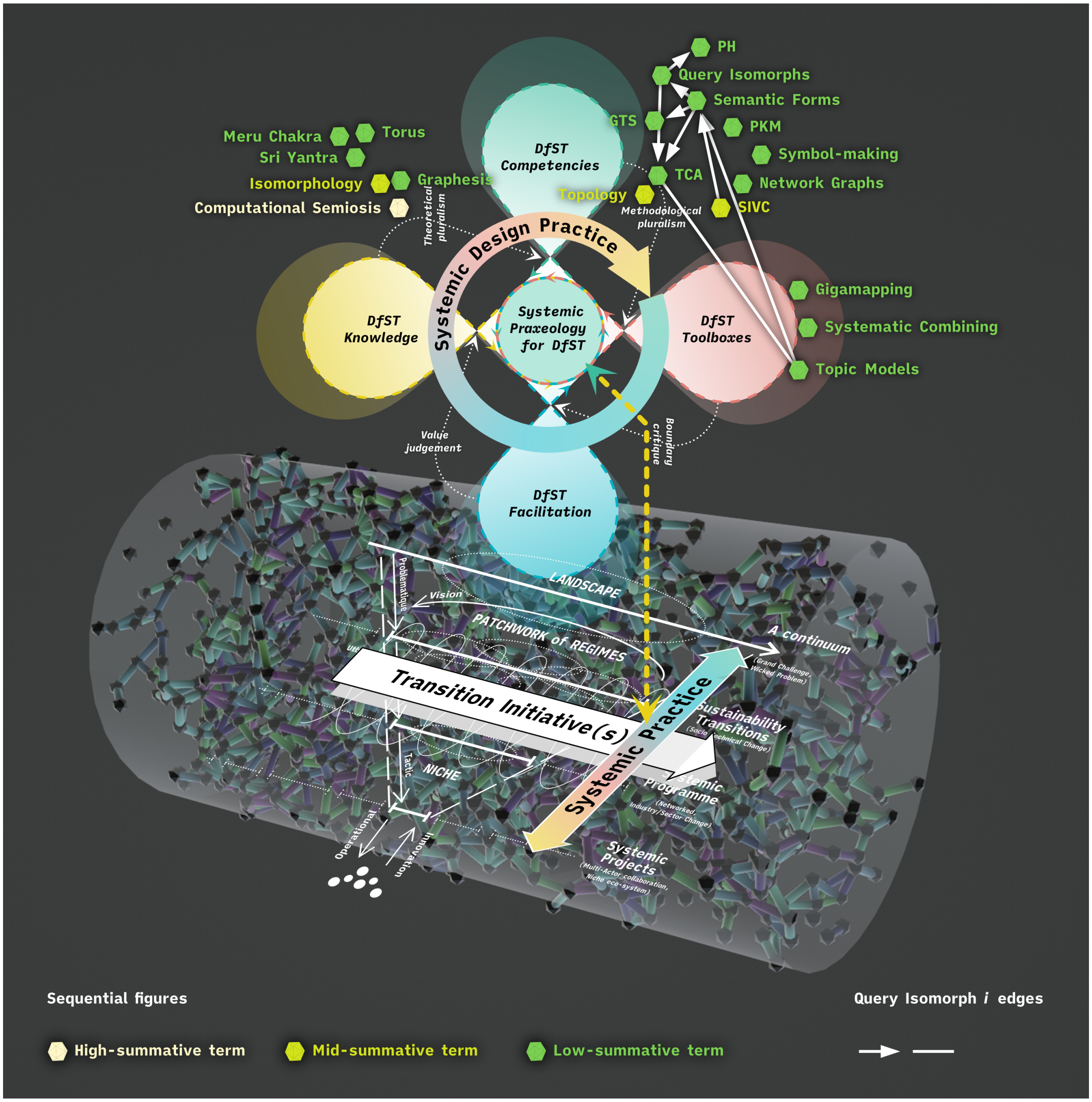

Figure 5.25: Kjøde's DfST Systematic Combining gigamap visualized as Cylinder Semantic Form network graph with Query Isomorph *i* and Sample *s*. The portion of this figure which is Figure 5.24 is based on Kjøde's "Praxeological framework for DfST relating to systematic transition initiatives" (Kjøde, 2024, p. 144).

5.3.1.3 LLM as Sphere Semantic Form

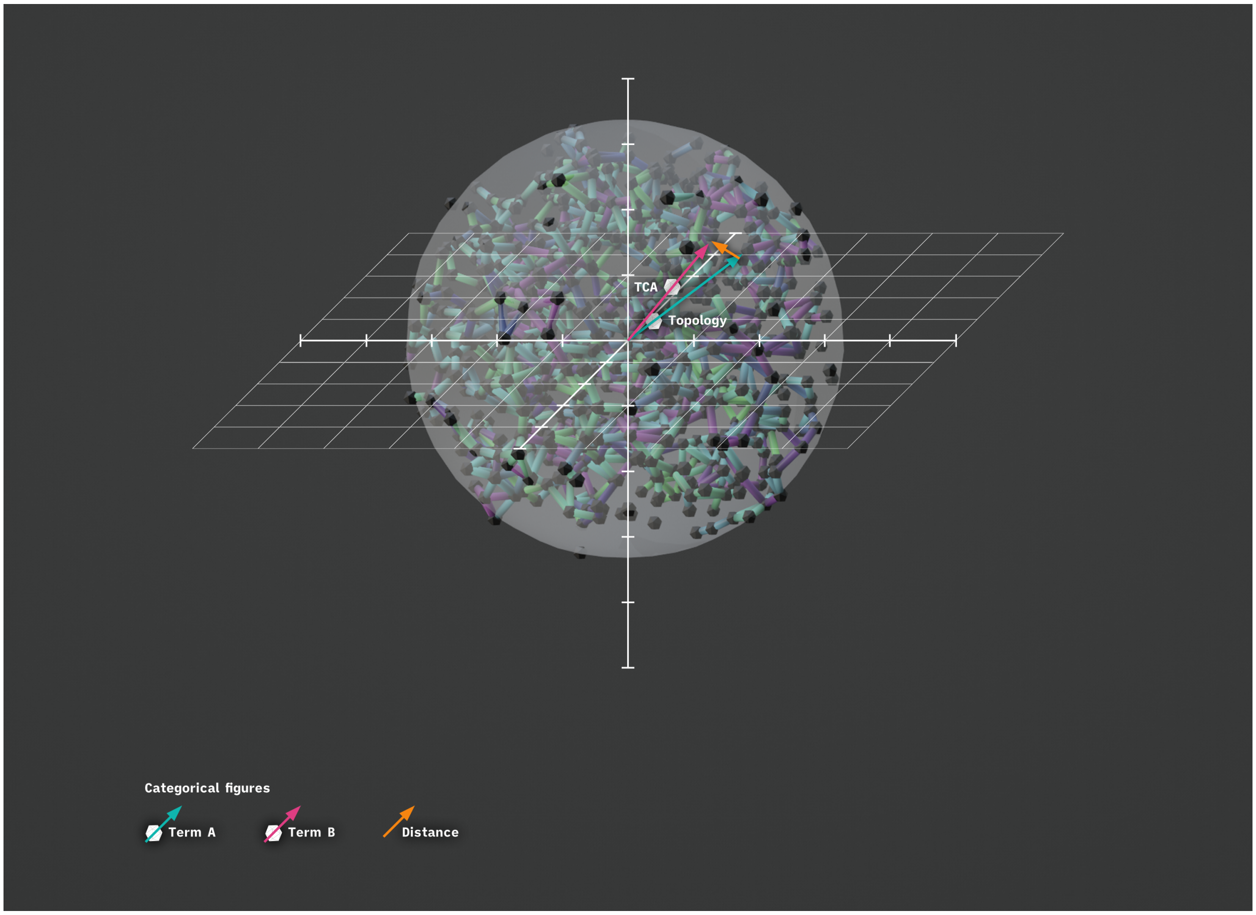

Figure 5.26: Sphere Semantic Form as LLM Vector Embeddings.

Although LLMs can rely on graphs of text, such as vector embeddings, they are not intended as information visualization. For a model to be usable as AI, it seems to requires a high-dimensionality that embed thousands of dimensions. In this sense LLM vector graphs are beyond visuospatial representation. They cannot be seen or captured spatially, at least not without compromising the semantic value of its dimensional interrelationships by using dimensionality reduction.

I turn here to Grant Sanderon's illustrations of vector space, which show how LLMs organize ideas as radii around a central origin point (Sanderson, 2024). Vector embeddings operate as the direction of a line-or vector-in space, but individual node positions work differently. However, the specificity of a vector still allows for graphing individual coordinates, though variable, with the use of topology, which is less concerned with exact coordinates. Query Isomorphs may be compatible with the LM vector graph; for the sake of UI, Query Isomorphs may be input as individual points but searched along vector lines within an LM. In this way, the LM is an example of a Sphere Semantic Form and a prospect for using Query Isomorphs within texts or groups of texts. This treatment of LM vector graphs opens up interoperability with network graphs, and their spherical composition can be represented and leveraged as a Semantic Form.

5.3.1.4 Section conclusion

I propose that by using Systematic Combining and other forms of Systemic Design in the Design for Sustainability Transitions (DfST), Kjøde and I are engaging in a Systemic Design for Sustainability Transitions (SDfST). However, building on Pangaro, TCA Workspace is a "Conversation to Design the Designing" (Pangaro, 2011, p. 185). By proposing the design of a computational expansion of SDfST and using meta-Systematic Combining, my work is, then, a meta-design of SDfST.

As a member of the Systemic Design Association (SDA), I have witnessed the rising popularity of Systems Oriented Design and Systemic Design with the use of gigamaps (Sevaldson, 2011, 2022b). As a student at OCAD University's Digital Futures program, I have witnessed the increased use of virtual three-dimensional visualization in game design, interface design, and LMs. Spaces with a codified practice like Systems Oriented Design and Systemic Design would benefit from a self-awareness of composition forms to diversity their practitioner base. Furthermore, practitioners of three-dimensional visualizations and Systemic Design Practitioners both are poised to benefit from applying LM-assisted mathematical approaches to graph analysis like TDA and TCA if they were to use a tool like TCA Workspace.

Semantic Forms, Query Isomorphs, and TCA Workspace represent how my work is a visuospatialization of theory. Semantic Forms emerged from my survey of symbols, Query Isomorphs are a means of examining isomorphologies within the Semantic Form isomorphs, and TCA Workspace is a means to incorporate both Semantic Forms and Query Isomorphs within the larger practice of codifying three-dimensional modes of Visuospatial Knowledge Activation.

5.4 From visuospatial models to theory and method

The following contributions are ways my visuospatial models inform my theoretical and methodological proposals that build on my literature review: C3. Ontological Semantic Network Summary (OSNS), C4. Symbol-setting, C5. Terroir of Text and Graphs (TTG), and C6. TCA Researcher Grouping.

5.4.1 Contribution 3. Ontological Semantic Network Summaries

C3 *Ontological Semantic Network Summaries (OSNS)* as a means of revealing ontological relationships between ideas in a given body of research using HITL CATG, HATG, or both.

Considering the significance of the Tree of Porphyry, I propose Ontological Semantic Network Summary (OSNS) as a framework for human-in-the-loop semantic network mapping of ontologies in an LM or group of texts. Developing such summaries would assist researchers in identifying the inheritance of key ideas in the logic of a text or body of texts as a tool for its own sake, and to categorize sources in reference pools.

The operationalization of OSNS would accelerate choosing from among research resources, including the choice between groups of texts and Language Model aggregates of texts. The graphic simplicity of the Tree of Porphyry offers an entry point for more complex representations that integrate the insights of this study. For instance: dimensional addition into a three-dimensional OSNS would accommodate more nodes; quantification of nodes and vectors would indicate more or less influence of a particular idea; the analysis of degree-difference can be used among network graph vertices; Query Isomorphs using Topological Capta Analysis and small graph chunks can be used to derive more information from OSNS; Semantic Form configuration can be used to reveal semantic compositions in OSNS; TTG can be used to to examine text and its OSNS in relationship to place; Symbol-setting can articulate culturally-specific summaries of insights in conjunction with OSNS; last, OSNS can be used to reveal alignment between researchers in universities and among other research organizations.

Figure 5.27 is an example of what a simple two-dimensional Ontological Semantic Network Summary of the *Great Works of the Western World* (1952) would look like by overlaying the terms of the *Syntopicon* (Adler et al., 1952a, p. xii) onto the Tree of Porphyry (Sowa, 2000, p. 4). This example is simplified by the shared Aristotelian orientation of Adler, Sowa, and Porphyry, but a fully realized computationally-produced OSNS would produce graphs for texts from more diverse semantic fields.

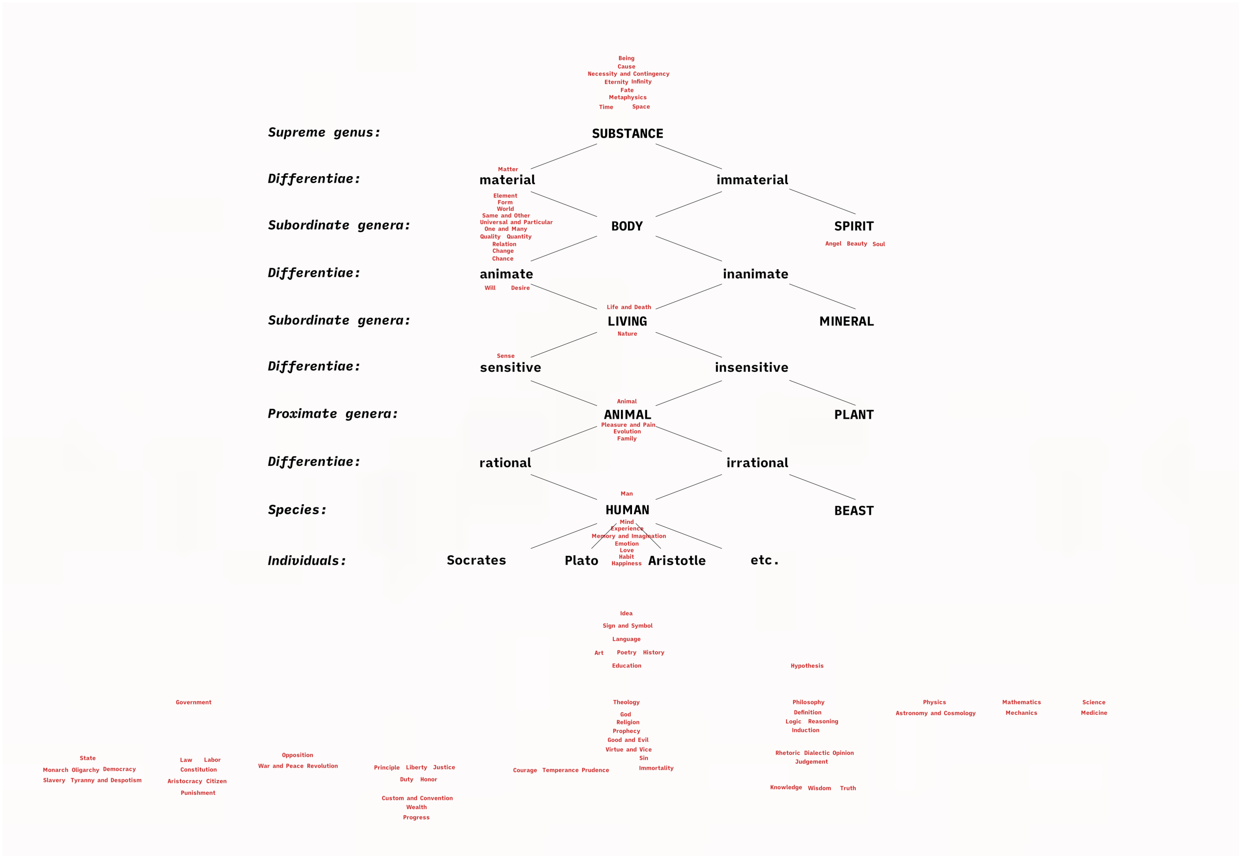

Figure 5.27: An Ontological Summary Graph of the Syntopicon's Great Ideas (Adler et al., 1952a, p. xii) onto the Tree of Porphyry (Sowa, 2000, p. 4).

