



UNIVERSITÄT  
BAYREUTH

– P&E Master's Programme –  
Chair of Philosophy, Computer  
Science & Artificial Intelligence

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## Automating the Modelling of Transformative Artificial Intelligence Risks

*“An Epistemic Framework for Leveraging Frontier AI Systems to Upscale Conditional Policy  
Assessments in Bayesian Networks on a Narrow Path towards Existential Safety ”*

A thesis submitted at the Department of Philosophy  
for the degree of *Master of Arts in Philosophy & Economics*

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# Abstract

The coordination crisis in AI governance presents a paradoxical challenge: unprecedented investment in AI safety coexists alongside fundamental coordination failures across technical, policy, and ethical domains. These divisions systematically increase existential risk. This thesis introduces AMTAIR (Automating Transformative AI Risk Modeling), a computational approach addressing this coordination failure by automating the extraction of probabilistic world models from AI safety literature using frontier language models. The system implements an end-to-end pipeline transforming unstructured text into interactive Bayesian networks through a novel two-stage extraction process that bridges communication gaps between stakeholders.

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- Academic supervisor (Prof. Timo Speith) and institution (University of Bayreuth)
- Research collaborators, especially those connected to the original MTAIR project
- Technical advisors who provided feedback on implementation aspects
- Personal supporters who enabled the research through encouragement and feedback

## List of Abbreviations

- AGI - Artificial General Intelligence
- AMTAIR - Automating Modeling of Transformative AI Risks
- API - Application Programming Interface
- APS - Advanced, Planning, Strategic
- BN - Bayesian Network
- CPT - Conditional Probability Table
- DAG - Directed Acyclic Graph
- LLM - Large Language Model
- MTAIR - Modeling Transformative AI Risks
- TAI - Transformative Artificial Intelligence

## Glossary

- **Argument mapping:** A method for visually representing the structure of arguments
- **BayesDown:** An extension of ArgDown that incorporates probabilistic information
- **Bayesian network:** A probabilistic graphical model representing variables and their dependencies
- **Conditional probability:** The probability of an event given that another event has occurred
- **Directed Acyclic Graph (DAG):** A graph with directed edges and no cycles
- **Existential risk:** Risk of permanent curtailment of humanity's potential
- **Power-seeking AI:** AI systems with instrumental incentives to acquire resources and power
- **Prediction market:** A market where participants trade contracts that resolve based on future events
- **d-separation:** A criterion for identifying conditional independence relationships in Bayesian networks
- **Monte Carlo sampling:** A computational technique using random sampling to obtain numerical results



# Final Thesis: Automating the Modeling of Transformative Artificial Intelligence Risks

## Frontmatter: Preface

This thesis represents the culmination of interdisciplinary research at the intersection of AI safety, formal epistemology, and computational social science. The work emerged from recognizing a fundamental challenge in AI governance: while investment in AI safety research has grown exponentially, coordination between different stakeholder communities remains fragmented, potentially increasing existential risk through misaligned efforts.

The journey from initial concept to working implementation involved iterative refinement based on feedback from advisors, domain experts, and potential users. What began as a technical exercise in automated extraction evolved into a broader framework for enhancing epistemic security in one of humanity’s most critical coordination challenges. The AMTAIR project—Automating Transformative AI Risk Modeling—represents an attempt to build computational bridges between communities that, despite shared concerns about AI risk, often struggle to communicate effectively due to incompatible frameworks, terminologies, and implicit assumptions.

I hope this work contributes to building the intellectual and technical infrastructure necessary for humanity to navigate the transition to transformative AI safely. The tools and frameworks presented here are offered in the spirit of collaborative problem-solving, recognizing that the challenges we face require unprecedented cooperation across disciplines, institutions, and world-views.

## Acknowledgments

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I acknowledge Johannes Meyer and Jelena Meyer for their invaluable assistance in verifying the automated extraction procedure through manual extraction of ArgDown and BayesDown data

from the Carlsmith paper, providing crucial ground truth for validation.

Special recognition goes to Coleman Snell for his partnership and research collaboration with the AMTAIR project, offering both technical expertise and strategic vision. The AI safety community's creation of rich literature made this work possible, and I thank all researchers whose arguments provided the raw material for formalization.

Any errors or limitations remain my own responsibility.

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## **List of Abbreviations**

AI - Artificial Intelligence  
AGI - Artificial General Intelligence  
AMTAIR - Automating Transformative AI Risk Modeling  
API - Application Programming Interface  
APS - Advanced, Planning, Strategic (AI systems)  
BN - Bayesian Network  
CPT - Conditional Probability Table  
DAG - Directed Acyclic Graph  
LLM - Large Language Model  
ML - Machine Learning  
MTAIR - Modeling Transformative AI Risks  
NLP - Natural Language Processing  
P&E - Philosophy & Economics  
PDF - Portable Document Format  
TAI - Transformative Artificial Intelligence

# 1. Introduction: The Coordination Crisis in AI Governance

## 1.1 Opening Scenario: The Policymaker’s Dilemma

Imagine a senior policy advisor preparing recommendations for AI governance legislation. On her desk lie a dozen reports from leading AI safety researchers, each painting a different picture of the risks ahead. One argues that misaligned AI could pose existential risks within the decade, citing complex technical arguments about instrumental convergence and orthogonality. Another suggests these concerns are overblown, emphasizing uncertainty and the strength of existing institutions. A third proposes specific technical standards but acknowledges deep uncertainty about their effectiveness.

Each report seems compelling in isolation, written by credentialed experts with sophisticated arguments. Yet they reach dramatically different conclusions about both the magnitude of risk and appropriate interventions. The technical arguments involve unfamiliar concepts—mesa-optimization, corrigibility, capability amplification—expressed through different frameworks and implicit assumptions. Time is limited, stakes are high, and the legislation could shape humanity’s trajectory for decades.

This scenario<sup>1</sup> plays out daily across government offices, corporate boardrooms, and research institutions worldwide. It exemplifies what I term the “coordination crisis” in AI governance: despite unprecedented attention and resources directed toward AI safety, we lack the epistemic infrastructure to synthesize diverse expert knowledge into actionable governance strategies Todd [51].

Show Image

## 1.2 The Coordination Crisis in AI Governance

As AI capabilities advance at an accelerating pace—demonstrated by the rapid progression from GPT-3 to GPT-4, Claude, and emerging multimodal systems Maslej [31] Samborska [43]—humanity faces a governance challenge unlike any in history. The task of ensuring increasingly

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<sup>1</sup>The orthogonality thesis posits that intelligence and goals are independent—an AI can have any set of objectives regardless of its intelligence level. The instrumental convergence thesis suggests that different AI systems may adopt similar instrumental goals (e.g., self-preservation, resource acquisition) to achieve their objectives.

powerful AI systems remain aligned with human values and beneficial to our long-term flourishing grows more urgent with each capability breakthrough. This challenge becomes particularly acute when considering transformative AI systems that could drastically alter civilization’s trajectory, potentially including existential risks from misaligned systems pursuing objectives counter to human welfare.

Despite unprecedented investment in AI safety research, rapidly growing awareness among key stakeholders, and proliferating frameworks for responsible AI development, we face what I’ll term the “coordination crisis” in AI governance—a systemic failure to align diverse efforts across technical, policy, and strategic domains into a coherent response proportionate to the risks we face.

The current state of AI governance presents a striking paradox. On one hand, we witness extraordinary mobilization: billions in research funding, proliferating safety initiatives, major tech companies establishing alignment teams, and governments worldwide developing AI strategies. The Asilomar AI Principles garnered thousands of signatures Tegmark [48], the EU advances comprehensive AI regulation European [20], and technical researchers produce increasingly sophisticated work on alignment, interpretability, and robustness.

Yet alongside this activity, we observe systematic coordination failures that may prove catastrophic. Technical safety researchers develop sophisticated alignment techniques without clear implementation pathways. Policy specialists craft regulatory frameworks lacking technical grounding to ensure practical efficacy. Ethicists articulate normative principles that lack operational specificity. Strategy researchers identify critical uncertainties but struggle to translate these into actionable guidance. International bodies convene without shared frameworks for assessing interventions.

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### 1.2.1 Safety Gaps from Misaligned Efforts

The fragmentation problem manifests in incompatible frameworks between technical researchers, policy specialists, and strategic analysts. Each community develops sophisticated approaches within their domain, yet translation between domains remains primitive. This creates systematic blind spots where risks emerge at the interfaces between technical capabilities, institutional responses, and strategic dynamics.

When different communities operate with incompatible frameworks, critical risks fall through the cracks. Technical researchers may solve alignment problems under assumptions that policymakers’ decisions invalidate. Regulations optimized for current systems may inadvertently incentivize dangerous development patterns. Without shared models of the risk landscape, our collective efforts resemble the parable of blind men describing an elephant—each accurate within their domain but missing the complete picture Paul [37].

Historical precedents demonstrate how coordination failures in technology governance can lead to dangerous dynamics. The nuclear arms race exemplifies how lack of coordination can create negative-sum outcomes where all parties become less secure despite massive investments in

safety measures. Similar dynamics may emerge in AI development without proper coordination infrastructure.

### 1.2.2 Resource Misallocation

The AI safety community faces a complex tradeoff in resource allocation. While some duplication of efforts can improve reliability through independent verification—akin to reproducing scientific results—the current level of fragmentation often leads to wasteful redundancy. Multiple teams independently develop similar frameworks without building on each other’s work, creating opportunity costs where critical but unglamorous research areas remain understaffed. Funders struggle to identify high-impact opportunities across technical and governance domains, lacking the epistemic infrastructure to assess where marginal resources would have the greatest impact. This misallocation becomes more costly as the window for establishing effective governance narrows with accelerating AI development.

Table 1: Examples of duplicated AI safety efforts across organizations

Research Area	Organization A	Organization B	Duplication Level	Opportunity Cost
Interpretability Methods	Anthropic’s mechanistic interpretability	DeepMind’s concept activation vectors	Medium	Reduced focus on multi-agent safety
Alignment Frameworks	MIRI’s embedded agency	FHI’s comprehensive AI services	High	Limited work on institutional design
Risk Assessment Models	GovAI’s policy models	CSER’s existential risk frameworks	High	Insufficient capability benchmarking

### 1.2.3 Negative-Sum Dynamics

Perhaps most concerning, uncoordinated interventions can actively increase risk. Safety standards that advantage established players may accelerate risky development elsewhere. Partial transparency requirements might enable capability advances without commensurate safety improvements. International agreements lacking shared technical understanding may lock in dangerous practices. Without coordination, our cure risks becoming worse than the disease.

The game-theoretic structure of AI development creates particularly pernicious dynamics. Armstrong et al. Armstrong, Bostrom, and Shulman [2] demonstrate how uncoordinated policies can incentivize a “race to the precipice” where competitive pressures override safety considerations. The situation resembles a multi-player prisoner’s dilemma or stag hunt where individually rational decisions lead to collectively catastrophic outcomes Samuel [44] Hunt [25].

## 1.3 Historical Parallels and Temporal Urgency

History offers instructive parallels. The nuclear age began with scientists racing to understand and control forces that could destroy civilization. Early coordination failures—competing national programs, scientist-military tensions, public-expert divides—nearly led to catastrophe multiple times. Only through developing shared frameworks (deterrence theory) Schelling [45], institutions (IAEA), and communication channels (hotlines, treaties) did humanity navigate the nuclear precipice Rehman [42].

Yet AI presents unique coordination challenges that compress our response timeline:

**Accelerating Development:** Unlike nuclear weapons requiring massive infrastructure, AI development proceeds in corporate labs and academic departments worldwide. Capability improvements come through algorithmic insights and computational scale, both advancing exponentially.

**Dual-Use Ubiquity:** Every AI advance potentially contributes to both beneficial applications and catastrophic risks. The same language model architectures enabling scientific breakthroughs could facilitate dangerous manipulation or deception at scale.