5.4.2 Contribution 4. Symbol-setting

C4 *Symbol-setting*, a method for expanding the semiotic range of knowledge production using symbol co-creation in HITL CATG, HATG, or both.

The relationship between word and symbol is fluid and dynamic, so a treatment of approaches that use symbols in KA follows. Symbol-setting is my proposed framework to expand word-based definition to include visuospatial modalities of symbolic co-production.

Carl G. Liungman (or in other texts Ljungman) categorized the composition of a wide array of symbols from a variety of cultural contexts and academic disciplines in *Thought Signs* (1995)[9]. While Liungman includes symbols from outside of Europe, and similarly to Adler's work, Liungman's collection of symbols center Western intellectual tradition. I do not propose Liungman's work as a universal categorization but as a starting point for

[9] Liungman categories are more intricate, but they generally group symbols by symmetry, openness, straightness of line, and the crossing of lines. (Liungman, 1995, p. 49-93).

the practice of categorizing the composition of symbols that inform their collaborative co-production.

Symbol-setting can benefit from various practices to represent a community's perspective. Branding, which might come to mind to the reader first in a design context, lends itself to a variety of tools and research approaches for the production of symbols. For example, symbol-setting already happens to a degree in making pictographs, UX icons, and emojis. Gigamapping (Sevaldson, 2011) and Systematic Combining (Kjøde, 2024) are already a kind of symbolic co-production through the use of graphs, and are thus a form of Symbol-setting. Additionally, they lend themselves to Symbol-setting by co-creating Liungman thought signs that integrate an idea or a combination of ideas into a glyph. The production of symbolic objects physically or virtually makes Symbol-setting a visuospatial form of knowledge production, not just a visual one.

The historical significance of symbols or "thought signs" (Liungman, 1995) is vast and can take on a great deal of cultural seriousness, so I do not propose the process of symbolic co-production lightly. Symbol-setting can be hierophanic and even be part of a community's understanding of the manifestation of the divine or transcendent, introduced in my critical discussion of Eliade (Eliade, 1987, p. 11).

I believe the visuospatial co-production of the symbol is underdeveloped in the design space, systemic and otherwise. Pangaro's conversational model of co-evolutionary design for narrowing and expanding language (Pangaro, 2011, p. 185) and Equity-Centered Community Design (ECCD) "language setting" (Creative Reaction Lab, 2018, p. 8-9) can both benefit from Symbol-setting. By providing new ways to arrive at a common understanding, TCA Workspace would facilitate conversations across academic and power differences by empowering equity-oriented approaches like ECCD.

By proposing Symbol-setting, I aim to support co-creative KA that uses more interpretative facets of visuospatial epistemology in producing "thought signs" (Liungman, 1995). When practiced in TCA Workspace, Symbol-setting would take the forms and hyper-forms of multidimensional text analysis and expand the capabilities of various design practices.

5.4.3 Contribution 5. Terroir of Text and Graphs

C5 *Terroir of Text and Graphs (TTG)*, a method of HITL CATG that uses TCA to interpret and reveal semantic relationships between (a) texts and graphs, and (b) the features and systems of ecological place.

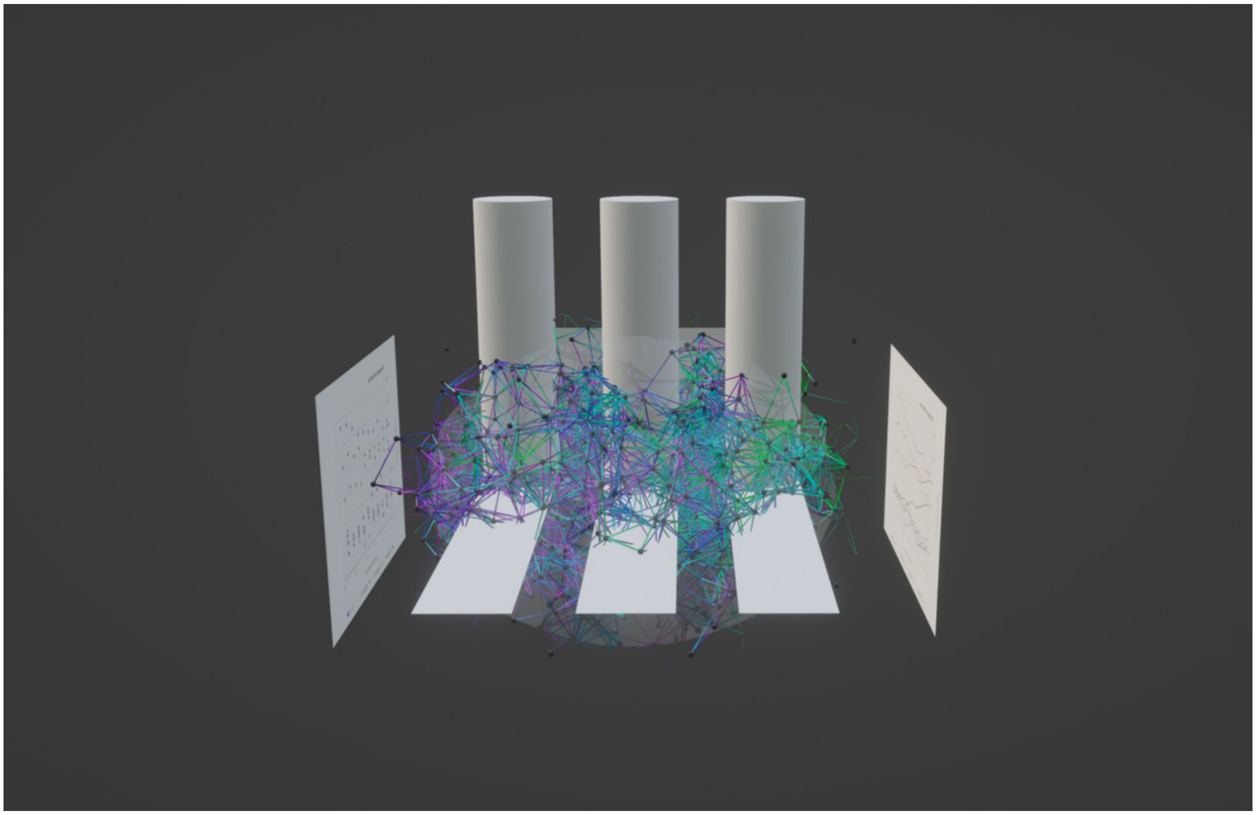

Figure 5.28: Torus vs Silos. Illustration of spatial gigamap with Horn Torus Semantic Form text network graph. This example visualizes an analysis of three siloed hyper-specialized work "communities" and three agricultural monoculture operations nearest them in the same province or municipality. This model proposes TCA to identify solutions for siloed over-work *and* extractive monoculture agriculture.

I first learned about wine from my father, who taught my brother and me to taste for region. It is from viticulture that I borrow the term *terroir*, where the term is used to relate "the sensory attributes of wine to the environmental conditions in which the grapes are grown", which involves considering interacting factors like "climate, soil, cultivar, and human practices" (Van Leeuwen and Seguin, 2006, p. 1). In *The Caribou Taste Different Now*, editors Gérin-Lajoie et al. present observations by Inuit elders of how climate change is causing such drastic changes to flora and fauna that it can be perceived by taste (Gerin-Lajoie, 2016, p. 35, 71, 72, 86, 269, 280, 281). The embodied urgency of a human need for food serves as a reminder to me about how connected and vulnerable we all are to climate change. The trans-sensorial synaesthetic quality of tasting information about global warming is the *terroir* in Terroir of Text and Graphs (TTG), which is itself a trans-modal Topological Capta Analysis of the land-thought relationship.

The relationship between place and language influences fundamental characteristics of how we think. As an example of how this plays out in the materiality of language the rounded wavy lines that characterize many scripts from Southern India are "usually explained as a result of the exigencies of writing with a stylus on palm leaves" (Salomon, 1998, p. 39). Of course, many other types of relationships exist between place and language. So, I propose TCA as a method to better understand the relationship between the ecological and conceptual as a means of improving the translation of information from one ecologically located discipline or tradition to another. In the use of interdisciplinary ecological TCA, I anticipate observing more numerous and complex forms of the Terroir of Text and Graphs.

Examining the relationship between place and idea using TCA in TTG has significant implications for understanding contemporary classifications of city, country, and wilderness. In Figure 5.28, my illustration of a spatial gigamap with a Horn Torus Semantic Form network graph, I propose that rewilding as a means of ecological diversity in food supply can consiliently inform the diversification of interdisciplinary forums in academic settings. Such a model would derive insight from solutions in sustainable climate-resilient polyculture food production methods as a means of assuaging the ecological risks of overreliance on agricultural monoculture (Altieri et al., 2015, p. 1). Applying said solutions to siloed hyper-specialized monocultural over-work could provide insight into the best types of opportunities for disciplinary inter-pollination solutions. These and other entry points to relief via systemic analysis can be expected from developing Topological Capta Analysis into a wider de-siloing practice like TTG where text and graphs are examined in relation to frameworks outside their discipline and location of origin using HITL CATG.

Developing a TCA practice to understand TTG would go on to address gaps that were not covered in this study, namely empirical gaps and spatial gaps. Empirically, we could collect data or create capta to fully understand text terroir through data model experiments. Spatially, understanding the relationship between text and place is limited compared to what can be achieved with a text terroir analysis. Expanding research on Query Isomorphs using TCA and TTG could provide new insight into interregional relationships to empower underrepresented areas. As I will discuss later, TTG can bolster new climate justice and resilience technologies if adjoined to Indigenous approaches to Artificial Intelligence.

My TTG model *Torus vs Silos* illustrates the way Topological Capta Analysis can map relationships between ecological systems and information systems using Semantic Forms, Query Isomorphs and visuospatial gigamapping. More specifically, Figure 5.28 visualizes an analysis of three siloed hyper-specialized and overworked groups of people and three extractive agricultural monoculture operations nearest them. Using TTG in this way, I would seek to reveal parallels of extractive capitalism that are at play in both ecological space and idea space to support their transition into more anthropo-symbiotic[10] ways of being and knowing.

TTG can more explicitly delineate relationships between land and language in human and non-human ways of knowing. From an Indigenous perspective, the wisdom that is carried in story and cultural practice can be articulated through the expanded field of graphs of texts, which includes Semantic Forms, Query Isomorphs and TCA Workspace in gigamaps, Systematic Combinations, topic models, and the vector graphs that form the basis of AI Large Language Models. The benefits of TTG as the integration of diverse wisdom lineages, including the distinctly anthropo-symbiotic Indigenous ways of knowing, can be simultaneously an act of ecojustice and a means of informing Sustainability Transitions. At the core of TTG is my commitment to Indigenous data sovereignty (Lewis et al., 2024, p. 12) in which "Indigenous practitioners are making the decisions that guide the development of AI themselves" (Lewis et al., 2024, p. 8). A TTG-based HITL CATG of fields like ethnobotany, ethnoecology[11], biocultural memory [12], plant-human co-evolution is foundational to the future of TCA Workspace Knowledge Activation.

5.4.3.1 Land and Indigeneity

On a personal level, this thesis research has been driven by my work to honour and reconnect with my South American Indigenous roots which were buried by colonialism and xenophobia for most of my life. In my research about the development of computational tools that support climate justice and resilience alongside Indigenous perspectives, I seek collaborators who share these goals.

I have found significant welcome and significant alignment with the Abundant Intelligences project, an international research effort spanning Canada, the United States, and New Zealand. Jason Edward Lewis, professor of computation arts at Concordia University and the University Research Chair in Computational Media and the Indigenous Future Imaginary, is co-leading the Abundant Intelligences project. Lewis et al. assert that the way AI is developed at present is limited by "Western rationalist epistemologies that exclude many ways of knowing", so, "the systematic operationalization of bias against non-white, non-male, and non-Western peoples" is also un-

[10] The term *anthropo-symbiotic* is borrowed from Fonseca et al.'s *Anthropo-symbiotic ethics: a path to the sustainability of life* which discusses ethical "theories with a more conciliatory and balanced view about the relation between the environment, humans and animals" (Fonseca et al., 2022).

[11] Turner et al. define the interrelated fields of ethnobotany and ethnoecology (Turner et al., 2020, p. 6-7).

[12] Monterrubio-Solis et al. define biocultural memory as follows: "Biocultural memory refers to the human reliance on intergenerational relationships, not only to one another but within territories, where the physicality of agroecosystems, material and symbolic meanings, as well as institutions join to constitute biocultural memory" (Monterrubio-Solís et al., 2023).

able to "adequately, robustly, and humanely conceptualize intelligence-much less attempt to replicate it." (Lewis et al., 2024, p. 1-2).

The OCAD University pod for Abundant Intelligences is called the *A Dish with One Spoon––Towards "Generous AI" Invention and Collaboration* project. I am honoured to be given the first OCAD U research assistant role. Our team will draw upon Indigenous frameworks to offer redefinitions of intelligence and develop computational practices that refashion AI from being tools of "exclusion, extraction, and eradication into engines for increasing our care of one another and our world" (Visual Analytics Lab, 2024).