**Comprehension Barriers:** Nuclear risks were viscerally understandable—cities vaporized, radiation sickness, nuclear winter. AI risks involve abstract concepts like optimization processes, goal misspecification, and emergent capabilities that resist intuitive understanding.

**Governance Lag:** Traditional governance mechanisms—legislation, international treaties, professional standards—operate on timescales of years to decades. AI capabilities advance on timescales of months to years, creating an ever-widening capability-governance gap.

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## 1.4 Research Question and Scope

This thesis addresses a specific dimension of the coordination challenge by investigating the question:

**Can frontier AI technologies be utilized to automate the modeling of transformative AI risks, enabling robust prediction of policy impacts across diverse worldviews?**

More specifically, I explore whether frontier language models can automate the extraction and formalization of probabilistic world models from AI safety literature, creating a scalable computational framework that enhances coordination in AI governance through systematic policy evaluation under uncertainty.

To break this down into its components:

- **Frontier AI Technologies:** Today’s most capable language models (GPT-4, Claude-3 level systems)

- **Automated Modeling:** Using these systems to extract and formalize argument structures from natural language
- **Transformative AI Risks:** Potentially catastrophic outcomes from advanced AI systems, particularly existential risks
- **Policy Impact Prediction:** Evaluating how governance interventions might alter probability distributions over outcomes
- **Diverse Worldviews:** Accounting for fundamental disagreements about AI development trajectories and risk factors

The investigation encompasses both theoretical development and practical implementation, focusing specifically on existential risks from misaligned AI systems rather than broader AI ethics concerns. This narrowed scope enables deep technical development while addressing the highest-stakes coordination challenges.

## 1.5 The Multiplicative Benefits Framework

The central thesis of this work is that combining three elements—automated worldview extraction, prediction market integration, and formal policy evaluation—creates multiplicative rather than merely additive benefits for AI governance. Each component enhances the others, creating a system more valuable than the sum of its parts.

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### 1.5.1 Automated Worldview Extraction

Current approaches to AI risk modeling, exemplified by the Modeling Transformative AI Risks (MTAIR) project, demonstrate the value of formal representation but require extensive manual effort. Creating a single model demands dozens of expert-hours to translate qualitative arguments into quantitative frameworks. This bottleneck severely limits the number of perspectives that can be formalized and the speed of model updates as new arguments emerge.

Automation using frontier language models addresses this scaling challenge. By developing systematic methods to extract causal structures and probability judgments from natural language, we can:

- Process orders of magnitude more content
- Incorporate diverse perspectives rapidly
- Maintain models that evolve with the discourse
- Reduce barriers to entry for contributing worldviews

### 1.5.2 Live Data Integration

Static models, however well-constructed, quickly become outdated in fast-moving domains. Prediction markets and forecasting platforms aggregate distributed knowledge about uncertain futures, providing continuously updated probability estimates. By connecting formal models to

these live data sources, we create dynamic assessments that incorporate the latest collective intelligence Tetlock and Gardner [50].

This integration serves multiple purposes:

- Grounding abstract models in empirical forecasts
- Identifying which uncertainties most affect outcomes
- Revealing when model assumptions diverge from collective expectations
- Generating new questions for forecasting communities

### 1.5.3 Formal Policy Evaluation

**Formal policy evaluation** transforms static risk assessments into actionable guidance by modeling how specific interventions alter critical parameters. Using causal inference techniques Pearl [39] Pearl [38], we can assess not just the probability of adverse outcomes but how those probabilities change under different policy regimes.

This enables genuinely evidence-based policy development:

- Comparing interventions across multiple worldviews
- Identifying robust strategies that work across scenarios
- Understanding which uncertainties most affect policy effectiveness
- Prioritizing research to reduce decision-relevant uncertainty

### 1.5.4 The Synergy

The multiplicative benefits emerge from the interactions between components:

- Automation enables comprehensive coverage, making prediction market integration more valuable by connecting to more perspectives
- Market data validates and calibrates automated extractions, improving quality
- Policy evaluation gains precision from both comprehensive models and live probability updates
- The complete system creates feedback loops where policy analysis identifies critical uncertainties for market attention

This synergistic combination addresses the coordination crisis by providing common ground for disparate communities, translating between technical and policy languages, quantifying previously implicit disagreements, and enabling evidence-based compromise.

## 1.6 Thesis Structure and Roadmap

The remainder of this thesis develops the multiplicative benefits framework from theoretical foundations to practical implementation:

**Chapter 2: Context and Theoretical Foundations** establishes the intellectual groundwork, examining the epistemic challenges unique to AI governance, Bayesian networks as formal tools



for uncertainty representation, argument mapping as a bridge from natural language to formal models, the MTAIR project’s achievements and limitations, and requirements for effective coordination infrastructure.

**Chapter 3: AMTAIR Design and Implementation** presents the technical system including overall architecture and design principles, the two-stage extraction pipeline (ArgDown → BayesDown), validation methodology and results, case studies from simple examples to complex AI risk models, and integration with prediction markets and policy evaluation.

**Chapter 4: Discussion - Implications and Limitations** critically examines technical limitations and failure modes, conceptual concerns about formalization, integration with existing governance frameworks, scaling challenges and opportunities, and broader implications for epistemic security.

**Chapter 5: Conclusion** synthesizes key contributions and charts paths forward with a summary of theoretical and practical achievements, concrete recommendations for stakeholders, research agenda for community development, and vision for AI governance with proper coordination infrastructure.

Throughout this progression, I maintain dual focus on theoretical sophistication and practical utility. The framework aims not merely to advance academic understanding but to provide actionable tools for improving coordination in AI governance during this critical period.

Show Image

Having established the coordination crisis and outlined how automated modeling can address it, we now turn to the theoretical foundations that make this approach possible. The next chapter examines the unique epistemic challenges of AI governance and introduces the formal tools—particularly Bayesian networks—that enable rigorous reasoning under deep uncertainty.