The OCAD U pod co-investigators, Dr. Sara Diamond and Archer Pechawis both worked with Cree/French Métis performance artist and theorist Âhasiw Maskêgon-Iskwêw (1958-2006), creator of *isi-pîkiskwêwin-ayapihkêsîsak (Speaking the Language of Spiders)* (Maskêgon-Iskwêw, 1996). Maskêgon-Iskwêw's work calls in the animist perspective of spider as maker of networks in hyperspace. In the age of AI, I would love to know what Maskêgon-Iskwêw would say about the web that is itself animate: the decentralization of ideas' provenances by reason-automatons, the opportunities of using rhi-zombies to transubstantiate the poisons of ecocide, balanced with the risks of becoming its host/s in a tangle of disinformation, confusion, and illusion.

Maskêgon-Iskwêw cites from the general "principles for the development of Indigenous networked art production" that were "established at the *drumbeats to drumbytes* gathering [...] at The Banff Centre from March 12 to 15, 1994, coordinated by the Aboriginal Film and Video Art Alliance": "To govern ourselves means to govern our stories and our ways of telling stories" (Maskêgon-Iskwêw, 2005, p. 19). If unchecked, AI will continue to exacerbate marginalization by expanding the tools of imperialism and colonization. The stakes of critical AI research like the Abundant Intelligences project are high and growing higher.

I am cautiously optimistic about using Large Language Models in a Two-Eyed[13] AI framework that draws strengths from both Indigenous and Western ways of knowing (Bourgeois-Doyle, 2019, p. 3). To echo Bourgeois-Doyle, I am committed to a critical evaluation of TTG to maintain a Two-Eyed Seeing model for Topological Capta Analysis, with and without AI, which works for "integrated thinking, respectful multidisciplinary collaboration, and transcending combinations of interests for public good" (Bourgeois-Doyle, 2019, p. 3).

[13] Two-Eyed Seeing as a principle was "advanced by Canadian Indigenous leaders, notably Mi'kmaw Elders Albert and Murdena Marshall" (Bourgeois-Doyle, 2019, p. 3).

5.4.4 Contribution 6. TCA Researcher Grouping

C6 *TCA Researcher Grouping*, a proposal to use TCA for grouping research collaborators more effectively using HITL CATG, HATG, or both.

Developing Computational Analysis of Texts and Graphs (CATG) can improve our work relationships in research institutions. As the administrative arm of TCA Workspace, TCA Researcher Grouping could manage rich graph databases to group researchers more effectively. Key areas of application will be suggesting researchers for groupings that can expand the scope of projects to access larger grants and pairing new researchers with existing complementary teams.

Innovating information technology for KA could improve climate resilience efforts. As a means of operationalizing CATG, TCA Workspace and TCA Researcher Grouping have the potential to catalyze solutions with more effective cross-pollination of disciplines.

When applied to ecological climate resilience efforts, TCA Workspace could become a symbiotic permaculture of knowledgeways and Earth custodianship, rewilding in and beneath the computer.

6

Discussion of contributions

In this section, I consider the implications of realizing Semantic Forms and Query Isomorphs to a fuller potential. To recontextualize this discussion, I re-introduce the problem. The climate crisis continues to accelerate faster than the deployment of climate knowledge can keep up, so we find ourselves in a crisis of understanding. We must work toward new research paradigms and frameworks when facing the vast amount, interdependent nature, and exponential growth of information in the work of Sustainability Transitions Knowledge Activation. We must differentiate the various modes of KA to lead with lower complexity and ecological cost when possible, working from knowledge **surfacing**, to **synthesis**, to **translation**, to **production** only after the others have been used (KSSTP). Knowledge Production is and will continue to be necessary, but it will be limited due to its high complexity and cost.

My thesis presents methods for activating large texts in the climate crisis as a means of Knowledge Activation

(KA). KA is both subject and method in this thesis. My literature review and geometric analysis were KA to develop models, or forms, from theory. Visuospatial Systematic Combining was KA for developing theory and methodology using form. In short, this thesis engaged in the inter-informing visuospatial epistemological methods for arriving at form through meaning and for arriving at meaning through form.

6.1 C1. Semantic Forms

In RQ1.1 I asked:

What forms of spatial information visualization are there, and how can they inform the composition of network graphs?

As a result of my research, I proposed C1, Semantic Forms, a taxonomy of three-dimensional topic model compositions for Human-in-the-Loop Computational Analysis of Texts and Graphs (HITL CATG), Human Analysis of Texts and Graphs (HATG), or both.

6.1.1 Vedic visuospatial culture

My survey of symbols provided a pivotal part of my thesis in connecting two-dimensional ideograms to three-dimensional versions of themselves. This interbeing of the Sri Yantra and the Meru Chakra inspired the cone Semantic Form. The etymology of the word yantra as "machine" (Bühnemann, 2003, p. 28) is activated beyond its two-dimensionality into three-dimensional Meru Chakra-inspired (Bühnemann, 2003, p. 31) cone Semantic Form "Literary Machines" (Nelson, 1981) for "knowledge engineering" (Wielinga et al., 1992, p. 8) as a pivotal part my TCA Workspace "studio laboratory of knowledge design" (Drucker, 2014, p. 197).

While I do not invoke the associations to warfare in the etymology of the word *yantra* (Bühnemann, 2003, p. 28), I do propose that this work can facilitate genitive disagreement and anti-oppressive resistance.

6.1.2 Geometry and Topology

Semantic Forms are presented as geometric forms, but they encompass topological versatility. The ways their form can be used to interpret and reveal semantic relationships are not limited to a particular size of the data set, nor is it limited to a particular ratio of more consilient terms to less consilient terms. Therefore, their shape is a heuristic for the ways they work with semantic relationships, not a prescription. Furthermore, Semantic Forms can be nested within each other and overlap with each other, which further demonstrates the requirement for a multi-mathematical approach.

The computational operationalization of Semantic Forms will benefit from calculating their geometric topology. For example, the calculation of angles between edge vertices (Degree Difference) will inform how "similar or dissimilar neighbouring vertices are with respect to some quantity" (Farzam et al., 2020, p.2) (Global Assortativity). Homophily, which measures "the tendency to associate with like-minded or otherwise similar people" (Farzam et al., 2020, p.2), is already calculated using Degree Difference and Global Assortativity (Farzam et al., 2020, p.2).

6.1.3 Dimensional addition

Semantic Forms are derived from a Systematic Combination approach to dimensional addition of Semantic Shapes. Semantic Shapes are the two-dimensional units of network graph composition that are combined into Semantic Forms.

Ware and Mitchell report that the move from two-dimensional to three-dimensional node graphs increases "the size of the graph that can be "read"" by about one order of magnitude (Ware and Mitchell, 2008, p. 10). Tversky's investigations on the neuroscience of the visuospatial indicate that brains evolved to handle position in space before they evolved the ability to handle language. In Tversky's words, "spatial thinking is the foundation of all thought" and "the foundation for spatial thought is also the foundation for conceptual thought" (Tversky and Parrish, 2022).

Considering interfaces for the visuospatial that rely on our sense of sight, the pivotal middle area that includes human visuospatial ability and higher-dimensional graphs is the third dimension (with or without movement) since we can sense no further. LLMs embed many billions of pieces of information (Brown et al., 2020, p. 1) as tensors, or 'directions' in high-dimensional vector space (Sanderson, 2024). We rely on CATG, and hopefully, more HITL CATG, when it comes to Language Models.

Drucker's "visual forms of knowledge production" (Drucker, 2014), visual reasoning and visual argument (Tversky and Parrish, 2022), are also, then, visuospatial forms of Knowledge Activation when developed in tandem with Tversky's work and KSSTP.

6.1.4 Three-dimensional composition

Indexing forms for their affordances in interpreting and revealing semantic relationships with HATG, HITL CATG, or both is supported by their use in various research areas. Grant et al. propose that the meta-analysis literature review can be illustrated using a funnel plot (Grant and Booth, 2009, p. 94-95). Taylor's cones of plausibility even show the presence of double-cones (Taylor, 1990, p. 14) and provide the basis of Bezold and Hancock's futures cone (Bezold and Hancock, 1993, p. 73). Specifically within the area of climate, Kjøde's *Entanglement of Systemic Design and Sustainability Transitions uses Systematic Combining* uses Systematic Combinations composed with the cone (Kjøde, 2024, p. 123), sphere (Kjøde, 2024, p. 125), and cylinder (Kjøde, 2024, p. 144). Lenat et al.'s illustration of upper ontology in relation to middle ontology, which relates to various domain models, depicts a mountain range of meaning. I propose that their cone-like composition, individually and as a group, is remarkable because it captures the form of Adler's "syntopical reading" (Adler et al., 1952a, p. xi), consilience (Hepburn and Andersen, 2021; Wilson, 1999), and Peirce's abduction (Peirce, 1960b, p. 106) (Sowa, 2004, p. 20).

I have not found an explicit index of three-dimensional forms used to interpret and reveal semantic relationships. I aim for my Semantic Forms to be applied in (a) computational approaches like global topological synchronization (GTS) using filtration (Kovács et al., 2024, p. 1) (Giusti et al., 2016), bundling (Holten and Van Wijk, 2009, p. 1), weighting (Kovács et al., 2024, p. 2), and my magnetic approach to node grouping; (b) manual node placement in Systemic Design approaches like Systems Oriented Design (Sevaldson, 2022b), gigamapping (Sevaldson, 2011), Systematic Combining (Dubois and Gadde, 2002, p. 556) (Kjøde, 2024, p. 46), Boundary Critique (Midgley et al., 1998); and, (c) in some combination of both where HATG can us used independently or in tandem with HITL CATG.

6.2 C2. Query Isomorphs

In RQ1.2 I asked:

How can Computational Analysis of Texts and Graphs (CATG) identify isomorphic semantic structures within large network graphs?

As a result of my research, I proposed C2, Query Isomorphs as a means of Topological Capta Analysis (TCA) in HITL CATG using small graph chunks. To relate Query Isomorphs to C1. Semantic Forms, Semantic Forms necessarily include Query Isomorphs, but Query Isomorphs can be part of any network graph regardless of whether or not that graph is or uses a Semantic Form.

6.2.1 Topological network query graphlets

Query Isomorphs are necessarily topological in that they interpret and reveal semantic relationships across reconfigurable nested hierarchies through the scalable distances of the connections between individual nodes. These connections can form graphlets or "network subgraphs" with "a small number of nodes" (Pržulj et al., 2004, p. 5-6) in various permutations (Sarajlić et al., 2016, p. 3).

Considering the multidimensional range of TCA, I propose Query Isomorphs interpret and reveal meaning in low-dimensional formats, and as simplicial complexes, "higher-order networks that encode higher-order topology and dynamics of complex systems" (Wang et al., 2024, p. 1).

The earliest research I found that uses graph forms for database queries is the VivoMind Analogy Engine (VAE). The VAE uses Sowa's conceptual and query graphs to match labels, subgraphs and graph transformations (Sowa and Majumdar, 2003, p. 22).

The potential for Query Isomorphs in AI-powered semantic isomorphological query is demonstrated in TerminusDB's platform. Their vector search enables "efficient and accurate similarity-based querying" and "clustering algorithms to gain valuable insights from massive datasets," modeling data "in a more semantically meaningful manner, enabling a deeper understanding of the connections between different entities" (TerminusDB, 2023).

These graphlets can be imbued with entity-relationship information, including directed vectors in keeping with Chen's ER diagram notation (Chen, 1976; Rodina, 2024). These query graphs can reveal information from larger networks (Sowa, 1984, p. 313). Graphlets can be interpreted and revealed in large networks across dimensions using TDA (Aktas et al., 2019, p. 1), and TCA by extension. Furthermore, Query Isomorphs will benefit from development using geometric topology approaches like Degree Difference (Farzam et al., 2020).

My gap analysis of my literature review identifies aspects present in one area of literature but absent in another. I propose joining the various qualities of ER, query graphs, visuospatial forms of knowledge production, and TCA into Query Isomorphs as visuospatial directed query graphlets that can be used for queries in HITL CATG.

6.2.2 Weighting

A common problem in weighting is the loss of information through filtration used to assess hierarchical structure in weighted networks. Giusti et al. that in "In some situations, like measurements of correlation or coherence of activity, the resulting network has edges between every pair of nodes and it is common to *threshold* the network to obtain some sparser, unweighted network whose edges", revealing connections that are important to the researcher (Giusti et al., 2016, p. 11). By leveraging persistent homology (Giusti et al., 2016, p. 11) in TDA, and TCA by extension, the multi-scale topological features of data can be analyzed using Semantic Forms while preserving critical information that might be lost through conventional thresholding methods.

Furthermore, since Query Isomorphs resemble chemical molecules in various ways, point weighting can be applied to capture and reveal the semantic relationships of ideas by representing these molecules or datacules as "a union of balls in Euclidean space" (Otter et al., 2017, p. 14).

6.2.3 Interdisciplinarity powered by HITL CATG

By employing Query Isomorphs in HITL CATG KA, researchers can query for isomorphic network graphs inside larger text graphs facilitating the ability to detect and reveal analogous knowledge structures across different disciplines' datasets and captasets.

In conclusion, Query Isomorphs could offer a powerful approach for operationalizing the dimensional versatility of TCA in HITL CATG for interdisciplinary KA by finding isomorphic semantic structures within large network graphs.

6.3 C3. Ontological Semantic Network Summaries (OSNS)

In RQ1.3 I asked:

What methods can reveal the relationships between fundamental ideas in texts, graphs, or Large Language Models (LLMs)?

As a result of my research, I proposed C3, Ontological Semantic Network Summaries (OSNS) to reveal ontological relationships between ideas in a given body of research using HITL CATG, HATG, or both.

OSNS is a method to interpret and reveal ontological relationships using semantic networks in HATG, HITL

CATG, or both. OSNS, like any other network graph form, can be integrated with Semantic Form and Query Isomorph approaches for KA.

Many refer to philosophers like Aristotle and Porphyry as guides for how we approach ontology or the "systematic account of Existence" (Gruber, 1995, p. 1) Ontology is fundamental in computer science, in which "what "exists" is that which can be represented" (Gruber, 1995, p. 1). As a definition that can encompass philosophy and computer science, ontology can be considered "an explicit specification of a conceptualization" (Gruber, 1995, p. 1).

Naming and relating what we consider to exist is elusive yet fundamental to this thesis's various modes of reasoning, like Adler's "syntopical reading" (Adler et al., 1952a, p. xi), consilience (Hepburn and Andersen, 2021; Wilson, 1999), and Peirce's abduction (Peirce, 1960b, p. 106) (Sowa, 2004, p. 20). Using OSNS, researchers can examine syntopical, consilient, or abductive terms to each other in an overview of how key terms relate, including the inheritance of key properties like in the Tree of Porphyry. In this way, OSNS can serve to categorize and compare large texts, groups of texts, or LMs.

6.3.1 AI

OSNS could be used to bring people more in the loop during language model training, and to compare language models after they are trained. OSNS would allow researchers to assess the depth and breadth of an LM's proficiencies, gaps, and biases in a given language domain.

In short, I propose OSNS as a tool to interpret and reveal relationships between fundamental ideas in texts, graphs, and LMs to navigate constellations of information more effectively in KA.

6.4 C4. Symbol-setting

In RQ1.4 I asked:

Given the semantic versatility of symbols, how can a practice of collaborative symbol-making support Knowledge Production?

As a result of my research, I proposed C4, Symbol-setting, a method for expanding the semiotic range of Knowledge Production using symbol co-creation in HITL CATG, HATG, or both.

As I have discussed, Knowledge Activation happens in multiple modes, with and without written words. Visuospatial forms of Knowledge Activation can use the wide range of meaning-making methods available to us to interpret and reveal meaning which written words may not be able to capture effectively.

I expand Pangaro's "Conversation to Agree on Goals" (Pangaro, 2011, p. 185) and the Equity-Centred Community Design framework's "language setting" (Creative Reaction Lab, 2018, p. 8-9) with my proposal to use the wider variety of tools available in visuospatial epistemology, or Symbol-setting.

Similarly to Sevaldson's perspective on Systems Oriented Design, I propose that Symbol-setting is an open-source process design "methodology without a method" that does not prescribe specific techniques. (Sevaldson, 2022b, p. 30).

Nonetheless, I do offer a starting point and suggest that practitioners inform themselves of symbol composition (Liungman, 1995), information visualization composition (Vital, 2018; Ribecca, 2017), isomorphology (Anderson-Tempini, 2018), Systems Oriented Design (Sevaldson, 2022b, p. 343), gigamapping (Sevaldson, 2011) (Sevaldson, 2022b, p. 26), synthesis mapping (Jones and Bowes, 2016) (Jones et al., 2017, p. 129), Systematic Combining (Dubois and Gadde, 2002, p. 554) (Kjøde, 2024), Boundary Critique (Midgley et al., 1998), Semantic Forms, Query Isomorphs, OSNS, and the various contributions of my thesis.

Regarding the larger practices of three-dimensional analysis of words, Liungman's *Thought Signs* (Liungman, 1995) would make an excellent case study for the virtual visuospatial analysis of symbols. *Thought Signs* is particularly ready for such an analysis because of its interrelated classification criteria. Another starting point for such an analysis is the MNIST handwritten digits database (LeCun et al., 2012) and its use in the Embedding Projector on TensorFlow (Smilkov et al., 2016). Plotting the relationships of symbols into three-dimensional space would allow a researcher to discover new semantic patterns and categorizations within and between symbols and their compositions.

In short, Symbol-setting serves as a method for the semiotic expansion of the linguistics of Knowledge Activation and co-production. Symbol-setting can foster interdisciplinary understanding while emphasizing inclusion and community.

6.5 C5. Terroir of Text and Graphs (TTG)

In RQ1.5 I asked:

How can CATG reveal relationships between place and text?

As a result of my research, I proposed C5, Terroir of Text and Graphs (TTG), a method of HITL CATG that uses TCA to interpret and reveal semantic relationships between (a) texts and graphs, and (b) the features and systems of ecological place.

Beyond the shift to Small Language Models which use fewer resources to function, Language Models can be improved by being informed of ecological dynamics of the place where they are being used. To foster more sustainable ecological development that works more deeply across many ways of knowing, AI-assisted KSSTP of TTG must honour and be informed by Indigenous wisdom and its keepers whenever possible.

TTG aims to support experts in ecologically sustainable ways of living whose insights are vital to Sustainability Transitions and climate resilience. Centering Indigenous wisdom, TTG can be used for Knowledge Activation (Knowledge Surfacing, Synthesis, Translation, and Production) of resource use. Indigenous researchers from the Abundant Intelligences research network have enthusiastically received my research on computational methods for examining the relationship between place and ancestral wisdom.

TTG is compatible with Semantic Forms, Query Isomorphs, and OSNS as graph-based TCA. Furthermore, as a form of Symbol-setting, TTG interprets and reveals the symbolic and material relationships that inform how multiple communities can come to understand their shared and related environments. In this way, TTG reveals the connection of collective knowledge systems to place to symbol, story, and material culture. HITL CATG, in the mode of TTG, can provide insight into the tangible and intangible elements of culture interpreted as words and diagrams.

6.6 C6. TCA Researcher Grouping

In RQ1.6 I asked:

What strategies can improve university knowledge management to accelerate research?

As a result of my research, I proposed C6, TCA Researcher Grouping, a proposal to use TCA for grouping research collaborators more effectively using HITL CATG, HATG, or both.

Among the various ways researchers and institutions can help or hinder Sustainability Transitions Knowledge Activation is how we get to know each other and collaborate. Current bibliographic platforms seem to be limited to computational classification using metadata categories only, which limits their ability to group authors and works together based on research content. In my tests, I found that even the platforms capable of revealing terms shared by researchers, like the AI-assisted InfraNodus, were not equipped to analyze large numbers of authors and their respective bodies of work.

TCA of research databases has the potential to reveal commonalities between authors that can catalyze new types of research, simultaneously increasing the impact of Knowledge Activation and the quality of the researcher experience. The versatile methods I propose in this thesis work to connect research across conventionally siloed disciplines by supporting the people who make Knowledge Activation happen.

Current PKM tools like Obsidian are effective for managing an individual's information. Still, my testing has shown that they struggle to scale to the demands of larger datasets and complex repositories. TCA Researcher Grouping would build on the hyperlinked format of PKM but would necessarily have to operate with the versatility of scale and graph dimension, hence my urgency in proposing the application of a Topological Capta Analysis.

In the context of the climate crisis, it is fundamental that we develop information technology that involves all the various aspects of KSSTP (KA) to better support our researchers and better leverage our research resources. TCA Researcher Grouping seeks to build on the capabilities of existing PKM tools like Obsidian and topic modeling tools like InfraNodus to improve upon them. Developing knowledge management tools for institutions like TCA Researcher Grouping is a critical step towards increasing the effectiveness of interdisciplinary Sustainability Transitions Knowledge Activation.

6.7 C7. TCA Workspace

In RQ1.7 I asked:

What sort of knowledge work software would I want to build to incorporate my various findings and use spatial information visualization to identify isomorphic semantic structures, reveal the relationships between fundamental ideas, build on collaborative symbol-making, reveal relationships between place and text, and improve university knowledge management?

As a result of my research, I proposed C7, TCA Workspace, a proposal for a collaborative HITL CATG + HATG platform to:

(a) House all my thesis contributions (*Semantic Forms*, *Query Isomorphs*, *OSNS*, *Symbol-setting*, *TTG*, and *TCA Researcher Grouping*).

(b) Facilitate their combined use with Systemic Design methods for visuospatial reasoning encountered through my literature review, such as gigamapping (Sevaldson, 2011), (Sevaldson, 2022b, p. 26) and Systematic Combining (Dubois and Gadde, 2002, p. 554), (Kjøde, 2024).

TCA Workspace is my proposed starting point for a shared effort between Systemic Design methods and topic modeling by using Semantic Forms, Query Isomorphs, and Topological Capta Analysis.

6.7.1 Design and philosophy

I propose TCA Workspace as a humanistic and post-structuralist interface, emphasizing the interpretative nature of language, information, and knowledge in KA. Inspired by thinkers such as Eagleton, Barthes, Drucker, and Thích Nhất Hạnh, TCA Workspace works with text and graphs by multidimensional means to reveal and interpret meaning.

TCA Workspace works within an ontological ethos that aims to engineer and implement a "diagrammatic and constellationary rhetoric" within an "infinitely extensible field" of new legibility conventions (Drucker, 2014, p. 197). It strives to move beyond disciplines that are "antithetical to interpretation", focusing instead on revealing the "constructedness of knowledge" (Drucker, 2014, p. 178).

TCA Workspace seeks to increase human agency over climate complexity by developing cybernetic methods that better leverage Tversky's neuroscience of the visuospatial (Tversky and Parrish, 2022) and Drucker's interpretation of humanistic information interfaces. By using "techniques of semantic web, topic maps, network diagrams, and other computational means", TCA Workspace seeks to 'spatialize' arguments and "relations among units of thought" for reconfiguration of their "constellationary form" (Drucker, 2014, p. 158).

6.7.2 Integration of theoretical perspectives

By proposing the development of TCA Workspace I aim to develop methods that further embrace fluid ontologies and diverse classifications, affording a new and richer way of representing knowledge structures that reveal rather than conceal their "constructedness" (Drucker, 2014, p. 178). Barthe writes that "The text is a tissue of quotations drawn from the innumerable centres of culture" (Barthes, 1977, p. 146). TCA Workspace de-emphasizes monolithic definition to visuospatialize how ideas exhibit the interpenetrating unity-and-diversity of interbeing (Nhất Hạnh, 2008, p. 80).

6.7.3 TCA Workspace as a tool for addressing climate complexity

Sustainability Transition is among the most significant challenges of our time, if not the greatest. Any work in any field is contextualized by or oriented towards improving or worsening it. Furthermore, a choice not to address ST is a choice in itself. To echo Finkelstein and Gran Fury's warning against complacency, "Silence = Death" (Finkelstein, 2018).

The rapidly growing amount of information in the many disparate fields of ST (Grin et al., 2011) makes developing research platforms like TCA Workspace all the more urgent as a means of managing information overload. I aim for TCA Workspace to function as as a "studio laboratory of knowledge design" (Drucker, 2014, p. 197) that advances the collective understanding necessary for mitigating the climate crisis using the various modes of KA.

6.7.4 Humanist post-structuralist design

Eagleton's description of text can be read as a vivid characterization of Query Isomorphs, Semantic Forms, and TCA Workspace: "The 'writable' text, usually a modernist one, has no determinate meaning, no settled signifieds, but is plural and diffuse, an inexhaustible tissue or galaxy of signifiers, a seamless weave of codes and fragments of codes, through which the critic may cut his own errant path" (Eagleton, 2006, p. 119). Similarly, Barthes addresses decentralization and dimensionality: "We know now that a text is not a line of words releasing a single 'theological' meaning (the 'message' of the AuthorGod) but a multi-dimensional space in which a variety of writings, none of them original, blend and clash. The text is a tissue of quotations drawn from the innumerable centres of culture" (Barthes, 1977, p. 146).

As a critical design for interpretative and humanistic interfaces, TCA Workspace facilitates interpretation by embracing "inconsistency among types of knowledge representation, classification, fluid ontologies, and navigation" (Drucker, 2014, p. 178). TCA Workspace represents an adaptive transformation of scholarly tools that exemplify a more dynamic, relational, and interpretative approach to humanistic information design.

To summarize TCA Workspace by turning towards language more explicitly about interface, I recall when Johanna Drucker mused the following:

"Are we merely part of an emerging constellation of potentialities for realization of aspects of knowledge design and interpretative acts that are closer to our once-sensible reading of natural and cultural landscapes? Perhaps we are reawakening habits of associative and spatialized knowledge we once read and through which we knew ourselves. We may yet awaken the cognitive potential of our interpretative condition of being, as constructs that express themselves in forms, contingently, only to be remade again, across the distributed condition of knowing" (Drucker, 2014, p. 192).

6.7.5 The future of TCA Workspace

I aim for TCA Workspace to build beyond existing information technology to further empower scholarly activity as relational and dynamic, emphasizing process over product. My goals in proposing TCA Workspace are not just to bring about a static tool but to adapt in tandem with emerging methods in digital humanities in a more expansive practice of making Visuospatial Knowledge Activation interfaces for complexity management.

Saint-Martin and Drucker mused of a future in which researchers contribute to a new language for interpreting graphical relationships in digital spaces (Saint-Martin, 1990, p. 225) (Drucker, 2014, p. 54). I propose the development of TCA Workspace to build that same future, not just for its own sake but in defence of the ecologically vulnerable.

Drucker can be read as capturing the epistemological impetus of TCA Workspace when she urged: "We have to find graphical conventions to show uncertainty and ambiguity in digital models, not just because these are conditions of knowledge production in our disciplines, but because the very model of knowledge itself that gets embodied in the process has values whose cultural authority matters very much" (Drucker, 2014, p. 190-191).

I propose that Saint-Martin's "semantic system of topological semiotics" (Saint-Martin, 1990, p. 225) and Drucker's "constellationary field" (Drucker, 2014, p. 196) capture the 'space' in TCA Workspace. My proposed platform, TCA Workspace, facilitates a multi-mathematical framework for the Computational Analysis of Texts and Graphs (CATG). In it, Semantic Form "thought forms" (Drucker, 2014, p. 196) would be interpreted and revealed with Query Isomorphs and TCA. This approach would allow us to study the ways thought and form co-inform each other as "content" and "configuration of knowledge" (Drucker, 2014, p. 196). The "organizing orders of graphical expression that take on their own legibility" (Drucker, 2014, p. 196) would be visuospatialized as the semantic relationships revealed with HATG and HITL CATG. More generally, TCA Workspace integrates semantic topological semiotics and constellationary fields to analyze texts and graphs for more efficiently revealing co-informing interdisciplinary knowledge structures.

6.7.6 Living networks of decentralized knowing

Current tools like keyword searches and statistical digital scholarship methods are limited in their effectiveness for navigating hyperspecialized jargon-laden texts and graphs across diverse disciplines. They often fail to reveal latent, transdisciplinary, and interdisciplinary insights.

With TCA Workspace, I aim to bridge innovation paths across disciplines, enabling specialists to identify novel approaches they might otherwise overlook. Novel approaches are especially critical now, when we may already possess life-saving Sustainability Transition insight. Yet, these insights may lay buried in our embarrassment of informational riches, concealed by context, form, or even intention. My aim is for researchers to use TCA Workspace as a cybernetic mycelium that reconstitutes the matter left behind after the "death" of an idea to activate words and graphs "across the distributed condition of knowing" (Drucker, 2014, p. 192).

We must examine the "detritus" of Knowledge Production to solve complex challenges and understand what is valuable to create insights. TCA Workspace can catalyze new forms of knowledge resurfacing, synthesis, translation, and production (as necessary) to reactivate the dormant ideas in our web of semantic interpretation into living networks of decentralized STKA.

6.7.7 Addressing information overload through interdisciplinary collaboration

In this age of massive data, we need new tools to facilitate functional interdisciplinary collaborations. We must develop more intuitive KA interfaces with wide semantic versatility to work simultaneously with multiple discipline-based approaches. By developing a shared terminology with methods like abductive and syntopically consilient language-setting, TCA Workspace would amplify the impact of knowledge in siloed academic disciplines.

Furthermore, using AI has the potential to reduce the cost of Knowledge Production by Surfacing, Synthesizing, and Translating knowledge that is already contained in texts, marginalia, and commentaries.