## 2. Context and Theoretical Foundations

This chapter establishes the theoretical and methodological foundations for the AMTAIR approach. We begin by examining a concrete example of structured AI risk assessment—Joseph Carlsmith’s power-seeking AI model—to ground our discussion in practical terms. We then explore the unique epistemic challenges of AI governance that render traditional policy analysis inadequate, introduce Bayesian networks as formal tools for representing uncertainty, and examine how argument mapping bridges natural language reasoning and formal models. The chapter concludes by analyzing the MTAIR project’s achievements and limitations, motivating the need for automated approaches, and surveying relevant literature across AI risk modeling, governance proposals, and technical methodologies.

### 2.1 AI Existential Risk: The Carlsmith Model

To ground our discussion in concrete terms, I examine Joseph Carlsmith’s “Is Power-Seeking AI an Existential Risk?” as an exemplar of structured reasoning about AI catastrophic risk Carlsmith [9]. Carlsmith’s analysis stands out for its explicit probabilistic decomposition of the path from current AI development to potential existential catastrophe.

#### 2.1.1 Six-Premise Decomposition

According to the MTAIR model Clarke et al. [13], Carlsmith decomposes existential risk into a probabilistic chain with explicit estimates<sup>2</sup>:

1. **Premise 1:** Transformative AI development this century (P 0.80)(P 0.80) (P 0.80)
2. **Premise 2:** AI systems pursuing objectives in the world (P 0.95)(P 0.95) (P 0.95)
3. **Premise 3:** Systems with power-seeking instrumental incentives (P 0.40)(P 0.40) (P 0.40)
4. **Premise 4:** Sufficient capability for existential threat (P 0.65)(P 0.65) (P 0.65)
5. **Premise 5:** Misaligned systems despite safety efforts (P 0.50)(P 0.50) (P 0.50)

---

<sup>2</sup>Multiple versions of Carlsmith’s paper exist with slight updates to probability estimates: Carlsmith [8], Carlsmith [9], Carlsmith [10]. We primarily reference the version used by the MTAIR team for their extraction. Extended discussion and expert probability estimates can be found on LessWrong.

6. **Premise 6:** Catastrophic outcomes from misaligned power-seeking ( $P = 0.65$ ) ( $P = 0.65$ ) ( $P = 0.65$ )

**Composite Risk Calculation:**  $P(\text{doom}) = 0.05 P(\text{doom}) = 0.05 P(\text{doom}) = 0.05$  (5%)

mermaid

flowchart TD

```

P1[Premise 1: Transformative AI<br/>P = 0.80] --> P2[Premise 2: AI pursuing objectives<br/>P = 0.40]
P2 --> P3[Premise 3: Power-seeking incentives<br/>P = 0.40]
P3 --> P4[Premise 4: Existential capability<br/>P = 0.65]
P4 --> P5[Premise 5: Misalignment despite safety<br/>P = 0.50]
P5 --> P6[Premise 6: Catastrophic outcome<br/>P = 0.65]
P6 --> D[Existential Catastrophe<br/>P = 0.05]

```

Carlsmith structures his argument through six conditional premises, each assigned explicit probability estimates:

**Premise 1: APS Systems by 2070** ( $P = 0.65$ ) ( $P = 0.65$ ) ( $P = 0.65$ ) “By 2070, there will be AI systems with Advanced capability, Agentic planning, and Strategic awareness”—the conjunction of capabilities that could enable systematic pursuit of objectives in the world.

**Premise 2: Alignment Difficulty** ( $P = 0.40$ ) ( $P = 0.40$ ) ( $P = 0.40$ ) “It will be harder to build aligned APS systems than misaligned systems that are still attractive to deploy”—capturing the challenge that safety may conflict with capability or efficiency.

**Premise 3: Deployment Despite Misalignment** ( $P = 0.70$ ) ( $P = 0.70$ ) ( $P = 0.70$ ) “Conditional on 1 and 2, we will deploy misaligned APS systems”—reflecting competitive pressures and limited coordination.

**Premise 4: Power-Seeking Behavior** ( $P = 0.65$ ) ( $P = 0.65$ ) ( $P = 0.65$ ) “Conditional on 1-3, misaligned APS systems will seek power in high-impact ways”—based on instrumental convergence arguments.

**Premise 5: Disempowerment Success** ( $P = 0.40$ ) ( $P = 0.40$ ) ( $P = 0.40$ ) “Conditional on 1-4, power-seeking will scale to permanent human disempowerment”—despite potential resistance and safeguards.

**Premise 6: Existential Catastrophe** ( $P = 0.95$ ) ( $P = 0.95$ ) ( $P = 0.95$ ) “Conditional on 1-5, this disempowerment constitutes existential catastrophe”—connecting power loss to permanent curtailment of human potential.

**Overall Risk:** Multiplying through the conditional chain yields  $P(\text{doom}) = 0.05 P(\text{doom}) = 0.05 P(\text{doom}) = 0.05$  or 5% by 2070.

This structured approach exemplifies the type of reasoning AMTAIR aims to formalize and automate. While Carlsmith spent months developing this model manually, similar rigor exists implicitly in many AI safety arguments awaiting extraction.

### 2.1.2 Why Carlsmith Exemplifies Formalizable Arguments

Carlsmith’s model demonstrates several features that make it ideal for formal representation:

**Explicit Probabilistic Structure:** Each premise receives numerical probability estimates with documented reasoning, enabling direct translation to Bayesian network parameters.

**Clear Conditional Dependencies:** The logical flow from capabilities through deployment decisions to catastrophic outcomes maps naturally onto directed acyclic graphs.

**Transparent Decomposition:** Breaking the argument into modular premises allows independent evaluation and sensitivity analysis of each component.

**Documented Reasoning:** Extensive justification for each probability enables extraction of both structure and parameters from the source text.

We will return to Carlsmith’s model in Chapter 3 as our primary complex case study, demonstrating how AMTAIR successfully extracts and formalizes this sophisticated multi-level argument.