6.7.8 Humanistic design elements of TCA Workspace

TCA Workspace and other forms of computational text analysis exist in the legacy of Vannevar Bush's memex (Bush, 1945), Ted Nelson's hypertext (Nelson, 1981), and Tim Berners-Lee's World-Wide Web, among many others. By proposing TCA Workspace I seek to build on these foundational technologies as part of what Drucker refers to as the "incunabula"—or cradle— of humanistic information design (Drucker, 2014, p. 176).

To comment on the current state of information software since Drucker's *Graphesis* (2014), bibliometric platforms like Obsidian and Litmaps are among the emerging "new conventions that do not rely on book structures" (Drucker, 2014, p. 176) and leverage "informational derivatives of data mining, analytics, visualization, and display" to represent networked relationships of academic dialogue, as Drucker describes (Drucker, 2014, p. 176). However, TCA Workspace would move a step further toward "the creation of an interface that is meant to expose and support the activity of interpretation, rather than to display finished forms" (Drucker, 2014, p. 179).

6.7.9 Conclusion to the TCA Workspace discussion

TCA Workspace is an approach to bibliometric analysis that aligns with Drucker's vision of humanistic information design, focusing on dynamic, relational scholarly activity and interpretative processes. I believe current open-source PKM hyperlinked writing platforms like Obsidian are most of the way to Drucker's "future book", which will "call to the vast repositories of knowledge, images, interpretation, and interactive platforms." (Drucker, 2014, p. 175). Books, PKM or otherwise, will continue to be "an interface, a richly networked portal, organized along lines of inquiry in which primary source materials, secondary interpretations, witnesses and evidence, are all available, incorporated, [and] made accessible for use" (Drucker, 2014, p. 175). Current PKM "books of the future" can be especially productive when using Luhmann's Zettelkasten method (Luhmann, 1981; Cevolini, 2016; Ahrens, 2017)[1] in conjunction with reference managers like Zotero.

By proposing TCA Workspace I aim to push "the "book" of the future" further forward using Topological Capta Analysis of texts and graphs. Developing these and other methods of hyperlinked information decentralization can help all researchers access perspectives analogous to Hegel's, extolled by Derrida as "the last philosopher of the book, and the first thinker of writing" (Derrida, 1997, p. 26). My proposal for TCA Workspace is about developing interfaces that shift emphasis from the book toward the wider decentralized rhizome (Deleuze and Guattari, 2007)[2] of interconnected writing and graphing. Ultimately, by proposing TCA Workspace, I aim to facilitate more agency over climate complexity through interfaces that manage more dynamic visuospatialized relationships between capta.

[1] For the list of tools I used in my knowledge management system, including its Zettelkasten tools like Obsidian, see Appendix section A.18.

[2] Characteristics of the rhizome are articulated in Deleuze and Guattari's *A thousand plateaus* "A rhizome has no beginning or end; it is always in the middle, between things, interbeing, *intermezzo*. The tree is filiation, but the rhizome is alliance, uniquely alliance" (Deleuze and Guattari, 2007, p. 25).

7

Conclusion

My thesis is a work of anticipatory design that sought to develop visuospatial, topological, computational, and Systemic Design approaches to Sustainability Transitions and interdisciplinary research as a whole.

The sprawling scope of this cybernetic Knowledge Activation rhizome may seem to point away from my relational embodiment. However, my work towards synthesizing across disciplines parallels an urgency in my life to connect with the *buried* histories of my family lineages, so many of which were withheld from me by the violence of armed conflict and oppression. Similarly to my personal mission of revealing inroads for honouring my physical and intellectual ancestors, I hope that the practice of developing Graphical User Interface design for Topological Capta Analysis helps the reader reveal co-benefits between their own intellectual and social lineages.

To integrate various disciplinary perspectives, I set an expansive semantic container for more fulsome representations of complex ideas. Horn Torus Semantic Form Isomorphs were a wondrous, simultaneously divergent and convergent blossoming of ideas at the core of my investigation, but I have the sense that they are only the beginning. Beyond TCA workspace and any individual Semantic Forms, I pursue to expand my practice of identifying, categorizing, and applying Information Visuospatialization Compositions. This practice is the root and basis of my proposed methods for Surfacing, Synthesizing, Translating, and Producing Knowledge with HATG, HITL CATG, or both.

I draw inspiration from the mycelium as a living teaching of transmutation and hope my cybernetic rhizome of isomorphic interbeing/s helps radically transmute our sustainability solutions frameworks as much as it helps us with unlearning unhelpful axiological paradigms.

7.1 Call to action: our collective future work

In the face of the accelerating climate crisis, our ability to harness and activate vast bodies of knowledge to bridge disciplinary gaps has never been more critical. Drawing inspiration from the Horn Torus Semantic Form—a form symbolizing continuous cycles and interconnectedness—we must ask ourselves, what is the re-origin point that will mobilize us in the face of climate catastrophe?

There is a more fundamental driver underlying tools and methodologies: Trust. Abbott et al. emphasize that among our most pressing needs, we "desperately need transparency and shared sacrifice to reinforce trust and solidarity" (Abbott et al., 2023, p. 24). Similarly, Terry Tempest Williams entreats that to "bear witness to this burning world" we must "trust one another not to look away" (Williams, 2024, 47:00).

Ever so delicate and ever so vital, trust becomes our starting point, endpoint, and the re-activating catalyst that propels us forward. We must begin, fail, and begin again with trust in one another, to not look away, to confront the climate crisis directly, and to collaborate across divides. As a network, we can transform vast amounts of information into insightful action for sustainability, reconciliation, and justice.

Perhaps a gift we could receive by facing the climate hyperobject, in all its dizzying scale, in which life is so vulnerable to global warming, is to shift our emphasis to the shared aims of the unified web of life. The only way out is through[1], and together.

[1] "The only way out is through" is a paraphrase of Robert Frost (Frost, 1917, p. 66) as an homage to the bison, which can live through extreme heat (World Wildlife Fund (WWF), n.d.) and have been known to respond to blizzards by facing them (Dapcevich, 2024).

A

Appendices

A.1 Thesis website

The ongoing developments of this thesis research and a gallery of moving Semantic Form models are available on the following website:

https://orusmateo.com/thesis-what-may-be-known-2024

A.2 LaTeX manuscript repository

The following web page provides access to the LaTeX code used to compile this thesis, including all figures and formatting details:

https://github.com/orusmateo/Orus-MA-Thesis

A.3 Moving and interactive models

The following web page provides access to the moving and interactive models which I developed for my thesis.

https://orusmateo.com/moving-semantic-forms

A.4 Semantic Forms surface and volume equations

The following table shows the volume and surface equations of the Semantic Forms' core geometries.

	Volume (V)	*Surface (S)*
cone	$\pi r^2 \frac{h}{3}$	$\pi r \sqrt{r^2 + h^2}$
cylinder	$\pi r^2 h$	$2\pi r h$
sphere	$\frac{4}{3}\pi R^3$	$4\pi r^2$
horn torus	$2\pi^2 a^3$	$4\pi^2 a^2$
ring torus	$\frac{1}{4}\pi^2 (R+r)(R-r)a^*$	$\pi^2 (R+r)(R-r)$

*Pappus's centroid theorem (Weisstein, n.d.b).

A.5 Application of Sarajlić et al. configurations to three-dimensional graphlets

As part of my style guide for Query Isomorphs analysis, I propose that the Sarajlić et al. graphlet configurations (Sarajlić et al., 2016, p. 3) can be used for graph input and graph analysis.

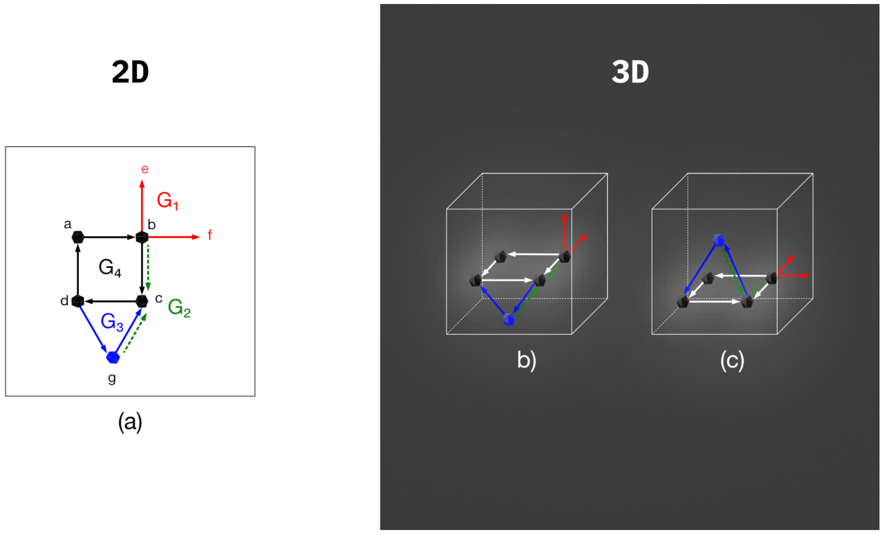

Figure A.1: Example Query Isomorph in two dimensions and three dimensions assembled from directed graphlets. (a) From Sarajlić et al. 2016's point b, "Illustration of how directed graphlets assemble together to form complex networks", from "Figure 1. Illustration of directed graphlets" (Sarajlić et al., 2016, p. 3). In keeping with Sarajlić et al., the whole network can be created by adding graphlets G4, G1, and G3, meaning that in the process, a new graphlet, G2, was created. The colours red, green, blue, and black are sourced from (Sarajlić et al., 2016, p. 3). (b) Spatial arrangement adds the semantic affordance of verticality to communicate hierarchy of the blue node. Red nodes are querying for nodes in both higher and lateral hierarchies. (c) Other arrangements can easily facilitate different relationships in the Query Isomorph. (b) and (c) The colours red, green, and blue are sourced from (Sarajlić et al., 2016, p. 3) here also, but white is used instead of black for contrast. Black nodes in this example are all placed in a lateral level of hierarchy. In a functional Query Isomorph platform, nodes could also be placed higher or lower than each other. Furthermore, the angles and directions of these graphlets are presented for simplicity of the variety they can have but do not represent the diversity of angles and forms that graphlets can be configured in as Query Isomorphs.

A.6 The Semantic Forms located in Bertin's taxonomy of network graphs

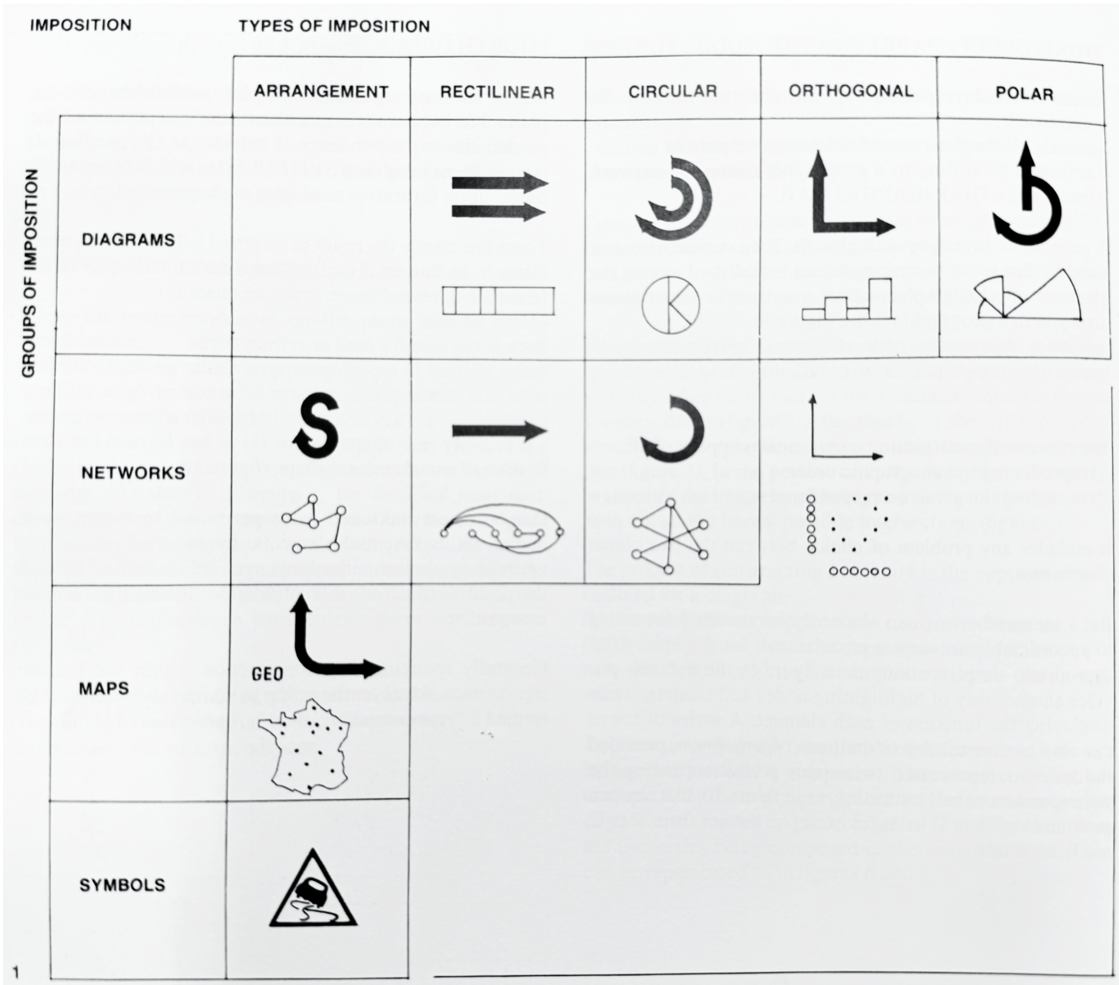

Figure A.2: Groups of imposition and types of imposition (Bertin, 2011, p. 52). From *Semiology of Graphics: Diagrams, Networks, Maps* by Jacques Bertin, translated by William J. Berg. Reprinted by permission of the University of Wisconsin Press.

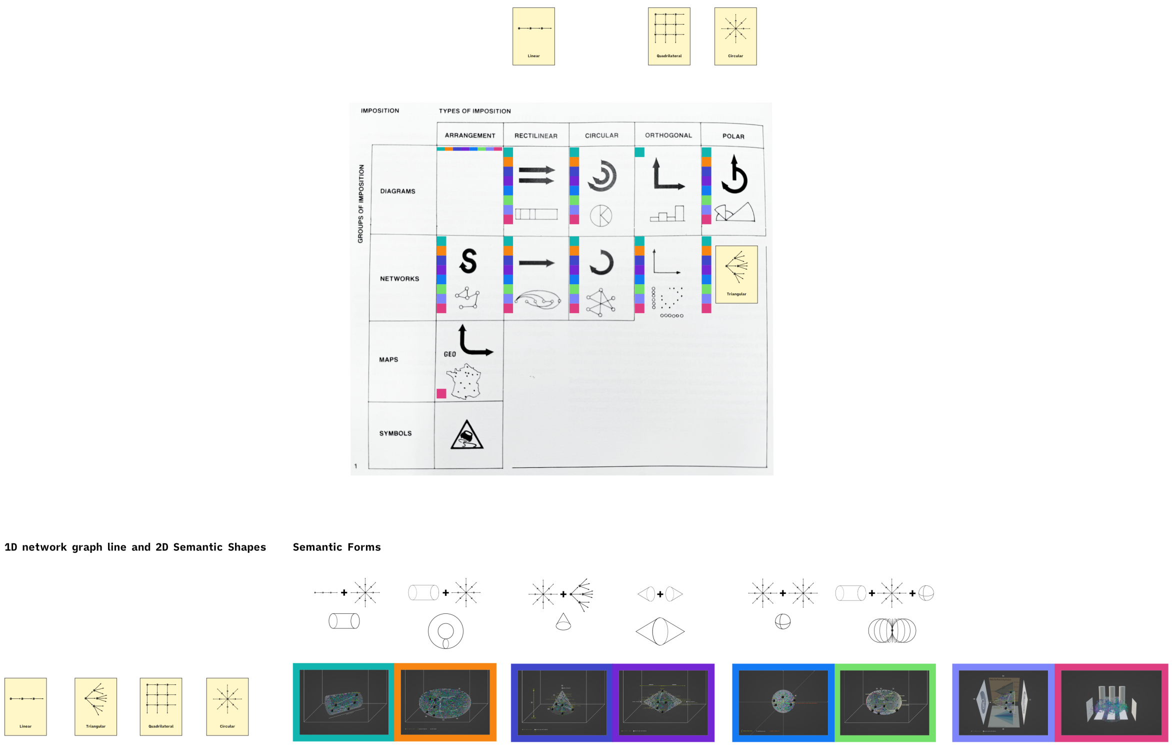

Figure A.3: Groups of imposition and types of imposition as categories for my Semantic Shapes, Semantic Forms, and three-dimensional gigamaps. My work is overlaid onto Bertin's categorization of network diagrams (Bertin, 2011, p. 52) from *Semiology of Graphics: Diagrams, Networks, Maps* by Jacques Bertin, translated by William J. Berg. Reprinted by permission of the University of Wisconsin Press.

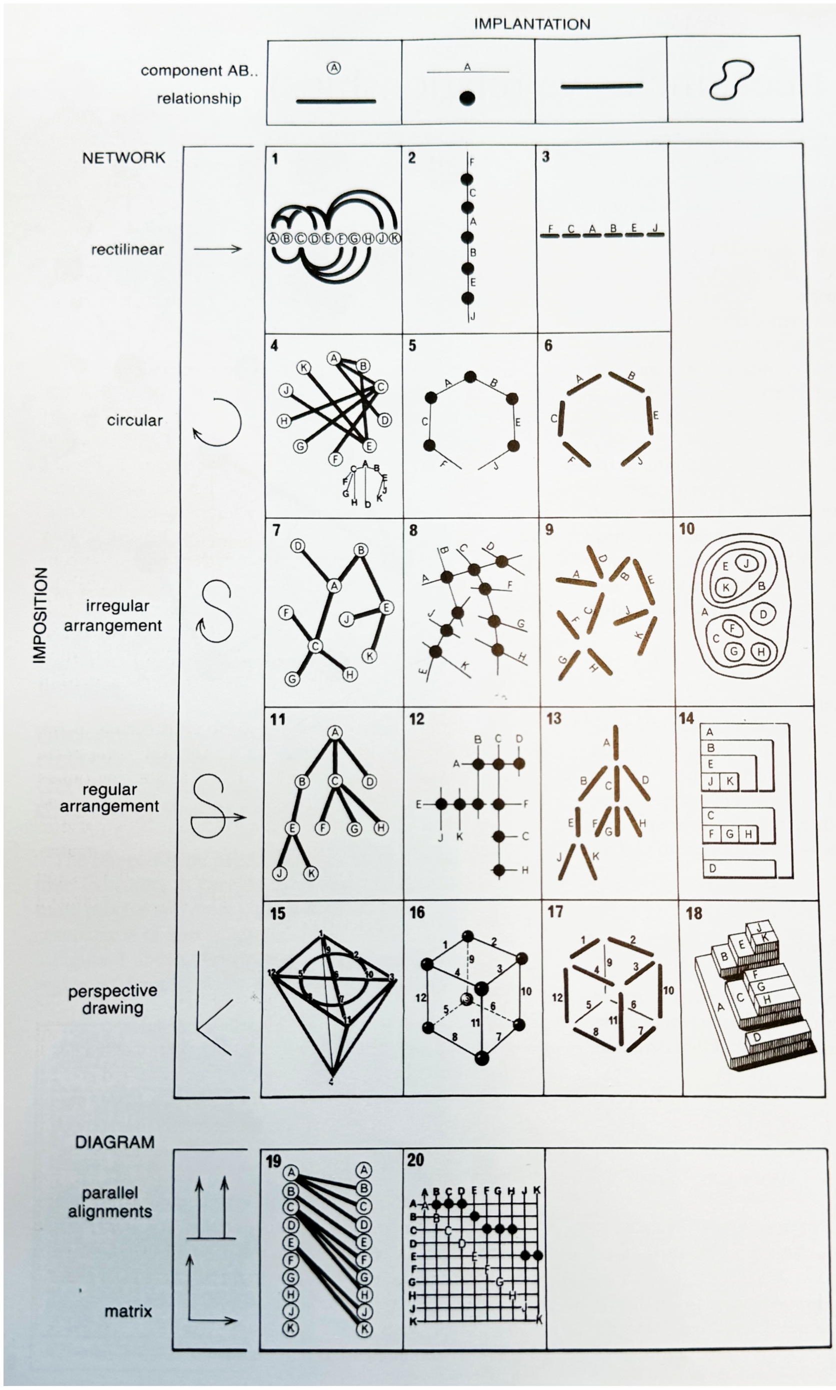

Figure A.4: Implantation and imposition of network diagrams (Bertin, 2011, p. 270)

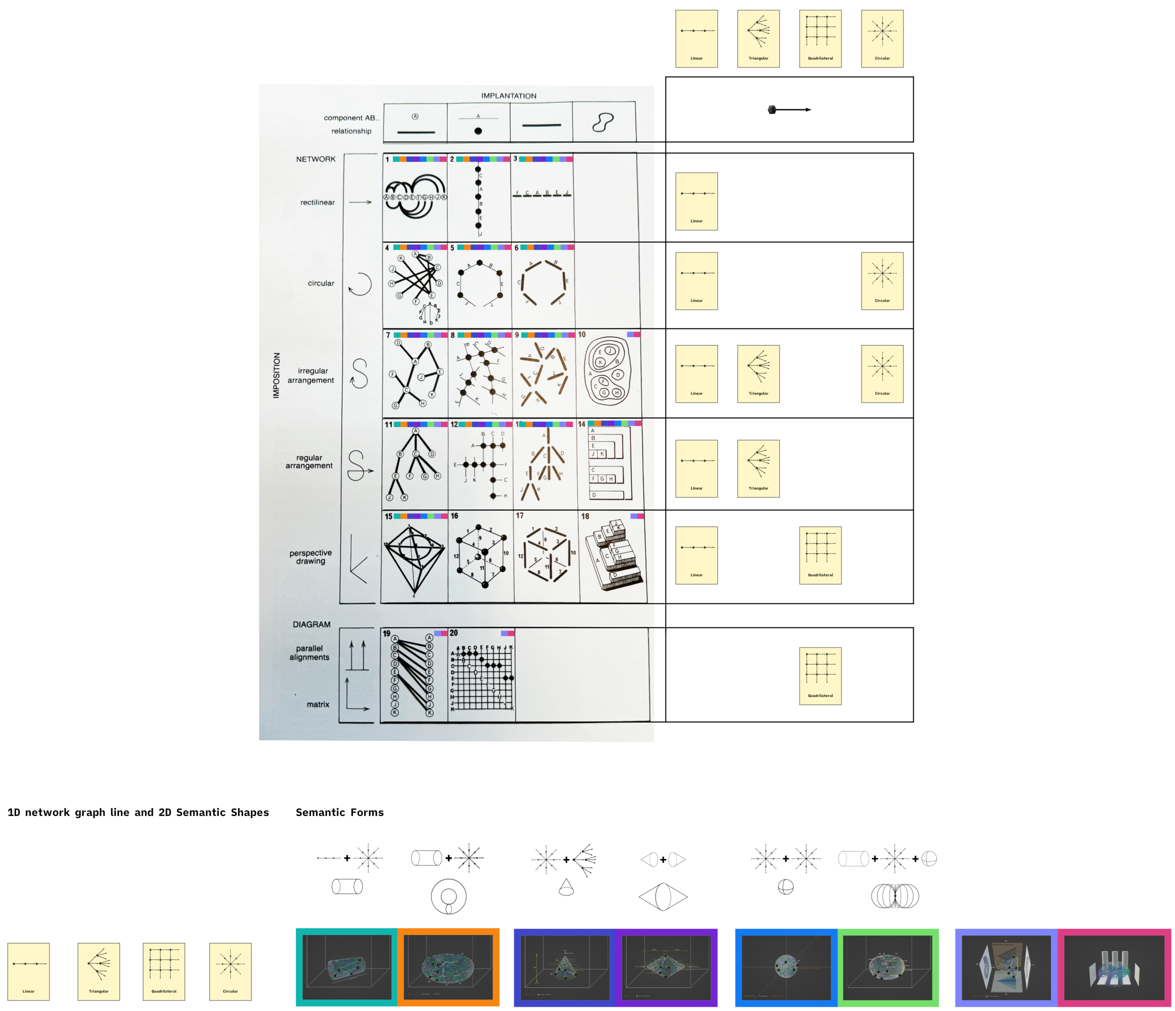

Figure A.5: Implantation and imposition of network diagrams as categories for my Semantic Shapes, Semantic Forms, and three-dimensional gigamaps. (Bertin, 2011, p. 270) My work is overlaid onto Bertin's categorization of network diagrams (Bertin, 2011, p. 270) from *Semiology of Graphics: Diagrams, Networks, Maps* by Jacques Bertin, translated by William J. Berg. Reprinted by permission of the University of Wisconsin Press. © 1983 by the Board of Regents of the University of Wisconsin System. All rights reserved.