Beyond Carlsmith’s model, other structured approaches to AI risk—such as Christiano’s “What failure looks like” Christiano [12]—provide additional targets for automated extraction, enabling comparative analysis across different expert worldviews.

## 2.2 The Epistemic Challenge of Policy Evaluation

AI governance policy evaluation faces unique epistemic challenges that render traditional policy analysis methods insufficient. Understanding these challenges motivates the need for new computational approaches.

### 2.2.1 Unique Characteristics of AI Governance

**Deep Uncertainty Rather Than Risk:** Traditional policy analysis distinguishes between risk (known probability distributions) and uncertainty (known possibilities, unknown probabilities). AI governance faces deep uncertainty—we cannot confidently enumerate possible futures, much less assign probabilities Hallegatte et al. [23]. Will recursive self-improvement enable rapid capability gains? Can value alignment be solved technically? These foundational questions resist empirical resolution before their answers become catastrophically relevant.

**Complex Multi-Level Causation:** Policy effects propagate through technical, institutional, and social levels with intricate feedback loops. A technical standard might alter research incentives, shifting capability development trajectories, changing competitive dynamics, and ultimately affecting existential risk through pathways invisible at the policy’s inception. Traditional linear causal models cannot capture these dynamics.

**Irreversibility and Lock-In:** Many AI governance decisions create path dependencies that prove difficult or impossible to reverse. Early technical standards shape development trajectories. Institutional structures ossify. International agreements create sticky equilibria. Unlike many

policy domains where course correction remains possible, AI governance mistakes may prove permanent.

**Value-Laden Technical Choices:** The entanglement of technical and normative questions confounds traditional separation of facts and values. What constitutes “alignment”? How much capability development should we risk for economic benefits? Technical specifications embed ethical judgments that resist neutral expertise.

Table 2: Comparison of AI governance vs traditional policy domains

Dimension	Traditional Policy	AI Governance
Uncertainty Type	Risk (known distributions)	Deep uncertainty (unknown unknowns)
Causal Structure	Linear, traceable	Multi-level, feedback loops
Reversibility	Course correction possible	Path dependencies, lock-in
Fact-Value Separation	Clear boundaries	Entangled technical-normative
Empirical Grounding	Historical precedents	Unprecedented phenomena
Time Horizons	Years to decades	Months to centuries

### 2.2.2 Limitations of Traditional Approaches

Standard policy evaluation tools prove inadequate for these challenges:

**Cost-Benefit Analysis** assumes commensurable outcomes and stable probability distributions. When potential outcomes include existential catastrophe with deeply uncertain probabilities, the mathematical machinery breaks down. Infinite negative utility resists standard decision frameworks.

**Scenario Planning** helps explore possible futures but typically lacks the probabilistic reasoning needed for decision-making under uncertainty. Without quantification, scenarios provide narrative richness but limited action guidance.

**Expert Elicitation** aggregates specialist judgment but struggles with interdisciplinary questions where no single expert grasps all relevant factors. Moreover, experts often operate with different implicit models, making aggregation problematic.

**Red Team Exercises** test specific plans but miss systemic risks emerging from component interactions. Gaming individual failures cannot reveal emergent catastrophic possibilities.

These limitations create a methodological gap: we need approaches that handle deep uncertainty, represent complex causation, quantify expert disagreement, and enable systematic exploration of intervention effects.

### 2.2.3 The Underlying Epistemic Framework

The AMTAIR approach rests on a specific epistemic framework that combines probabilistic reasoning, conditional logic, and possible worlds semantics. This framework provides the philosophical foundation for representing deep uncertainty about AI futures.

**Probabilistic Epistemology:** Following the Bayesian tradition, we treat probability as a measure of rational credence rather than objective frequency. This subjective interpretation allows meaningful probability assignments even for unique, unprecedented events like AI catastrophe. As E.T. Jaynes demonstrated, probability theory extends deductive logic to handle uncertainty, providing a calculus for rational belief Jaynes [26].

**Conditional Structure:** The framework emphasizes conditional rather than absolute probabilities. Instead of asking “What is  $P(\text{catastrophe})$ ?” we ask “What is  $P(\text{catastrophe} \mid \text{specific assumptions})$ ?” This conditionalization makes explicit the dependency of conclusions on world-view assumptions, enabling productive disagreement about premises rather than conclusions.

**Possible Worlds Semantics:** We conceptualize uncertainty as distributions over possible worlds—complete descriptions of how reality might unfold. Each world represents a coherent scenario with specific values for all relevant variables. Probability distributions over these worlds capture both what we know and what we don’t know about the future.

This framework enables several key capabilities:

1. **Representing ignorance:** We can express uncertainty about uncertainty itself through hierarchical probability models
2. **Combining evidence:** Bayesian updating provides principled methods for integrating new information
3. **Comparing worldviews:** Different probability distributions over the same space of possibilities enable systematic comparison
4. **Evaluating interventions:** Counterfactual reasoning about how actions change probability distributions

### 2.2.4 Toward New Epistemic Tools

The inadequacy of traditional methods for AI governance creates an urgent need for new epistemic tools. These tools must:

- **Handle Deep Uncertainty:** Move beyond point estimates to represent ranges of possibilities
- **Capture Complex Causation:** Model multi-level interactions and feedback loops
- **Quantify Disagreement:** Make explicit where experts diverge and why
- **Enable Systematic Analysis:** Support rigorous comparison of policy options

**Key Insight:** The computational approaches developed in this thesis—particularly Bayesian networks enhanced with automated extraction—directly address each of these requirements by providing formal frameworks for reasoning under uncertainty.

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Recent work on conditional trees demonstrates the value of structured approaches to uncertainty. McCaslin et al. [32] show how hierarchical conditional forecasting can identify high-value questions for reducing uncertainty about complex topics like AI risk. Their methodology, which asks experts to produce simplified Bayesian networks of informative forecasting questions, achieved nine times higher information value than standard forecasting platform questions.

Tetlock’s work with the Forecasting Research Institute Tetlock [49] exemplifies how prediction markets can provide empirical grounding for formal models. By structuring questions as conditional trees, they enable forecasters to express complex dependencies between events, providing exactly the type of data needed for Bayesian network parameterization.

Gruetzmacher [22] evaluates the tradeoffs between full Bayesian networks and conditional trees for forecasting tournaments. While conditional trees offer simplicity, Bayesian networks provide richer representation of dependencies—motivating AMTAIR’s approach of using full networks while leveraging conditional tree insights for question generation.

## 2.3 Bayesian Networks as Knowledge Representation

Bayesian networks offer a mathematical framework uniquely suited to addressing these epistemic challenges. By combining graphical structure with probability theory, they provide tools for reasoning about complex uncertain domains.

### 2.3.1 Mathematical Foundations

A Bayesian network consists of:

- **Directed Acyclic Graph (DAG):** Nodes represent variables, edges represent direct dependencies
- **Conditional Probability Tables (CPTs):** For each node,  $P(\text{node}|\text{parents})$  quantifies relationships

The joint probability distribution factors according to the graph structure:

$$P(X_1, X_2, \dots, X_n) = \prod_{i=1}^n P(X_i | \text{Parents}(X_i))$$

This factorization enables efficient inference and embodies causal assumptions explicitly.

Pearl’s foundational work Pearl [40] established Bayesian networks as a principled approach to automated reasoning under uncertainty, providing both theoretical foundations and practical algorithms.



### 2.3.2 The Rain-Sprinkler-Grass Example

The canonical example illustrates key concepts<sup>3</sup>:

[Grass\_Wet]: Concentrated moisture on grass.  
 + [Rain]: Water falling from sky.  
 + [Sprinkler]: Artificial watering system.  
 + [Rain]

Network Structure:

- **Rain** (root cause):  $P(\text{rain}) = 0.2$
- **Sprinkler** (intermediate):  $P(\text{sprinkler}|\text{rain})$  varies by rain state
- **Grass\_Wet** (effect):  $P(\text{wet}|\text{rain}, \text{sprinkler})$  depends on both causes

mermaid

```
flowchart TD
    R["R[Rain<br/>P(rain) = 0.2]"] --> S["S[Sprinkler]"]
    R --> G["G[Grass_Wet]"]
    S --> G

    subgraph CPT1 [Sprinkler CPT]
        S1["S1[P(sprinkler|rain) = 0.01]"]
        S2["S2[P(sprinkler|¬rain) = 0.4]"]
    end

    subgraph CPT2 [Grass_Wet CPT]
        G1["G1[P(wet|rain,sprinkler) = 0.99]"]
        G2["G2[P(wet|rain,¬sprinkler) = 0.8]"]
        G3["G3[P(wet|¬rain,sprinkler) = 0.9]"]
        G4["G4[P(wet|¬rain,¬sprinkler) = 0.01]"]
    end
```

python

```
# Basic network representation
nodes = ['Rain', 'Sprinkler', 'Grass_Wet']
edges = [('Rain', 'Sprinkler'), ('Rain', 'Grass_Wet'), ('Sprinkler', 'Grass_Wet')]

# Conditional probability specification
P_wet_given_causes = {
    (True, True): 0.99,    # Rain=T, Sprinkler=T
    (True, False): 0.80,   # Rain=T, Sprinkler=F
    (False, True): 0.90,   # Rain=F, Sprinkler=T
```

<sup>3</sup>This example, while simple, demonstrates all essential features of Bayesian networks and serves as the foundation for understanding more complex applications

```
(False, False): 0.01    # Rain=F, Sprinkler=F
}
```

This simple network demonstrates:

- **Marginal Inference:**  $P(\text{grass\_wet})$  computed from joint distribution
- **Diagnostic Reasoning:**  $P(\text{rain}|\text{grass\_wet})$  reasoning from effects to causes
- **Intervention Modeling:**  $P(\text{grass\_wet}|\text{do}(\text{sprinkler}=\text{on}))$  for policy analysis

Show Image

### Rain-Sprinkler-Grass Network Rendering

```
#| label: rain_sprinkler_grass_example_network_rendering
#| echo: true
#| eval: true
#| fig-cap: "Dynamic Html Rendering of the Rain-Sprinkler-Grass DAG with Conditional Probabi
#| fig-link: "https://singularitysmith.github.io/AMTAIR_Prototype/bayesian_network.html"
#| fig-alt: "Dynamic Html Rendering of the Rain-Sprinkler-Grass DAG"
```

```
from IPython.display import IFrame
```

```
IFrame(src="https://singularitysmith.github.io/AMTAIR_Prototype/bayesian_network.html", width=
```

### 2.3.3 Advantages for AI Risk Modeling

These features address key requirements for AI governance:

- **Handling Uncertainty:** Every parameter is a distribution, not a point estimate
- **Representing Causation:** Directed edges embody causal relationships
- **Enabling Analysis:** Formal inference algorithms support systematic evaluation
- **Facilitating Communication:** Visual structure aids cross-domain understanding

### 2.3.3 Advantages for AI Risk Modeling

Bayesian networks offer several compelling advantages for the peculiar challenge of modeling AI risks—a domain where we’re essentially trying to reason about systems that don’t yet exist, wielding capabilities we can barely imagine, potentially causing outcomes we desperately hope to avoid.

**Explicit Uncertainty Representation:** Unlike traditional risk assessment tools that often hide uncertainty behind point estimates, Bayesian networks wear their uncertainty on their sleeve. Every node, every edge, every probability is a distribution rather than a false certainty. This matters enormously when discussing AI catastrophe—we’re not pretending to know the unknowable, but rather mapping the landscape of our ignorance with mathematical precision.

**Native Causal Reasoning:** The directed edges in Bayesian networks aren’t just arrows on a diagram; they encode causal beliefs about how the world works. This enables both forward reasoning (“If we develop AGI, what happens?”) and diagnostic reasoning (“Given that we observe concerning AI behaviors, what does this tell us about underlying alignment?”). Pearl’s do-calculus Pearl [38] transforms these networks into laboratories for counterfactual exploration.