A.7 Graphical abstract of this thesis

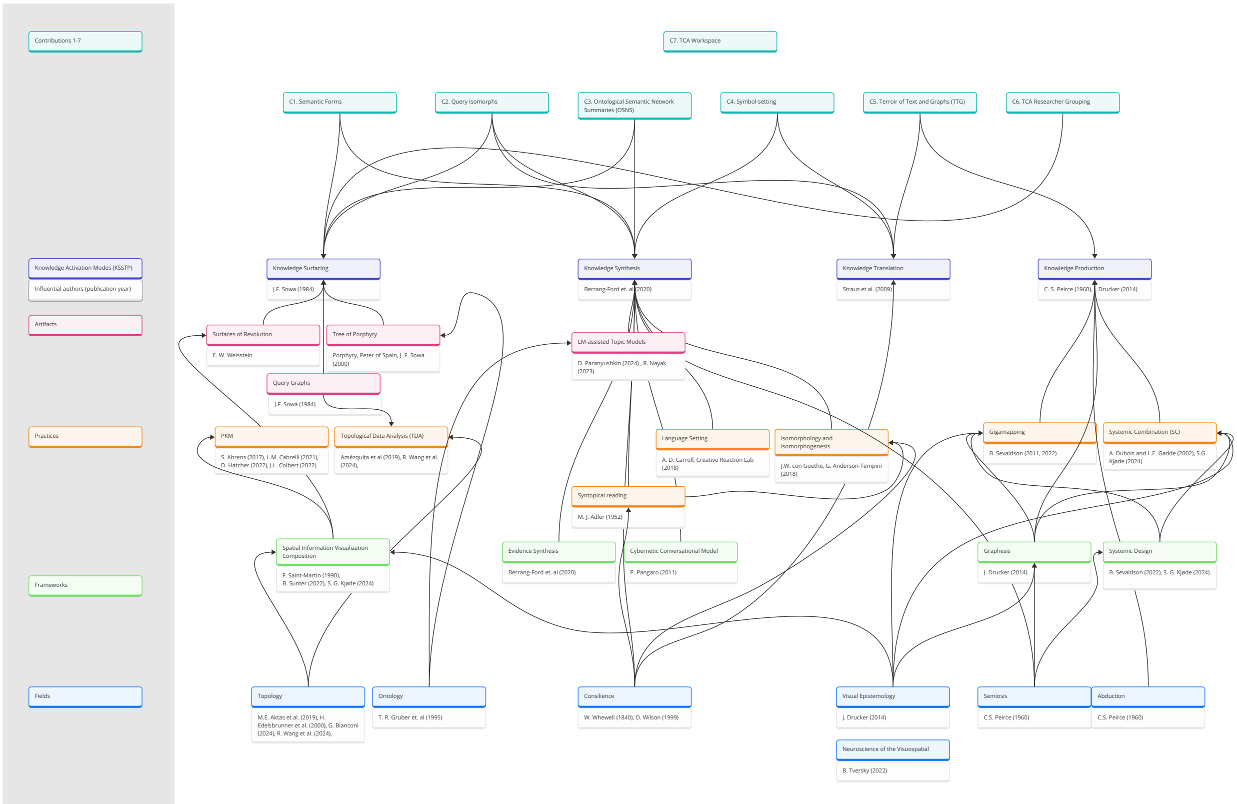

Figure A.6: Graphical abstract of this thesis

A.8 Horn of futures

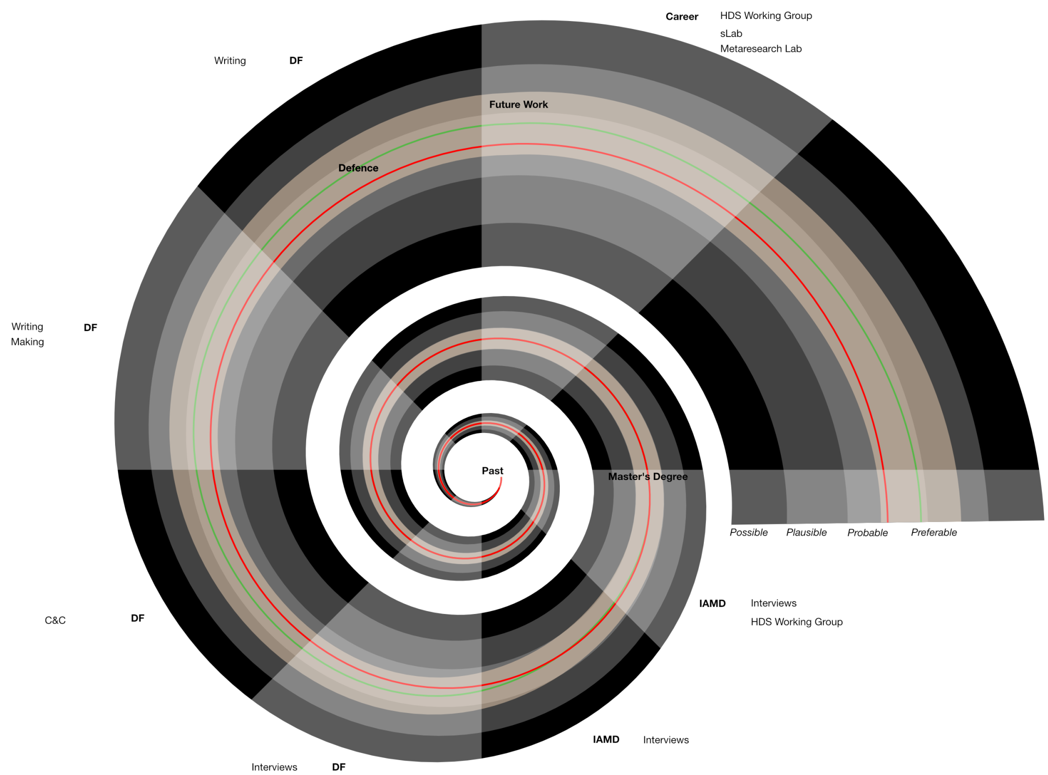

Figure A.7: Horn of Futures. This figure depicts the 2D dimensional reduction of the bottom view of a modified 3D Cone of Plausibility (Taylor, 1990, p. 14) (Bezold and Hancock, 1993, p. 73). This Cone Semantic Form is curved into a spiral similar to Figure 2.15 "Diagram of a design process with iterations" (Sevaldson, 2022b, p. 343) (Sevaldson, 2022a). The 3D version of this form twists like a ram's horn, and this thesis involves the study of the horn torus, hence the name *Horn of Futures*. To represent Possible futures, the widest spiralling area is represented with a black colour, Plausible futures in dark grey, Probable futures in light grey, and Preferable futures is shown as a beige deviation from the Probable futures. The middle of the Preferable futures range is labelled with a green through-line, and the middle of the light grey Probable range is labelled with a red through-line.

A.9 Horn Torus point cloud

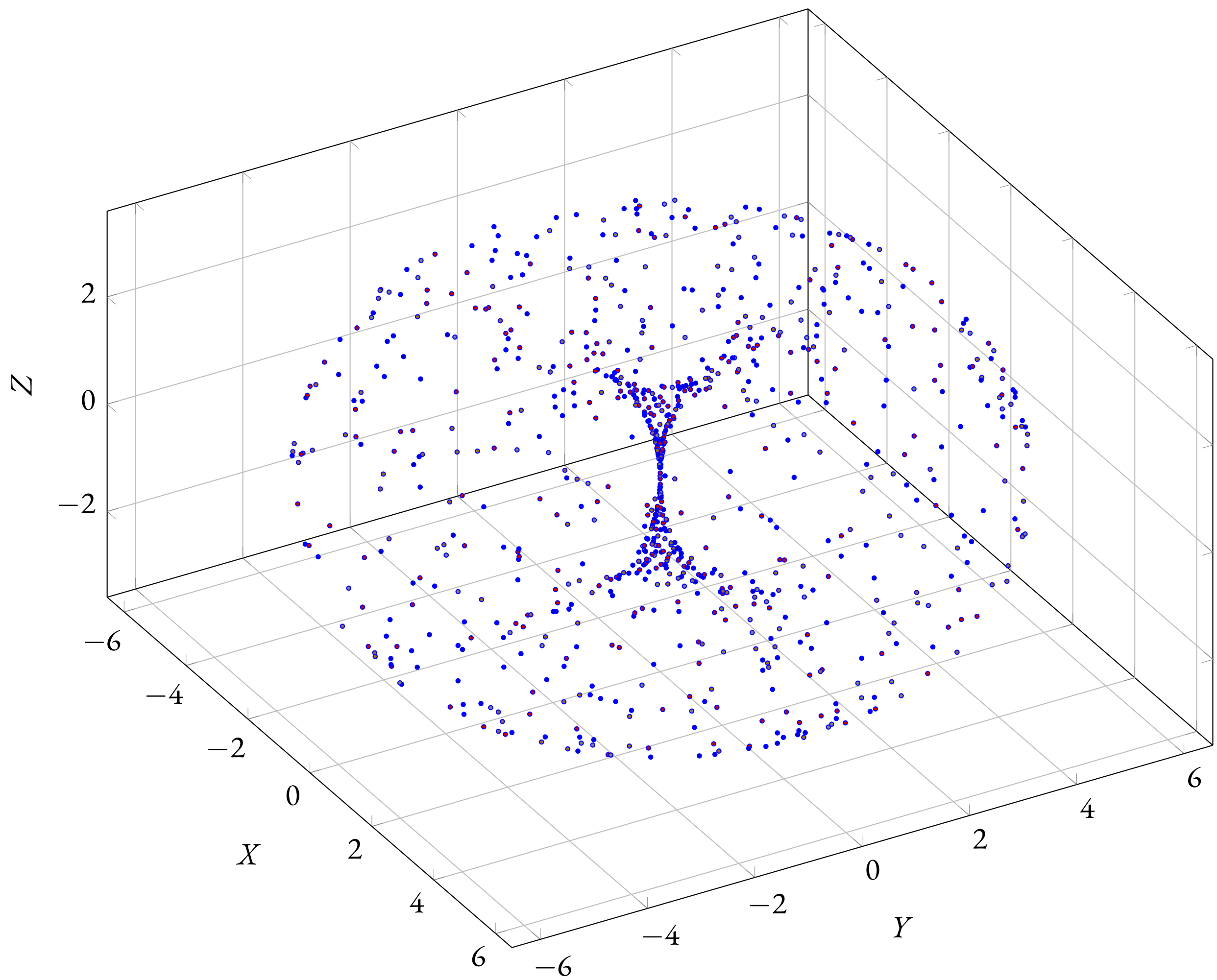

Figure A.8: Horn Torus point cloud. Coded in to render in LaTeX with the help of ChatGPT 4o.

A.10 The Data Visualisation Catalogue by Severino Ribecca

Figure A.9: The Data Visualisation Catalogue. (Ribecca, 2017). Used with permission.

A.11 Semantic Field *S*

In this section, I list the 310 terms of Semantic Field *S*, as discussed in Chapter 5. To arrive at this list, I uploaded my thesis as a PDF to ChatGPT 4o and parsed its keywords with the following prompt sequence:

1 "Categorize and list the key words in this document."

2 "Write these as a list separated by commas, ranked by their relevance in the text"

---

1. A Dish with One Spoon
2. abduction
3. Abundant Intelligences project
4. academic cross-pollination
5. academic knowledge management (AKM)
6. accessibility
7. Artificial General Intelligence (AGI)
8. AI energy consumption
9. algorithm
10. analogy
11. anti-oppression
12. Artificial Intelligence (AI)
13. axiological paradigms
14. biocultural memory
15. biodynamic agriculture
16. Blender
17. blind spots
18. Boundary Critique
19. capitalist extractivist economy
20. ChatGPT
21. Circle Semantic Shape
22. classification of natural forms
23. climate crisis
24. climate crisis mitigation
25. climate hyperobject
26. climate resilience
27. Carbon dioxide (CO_2)
28. collaborative co-creation
29. collaborative Knowledge Production
30. colligative theory formation
31. complexity management
32. composition
33. Computational Analysis of Texts and Graphs (CATG)
34. Computational Graphesis
35. Computational Semiosis
36. conceptual gateways
37. Conceptual Graphs

38. Conceptual Networks
39. Cone Semantic Form
40. Cones of Plausibility
41. consilience
42. consilience across disciplines
43. Consilience in Knowledge Activation (CKA)
44. Consilience of Inductions
45. consolation
46. constellationary fields
47. conversational model
48. Creation-as-Research
49. Creative Presentations of Research
50. criminal justice system
51. Critical Systems Thinking (CST)
52. cybernetic mycelium
53. cybernetic rhizome
54. Cylinder Semantic Form
55. data activation
56. data hierarchy
57. data hierarchy visualization
58. data ontology modeling
59. data-information-knowledge-wisdom hierarchy (DIKW)
60. data-to-knowledge transformation
61. database of databases
62. decentralized knowledge structure
63. decomposition
64. deduction
65. degree-difference
66. Design for Health (DH)
67. Design for Sustainability Transitions (DfST)
68. Design with a Capital D
69. desolation
70. diagrammatic reasoning
71. Digital Humanities
72. dimensional addition
73. dimensionality
74. disciplinary interchange
75. discourse fields
76. domain models
77. double cone in optics
78. Double-Cone Semantic Form
79. double-diamond shape
80. eco-justice
81. ecoanthroposymbiosis
82. ecojustice
83. ecological cost of AI
84. ecologically informed AI strategy
85. Embedding Projector
86. energy resources
87. Entity-Relationship (ER) diagrams
88. environmental crisis
89. environmental degradation
90. environmental sustainability

91. epistemological diversity
92. Epistemology
93. Equity-Centered Community Design
94. Equity-Centered Community Design (ECCD)
95. ethnobotany
96. ethnoecology
97. Euclidean
98. evidence synthesis
99. filtration
100. formation and growth in morphology
101. funnel plot
102. futures cone
103. general consilience (GC)
104. Generous AI
105. geometric compositions
106. Gestalt psychology
107. gigamapping
108. glass box AI
109. Global Assortativity
110. Global Topological Synchronization (GTS)
111. GPT-3
112. GPT-4
113. graph embeddings
114. graph isomorphology
115. graph LLMs
116. graph morphology
117. graph of concepts
118. graph-based ontology models
119. graphesis
120. graphical user interface (GUI)
121. graphically structured knowledge
122. graphlet interface
123. graphlets
124. hierophanic
125. HITL (Human-in-the-Loop)
126. HITL CATG KA
127. Horn of Futures
128. Horn Torus Semantic Form
129. Human Analysis of Text and Graphs (HATG)
130. humanistic interface design
131. hyper-specialization
132. hyperlinked bibliometric graphing
133. hyperobject
134. incipit
135. Inclusive Design (ID)
136. induction
137. information design
138. information overload
139. information visualization
140. information visuospatialization
141. InfraNodus
142. interbeing
143. interdisciplinarity
144. interdisciplinary consilience
145. interdisciplinary Knowledge co-Production
146. interdisciplinary Knowledge Production
147. interdisciplinary synthesis
148. interdisciplinary topic mapping
149. Intergovernmental Panel on Climate Change (IPCC)

150. interpretable AI
151. isomorphic inter-being
152. isomorphogenesis
153. isomorphology
154. knowledge abstraction and synthesis
155. Knowledge Activation (KA)
156. knowledge design studio laboratory
157. knowledge engineering
158. knowledge graphs
159. Knowledge Management (KM)
160. Knowledge Production (KP)
161. Knowledge Production for Sustainability Transitions (KPST)
162. Knowledge Production through composition
163. Knowledge Production through visuospatial Semantic Form composition
164. Knowledge Pyramid
165. Knowledge Surfacing (KSu)
166. Knowledge Surfacing, Synthesis, Translation, and Creation(KSSTP)
167. Knowledge Synthesis (KSy)
168. Knowledge Translation (KT)
169. knowledge work platforms
170. KP quantification
171. Large Language Model (LLM)
172. logoi
173. logos of form
174. Logseq
175. Loop-line
176. Low-dimensional topology
177. ludic quality
178. major diameter
179. major radius
180. manual node placement
181. Markdown language
182. material infrastructure
183. Meru Chakra
184. meta-analysis
185. meta-language
186. meta-Systematic Combining (MSC)
187. metaphysics
188. methodological framework
189. methodological pluralism
190. middle ontology
191. minor diameter
192. minor radius
193. Mistral 7B
194. MNIST handwritten digits database
195. monocrops
196. morphology
197. moving spatial network graphs
198. multi-dimensional network graphs
199. multi-mathematical approach
200. multi-scale topological data features
201. natural resources
202. network graph
203. network graph composition
204. network graphlet

205. network subgraphs
206. networked data visualization
207. node grouping
208. Obsidian
209. Ontological Semantic Network Summaries (OSNS)
210. ontology
211. opaque AI
212. oppressive terminology
213. Oslo School of Systemic Design
214. outer diameter
215. outer radius
216. particle accelerator of ideas
217. Perceptual Artifacts Lab (PAL)
218. permaculture
219. Persistence Homology (PH)
220. Personal Knowledge Management (PKM)
221. perspective in art
222. plant-human coevolution
223. point cloud
224. point plot heatmap
225. power relations
226. qualitative methods
227. query graphs
228. Query Isomorphs
229. rectangular coordinate system
230. Research-Creation
231. Research-for-Creation
232. Research-from-Creation
233. researcher grouping
234. rewilding
235. Ring Torus Semantic Form
236. Roam Research
237. Semantic Field S
238. Semantic Forms
239. semantic network mapping
240. Semantic Shapes
241. Semantic Topological Semiotics
242. simplicial complex
243. Small Language Models
244. social inequality
245. social justice
246. Social Sciences and Humanities Research Council
247. spatial and temporal modeling
248. spatial composition
249. spatial network graphs
250. spatial semiotic representation
251. spatial topic model network graphs
252. Sphere Semantic Form
253. Sri Yantra
254. stakeholder
255. Sustainability Transitions Knowledge Activation (STKA)
256. studio laboratory of knowledge design
257. surfaces of revolution
258. sustainability solutions frameworks
259. Sustainability Transitions (ST)
260. symbol composition
261. Symbol-setting

262. symbolic representation
263. syntopical consilience
264. Syntopical Consilience Abduction (SCA)
265. syntopical reading
266. Syntopicon
267. Systematic Combining (SC)
268. Systemic Design
269. Systemic Design Association (SDA)
270. Systems Oriented Design (SOD)
271. Systems Theory
272. Systems Thinking
273. Topological Capta Analysis (TCA)
274. TCA Researcher Grouping
275. TCA Workspace
276. tensors
277. Terroir of Text and Graphs (TTG)
278. text graphs
279. thought forms
280. thought signs
281. three-dimensional forms
282. three-dimensional information visualization
283. three-dimensional topic models
284. topic model network graphs
285. Topic Models
286. Topological Data Analysis (TDA)
287. Topological Capta Analysis (TCA)
288. topological semiotics
289. Topology
290. toroidal manifold
291. torus
292. transdisciplinary KA (Knowledge Activation)
293. Tree of Porphyry
294. UN Sustainable Development Goals (SDGs)
295. University
296. upper ontology
297. vector embeddings
298. vector search
299. Vedic visuospatial culture
300. visual argument
301. visual epistemology
302. visual reasoning
303. visuospatial epistemology
304. visuospatial forms of knowledge production
305. visuospatial knowledge activation interface
306. visuospatial reasoning
307. weighting
308. wicked problem
309. Zettelkasten
310. Zone of Semantic Stasis

A.12 Adler's 102 *Great Ideas*

The following terms are listed alphabetically as per The *Great Ideas: a Syntopicon of Great Books of the Western World* (1952), derived from the texts in *Great Books of the Western World* (1952).