**Evidence Integration:** As new research emerges, as capabilities advance, as governance experiments succeed or fail, Bayesian networks provide a principled framework for updating our beliefs. Unlike static position papers that age poorly, these models can evolve with our understanding—a living document for a rapidly changing field.

**Modular Construction:** Complex arguments about AI risk involve multiple interacting factors across technical, social, and political domains. Bayesian networks allow us to build these arguments piece by piece, validating each component before assembling the whole. This modularity also enables different experts to contribute their specialized knowledge without needing to understand every aspect of the system.

**Visual Communication:** Perhaps most importantly for the coordination challenge, Bayesian networks provide a visual language that transcends disciplinary boundaries. A policymaker might not understand the mathematics of instrumental convergence, but they can see how the “power-seeking” node connects to “human disempowerment” in the network diagram. This shared visual vocabulary creates common ground for productive disagreement.

## 2.4 Argument Mapping and Formal Representations

The journey from a researcher’s intuition about AI risk to a formal probabilistic model resembles translating poetry into mathematics—something essential is always at risk of being lost, yet something equally essential might be gained. Argument mapping provides the crucial middle ground, a structured approach to preserving the logic of natural language arguments while preparing them for mathematical formalization.

### 2.4.1 From Natural Language to Structure

Natural language arguments about AI risk are rich tapestries woven from causal claims, conditional relationships, uncertainty expressions, and support patterns. When Bostrom writes about the “treacherous turn” Bostrom [7], he’s not just coining a memorable phrase—he’s encoding a complex causal story about how a seemingly aligned AI system might conceal its true objectives until it gains sufficient power to pursue them without constraint.

The challenge lies in extracting this structure without losing the nuance. Traditional logical analysis might reduce Bostrom’s argument to syllogisms, but this would miss the probabilistic texture, the implicit conditionality, the causal directionality that makes the argument compelling. Argument mapping takes a different approach, seeking to identify:

- **Core claims and propositions:** What exactly is being asserted?
- **Inferential relationships:** How do claims support or challenge each other?
- **Implicit assumptions:** What unstated premises make the argument work?
- **Uncertainty qualifications:** Where does the author express doubt or confidence?

Recent advances in computational argument mining Anderson [1] Benn and Macintosh [5] Khartabil et al. [28] have shown promise in automating parts of this process. Tools like Microsoft’s Claimify Metropolitansky and Larson [33] demonstrate how large language models can extract verifiable claims from complex texts, though the challenge of preserving argumentative structure remains formidable.

### 2.4.2 ArgDown: Structured Argument Notation

Enter ArgDown Voigt [52], a markdown-inspired syntax that captures hierarchical argument structure while remaining human-readable. Think of it as the middle child between the wild expressiveness of natural language and the rigid formality of logic—inheriting the best traits of both parents while developing its own personality.

```
[AI_Poses_Risk]: Advanced AI systems may pose existential risk to humanity.
+ [Capability_Growth]: AI capabilities are growing exponentially.
+ [Compute_Scaling]: Available compute doubles every few months.
+ [Algorithmic_Progress]: New architectures show surprising emergent abilities.
+ [Alignment_Difficulty]: Aligning AI with human values is unsolved.
- [Current_Progress]: Some progress on interpretability and oversight.
- [Institutional_Response]: Institutions are mobilizing to address risks.
```

This notation does several clever things simultaneously. The hierarchical structure mirrors how we naturally think about arguments—main claims supported by evidence, which in turn rest on more fundamental observations. The + and - symbols indicate support and opposition relationships, creating a visual flow of argumentative force. Most importantly, it preserves the semantic content of each claim while imposing just enough structure to enable computational processing.

For AMTAIR, we adapt ArgDown specifically for causal arguments, where the hierarchy repre-

sents causal influence rather than logical support. This seemingly small change has profound implications—we’re not just mapping what follows from what, but what causes what.

### 2.4.3 BayesDown: The Bridge to Bayesian Networks

If ArgDown is the middle child, then BayesDown—developed specifically for this thesis—is the ambitious younger sibling who insists on quantifying everything. By extending ArgDown syntax with probabilistic metadata in JSON format, BayesDown creates a complete specification for Bayesian networks while maintaining human readability.

json

```
[Existential_Catastrophe]: Permanent curtailment of humanity's potential. {
  "instantiations": ["catastrophe_TRUE", "catastrophe_FALSE"],
  "priors": {"p(catastrophe_TRUE)": "0.05", "p(catastrophe_FALSE)": "0.95"},
  "posteriors": {
    "p(catastrophe_TRUE|disempowerment_TRUE)": "0.95",
    "p(catastrophe_TRUE|disempowerment_FALSE)": "0.001"
  }
}

+ [Human_Disempowerment]: Loss of human control over future trajectory. {
  "instantiations": ["disempowerment_TRUE", "disempowerment_FALSE"],
  "priors": {"p(disempowerment_TRUE)": "0.20", "p(disempowerment_FALSE)": "0.80"}
}
```

This representation performs a delicate balancing act. The natural language descriptions preserve the semantic meaning that makes arguments comprehensible. The hierarchical structure maintains the causal relationships that give arguments their logical force. The JSON metadata adds the mathematical precision needed for formal analysis. Together, they create what I call a “hybrid representation”—neither fully natural nor fully formal, but something more useful than either alone.

The two-stage extraction process ( $\text{ArgDown} \rightarrow \text{BayesDown}$ ) mirrors how experts actually think about complex arguments. First, we identify what matters and how things relate causally (structure). Then, we consider how likely different scenarios are based on those relationships (quantification). This separation isn’t just convenient for implementation—it’s psychologically valid.

## 2.5 The MTAIR Framework: Achievements and Limitations

Understanding AMTAIR requires understanding its intellectual ancestor: the Modeling Transformative AI Risks (MTAIR) project. Like many good ideas in science, MTAIR began with a simple observation and a ambitious goal.