1. Angel
2. Animal
3. Aristocracy
4. Art
5. Astronomy and Cosmology
6. Beauty
7. Being
8. Cause
9. Chance
10. Change
11. Citizen
12. Constitution
13. Courage
14. Custom and Convention
15. Definition
16. Democracy
17. Desire
18. Dialectic
19. Duty
20. Education
21. Element
22. Emotion
23. Eternity
24. Evolution
25. Experience
26. Family
27. Fate
28. Form
29. God
30. Good and Evil
31. Government
32. Habit
33. Happiness
34. History
35. Honor
36. Hypothesis
37. Idea
38. Immortality
39. Induction
40. Infinity
41. Judgement
42. Justice
43. Knowledge
44. Labor
45. Language
46. Law
47. Liberty
48. Life and Death
49. Logic
50. Love
51. Man
52. Mathematics
53. Matter
54. Mechanics
55. Medicine
56. Memory and Imagination
57. Metaphysics
58. Mind
59. Monarch
60. Nature
61. Necessity and Contingency
62. Oligarchy
63. One and Many
64. Opinion
65. Opposition
66. Philosophy
67. Physics
68. Pleasure and Pain
69. Poetry
70. Principle

71. Progress
72. Prophecy
73. Prudence
74. Punishment
75. Quality
76. Quantity
77. Reasoning
78. Relation
79. Religion
80. Revolution
81. Rhetoric
82. Same and Other
83. Science
84. Sense
85. Sign and Symbol
86. Sin
87. Slavery
88. Soul
89. Space
90. State
91. Temperance
92. Theology
93. Time
94. Truth
95. Tyranny and Despotism
96. Universal and Particular
97. Virtue and Vice
98. War and Peace
99. Wealth
100. Will
101. Wisdom
102. World

A.13 Authors included in *Great Books of the Western World* (1952)

The *Great Books of the Western World* (1952) includes works by the following authors:

Homer
Aeschylus
Sophocles
Euripides
Aristophanes
Herodotus
Thucydides
Plato
Aristotle
Hippocrates
Galen
Euclid
Archimedes
Apollonius
Nichomachus
Lucretius
Epictetus
Marcus Aurelius
Virgil
Plutarch
Tacitus
Ptolemy
Copernicus
Kepler
Plotinus
Augustine
Thomas Aquinas
Dante
Chaucer
Machiavelli
Hobbes
Rabelais
Montaigne
Shakespeare
Gilbert
Galileo
Harvey
Cervantes
Francis Bacon
Descartes
Spinoza
Milton
Pascal
Newton
Huygens
Locke
Berkeley
Hume
Swift
Sterne
Fielding
Montesquieu
Rousseau
Adam Smith
Gibbon
Kant
J. S. Mill
Boswell
Lavoisier
Fourier
Faraday
Hegel
Goethe
Melville
Darwin
Marx
Engels
Tolstoy
Dostoyevsky
William James
Freud

A.14 Categorizing the subjects of this thesis

Computer Science

Artificial Intelligence (AI)

Machine Learning

Natural Language Processing (NLP)

Computational Linguistics

Data Science

Human-Computer Interaction (HCI)

Information Retrieval

Knowledge Representation and Reasoning

Topological Data Analysis (TDA)

Graph Theory

Mathematics

Topology

Geometry

Computational Topology

Mathematical Modeling

Philosophy

Philosophy of Information

Philosophy of Language

Epistemology

Semiotics

Philosophy of Science

Ontology

Cognitive Sciences

Cognitive Psychology

Cognitive Neuroscience

Visual Cognition

Embodied Cognition

Information Science

Knowledge Management

Personal Knowledge Management (PKM)

Information Visualization

Library and Information Science

Ontologies

Digital Libraries

Design

Systems Oriented Design (SOD)

Systemic Design

Information Design

Visual Communication Design

Human-Centered Design

Digital Humanities

Computational Humanities

Digital Scholarship

Humanistic Interface Design

Interdisciplinary Studies

Sustainability Transitions

Environmental Studies

Climate Science

Ecojustice

Indigenous Studies

Decolonizing Methodologies

Linguistics

Computational Linguistics

Semantics

Pragmatics

Language and Thought

Education

Knowledge Activation

Collaborative Learning

Interdisciplinary Education

Educational Technology

Sociology

Sociology of Knowledge

Science and Technology Studies (STS)

Cultural Studies

Communication Studies

Media Studies

Information Theory

Symbolic Communication

Ethnography and Anthropology

Ethnoecology

Ethnobotany

Cultural Anthropology

Visual Studies

Visual Epistemology

Visual Reasoning

Visual Semiotics

Graphical Representation

A.15 Experts consulted

I acknowledge with professional admiration the subject matter experts who provided formative feedback for this thesis. I list their names here in alphabetical order by surname:

Dr. Evan Timothy Barba, Associate Professor at Georgetown University

Tega Brain, artist and Associate Professor at New York University (NYU)

Antionette D. Carroll, founder of the Institute of Equitable Design and Justice, and Creative Reaction Labs

John P. Comer, founder of Architects Of Justice; National Organizing Director of The Redress Movement

Dr. Sara Diamond, OCAD University Research Chair, Director of the Visual Analytics Lab, and Co-investigator of the OCAD U Abundant Intelligences A Dish with One Spoon – Towards "Generous AI" Invention and Collaboration project

Dr. Michael Doser, senior research physicist at the European Council for Nuclear Research/Conseil Européen pour la Recherche Nucléaire (CERN)

Balazs Farago, founder and CEO of Walters Cube.

Ekaterina Grgurić, Digital Scholarship Librarian at the University of British Columbia (UBC)

Michael Groenendyk, Digital Scholarship Librarian at Concordia University

Micki Kaufman, historian and digital scholar at the City University of New York

Dr. Peter Jones, founder of the Strategic Innovation Lab, co-founder of the Systemic Design Association, and Distinguished Professor in Systemic Design for the School of Architecture, Art and Design at the Tecnológico de Monterrey

Amanda Licastro, Digital Scholarship Librarian at Swarthmore College

Dr. Blake Madill, Associate Professor of Pure Mathematics at the University of Waterloo

Cheryl May, Executive Editor for the Systemic Design Association, and PhD candidate at London South Bank University

Dr. Gavin Mendel-Gleason, CTO of TerminusDB, and former research fellow at Trinity College Dublin in the School of Statistics and Computer Science

Ola Mazzuca, exhibition operations at the Gallery at Mason Studio

Antonio Muñoz Gomez, Digital Scholarship Librarian at the University of Waterloo

Dr. Lennart Nacke, University Research Chair and Professor at the University of Waterloo, and Associate Director of the Stratford School of Interaction Design and Business, and Director of the HCI Games Group at the University of Waterloo's Games Institute

Rahul Nayak, data scientist from the Indian Institute of Technology

Dr. Dmitry Paranyushkin, founder of InfraNodus and senior researcher at Nodus Labs

Dr. Paul Pangaro, President of the American Society for Cybernetics

Dr. Michael J. Prokopow, cultural historian, curator, and professor at OCAD University

Santiago Ortiz, director of Moebio Labs

Ryan J. A. Murphy, PhD candidate at the University of Newfoundland and Co-Secretary of the Systemic Design Association

Dr. Birger Sevaldson, professor at the Oslo School of Architecture and Design, and at the University of South-Eastern Norway

Peter Scott, lecturer at OCAD University

Dr. Maria Aleksandrovna Simakova, Foucault scholar from the University of Toronto

Kirsta Stapelfeldt, Associate Librarian, Research and Digital Initiatives at the University of Toronto Scarborough Digital Scholarship Unit

Brian Sunter, software engineer from the University of Florida

Serkan Özkaya, conceptual artist

David Kwasny, Data and Digital Literacy Librarian at the University of Toronto Scarborough Digital Scholarship Unit

Kyle Winters, CEO of NEXT Canada

A.16 Research presentations

In this section, I list the presentations I delivered about my work during my thesis research:

2024 *Systems Oriented Disruptions*, presented for the annual International Innovation Forum hosted by the Strategic Foresight and Innovation program in the OCAD University School of Graduate Studies

2024 *Systems Oriented Disruptions*, presented for Creative Disruptions// re-imagining our futures the graduate thesis exhibition by the Digital Futures program in the OCAD University's School of Graduate Studies

2024 *Body of Aesthetics*, a panel discussion moderated by curator Sara Dagovic and joined by artist Artemis Han, The Gallery at Mason Studio, Toronto

2023 *Three-dimensional plotting of information categories using P5.js*, Perceptual Artifacts Lab in OCAD University, moderated by the PAL Director Dr. Peter Coppin

2023 *Song Within a Sacrifice Zone*, presented for *Uses and Abuses of Power in Alternative Spiritualities*, the annual conference by the Program for the Evolution of Spirituality in the Harvard Divinity School

2023 *The biopower of faith leaders who are also alternative medicine practitioners in alternative spiritual communities*, presented for *Uses and Abuses of Power in Alternative Spiritualities*, the annual conference by the Program for the Evolution of Spirituality in the Harvard Divinity School

2023 *Knowledge Translation vs the Climate Crisis* presented for the annual colloquium hosted by the Digital Futures in the OCAD University School of Graduate Studies

2022 *Dissonance*, presented for the Too Big To Fail Exhibition organized by the Interdisciplinary Master's of Art, Media and Design in the OCAD University School of Graduate Studies

2022 *Data Tori*, presented for the annual Graduate Colloquium, moderated by Duchamp scholar Dr. Julian Haladyn, in the OCAD University School of Graduate Studies

2022 *Medicinallity of Symbol*, presented for the annual research panel organized by the Interdisciplinary Master's of Art, Media and Design, in the OCAD University School of Graduate Studies, moderated by Graduate Program Director Jay Irizawa

A.17 Art exhibitions

In this section, I list the art exhibitions in which I showcased my work during my thesis research:

2024 *GradEx 109*, OCAD University

2024 *Creative Disruptions// re-imagining our futures*, Digital Futures graduate thesis exhibition, OCAD University, Waterfront Campus.

2024 *Body of Aesthetics, curated by Sara Dagovic*, The Gallery at Mason Studio, Toronto

2023 *Digital Futures Open Show*, OCAD University, School of Graduate Studies

2023 *Song Within a Sacrifice Zone*, Harvard Divinity School, Swartz Hall

2023 *Resilience and Connection: artistic explorations of mental health*, L.R. Wilson Building, McMaster University

2023 *Too Big to Fail*, Open Space Gallery, OCADU

2022 *The Incomplete*, The Great Hall Gallery, OCADU

A.18 Resources and tools tested and used during thesis

Hardware

Macbook Pro, 16-inch, 2021, Apple M1 Max, 32 GB RAM

Source Management

Zotero

Zotero Better BibTex extension v 6.7.202 by Emiliano Heyns (to generate citation keys)

Zotero Connector Chrome extension

Personal Knowledge Management (PKM)

Obsidian

Logseq

Logseq PDF reader

Readwise Official Plugin v1.4.9

Roam Research

Three-Dimensional Forms

Blender, node programming

Document Drafting

Overleaf, Online LaTeX editor

Pandoc for populating Better BibTeX citation keys into in-sentence citation and list of references

Google Docs

Google Chrome extension DocsAfter Dark

Microsoft Word

Document Reading

Zotero PDF reader

ProQuest Ebook Central

The Internet Archive

Logseq PDF reader

Readwise

Readwise Reader

Readwise Chrome extension (synced to Logseq and Obsidian)

Apple Photos Optical Character Recognition

Adobe Acrobat

Adobe Digital Editions

Infinite Canvas Text Analysis Tools

Miro

Scapple

Text Graphing Tools

InfraNodus

InfraNodus Chrome extension for its 3D knowledge graph

MIT's SIMILE Timeline widget, run on Zotero

Obsidian Canvas, core plugin

Obsidian Outline, core plugin

Obsidian Graph View, core plugin

Obsidian 3D Graph v1.0.5, community plugin by Alexander Weichart

Python 3.8.12

PiVis*

Pandas Dataframes*

NetworkX*

Voyant Tools

* Python libraries

LLMs

Mistral 7B Open Orca*

Zephyr*

Grammarly AI Writing Assistant

Claude 3.5 Sonnet

Google Gemini Advanced 1.5 Pro

Chat GPT 3.5

Chat GPT 4

Chat GPT 4 Turbo

Chat GPT 4o

Chat GPT 4-mini

Chat GPT o1-preview

Chat GPT o1

Chat GPT o1-mini

* set up using Ollama

Image Management

Apple Photos

Affinity

Affinity Designer

Affinity Publisher

Pinterest

QuickTime Player

Audio and Video Production

Final Cut Pro

Logic Pro

Typefaces in Figures

iA Writer Quattro S

Helvetica Neue

Arial Black

Avenir Next Condensed

Typefaces in Document

Lato - used for text captions

Noto Mono - used for code

EB Garramond - used for all other text

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Subject Index

Invitation

To recall a humorous example from the inspirational origins of the World Wide Web, Tim Berners-Lee's *Information Management* (1989) was described by his supervisor Mike Sendall as "Vague, but exciting..." (CERN, 2008). If you are a topologist or computer scientist inclined to lean forward past my work's vagueness into excitement, I heartily welcome your collaboration. To reach me, email mateocs[at]ocadu[dot]ca.

About the Author

Orus Mateo Castaño-Suárez is an award-winning researcher, designer, and artist based in Treaty 13, Tkaronto (Toronto, Canada). Their work responds to the escalating severity of the climate crisis by designing visuospatial, topological, computational, and Systemic Design approaches for innovation across disciplines. Castaño-Suárez contributes to international research through the Harvard Divinity School Program for the Evolution of Spirituality, Abundant Intelligences Indigenous Artificial Intelligence project, American Society for Cybernetics, Systemic Design Association, and the Creative Reaction Lab. In Canada, they contribute to the University of Toronto's Creative Destruction Lab and OCAD University's Visual Analytics Lab, Strategic Innovation Lab, Perceptual Artifacts Lab, and Global Centre for Climate Action. Castaño-Suárez's achievements have been recognized through numerous awards, including the Ontario Graduate Scholarship. Their work has been showcased in exhibitions, conferences, and publications internationally.