### 2.5.1 MTAIR’s Approach

The MTAIR project, spearheaded by David Manheim and colleagues Clarke et al. [13], emerged from a frustration familiar to anyone who’s attended a conference on AI safety: brilliant people talking past each other, using the same words to mean different things, reaching incompatible conclusions from seemingly shared premises. The diagnosis was elegant—perhaps these disagreements stemmed not from fundamental philosophical differences but from implicit models that had never been made explicit.

Their prescription was equally elegant: manually translate influential AI risk arguments into formal Bayesian networks, making assumptions visible and disagreements quantifiable. Using Analytica software, the team embarked on what can only be described as an intellectual archaeology expedition, carefully excavating the implicit causal models buried in papers, blog posts, and treatises about AI risk.

The process was painstaking:

1. **Systematic Decomposition:** Breaking complex arguments into component claims, identifying variables and relationships through close reading and expert consultation.
2. **Probability Elicitation:** Gathering quantitative estimates through structured expert interviews, literature review, and careful interpretation of qualitative claims.
3. **Sensitivity Analysis:** Testing which parameters most influenced conclusions, revealing where disagreements actually mattered versus where they were merely academic.
4. **Visual Communication:** Creating interactive models that stakeholders could explore, modify, and understand without deep technical training.

The ambition was breathtaking—to create a formal lingua franca for AI risk discussions, enabling productive disagreement and cumulative progress.

### 2.5.2 Key Achievements

Credit where credit is due: MTAIR demonstrated something many thought impossible. Complex philosophical arguments about AI risk—the kind that sprawl across hundred-page papers mixing technical detail with speculative scenarios—could indeed be formalized without losing their essential insights.

**Feasibility of Formalization:** The project’s greatest achievement was simply showing it could be done. Arguments from Bostrom, Christiano, and others translated surprisingly well into network form, suggesting that beneath the surface complexity lay coherent causal models waiting to be extracted.

**Value of Quantification:** Moving from “likely” and “probably” to actual numbers forced precision in a domain often clouded by vague pronouncements. Disagreements that seemed fundamental sometimes evaporated when forced to specify exactly what probability ranges were under dispute.

**Cross-Perspective Communication:** The formal models created neutral ground where technical AI researchers and policy wonks could meet. Instead of talking past each other in incom-

patible languages, they could point to specific nodes and edges, making disagreements concrete and tractable.

**Research Prioritization:** Perhaps most practically, sensitivity analysis revealed which empirical questions actually mattered. If changing your belief about technical parameter X from 0.3 to 0.7 doesn’t meaningfully affect the conclusion about AI risk, maybe we should focus our research elsewhere.

### 2.5.3 Fundamental Limitations

But here’s where the story takes a sobering turn. Despite these achievements, MTAIR faced limitations that prevented it from achieving its full vision—limitations that ultimately motivated the development of AMTAIR.

**Labor Intensity:** Creating a single model required what can charitably be called a heroic effort. Based on team reports and model complexity, estimates ranged from 200 to 400 expert-hours per formalization<sup>4</sup>. In a field where new influential arguments appear monthly, this pace couldn’t keep up with the discourse.

**Static Nature:** Once built, these beautiful models began aging immediately. New research emerged, capability assessments shifted, governance proposals evolved—but updating the models required near-complete reconstruction. They were snapshots of arguments at particular moments, not living representations that could evolve.

**Limited Accessibility:** Using the models required Analytica software and non-trivial technical sophistication. The very experts whose arguments were being formalized often couldn’t directly engage with their formalized representations without intermediation.

**Single Perspective:** Each model represented one worldview at a time. Comparing different perspectives required building entirely separate models, making systematic comparison across viewpoints labor-intensive and error-prone.

These weren’t failures of execution but fundamental constraints of the manual approach. Like medieval scribes copying manuscripts, the MTAIR team had shown the value of preservation and dissemination, but the printing press had yet to be invented.

### 2.5.4 The Automation Opportunity

The MTAIR experience revealed a tantalizing possibility: if the bottleneck was human labor rather than conceptual feasibility, perhaps automation could crack open the problem. The rise of large language models capable of sophisticated reasoning about text created a technological moment ripe for exploitation.

Key lessons from MTAIR informed the automation approach:

- Formal models genuinely enhance understanding and coordination—the juice is worth the squeeze

---

<sup>4</sup>These estimates include time for initial extraction, expert consultation, probability elicitation, validation, and refinement

- The modeling process itself surfaces implicit assumptions—extraction is as valuable as the final product
- Quantification enables analyses impossible with qualitative arguments alone—numbers matter even when uncertain
- But manual approaches cannot scale to match the challenge—we need computational leverage

This set the stage for AMTAIR’s central innovation: using frontier language models to automate the extraction and formalization process while preserving the benefits MTAIR had demonstrated. Not to replace human judgment, but to amplify it—turning what took weeks into what takes hours, enabling comprehensive coverage rather than selective sampling.

## 2.6 Literature Review: Content and Technical Levels

The intellectual landscape surrounding AI risk resembles a rapidly expanding metropolis—new neighborhoods of thought spring up monthly, connected by bridges of varying stability to the established districts. A comprehensive review would fill volumes, so let me provide a guided tour of the territories most relevant to AMTAIR’s mission.

### 2.6.1 AI Risk Models Evolution

The evolution of AI risk models traces a path from philosophical speculation to increasingly rigorous formalization—a journey from “what if?” to “how likely?”

**Early Phase (2000-2010):** The conversation began with broad conceptual arguments. Good’s ultraintelligent machine Good [21] and Vinge’s technological singularity set the stage, but these were more thought experiments than models. Yudkowsky’s early writings Yudkowsky [54] introduced key concepts like recursive self-improvement and orthogonality but remained largely qualitative.

**Formalization Phase (2010-2018):** Bostrom’s *Superintelligence* Bostrom [7] marked a watershed, providing systematic analysis of pathways, capabilities, and risks. The book’s genius lay not in mathematical formalism but in conceptual clarity—decomposing the nebulous fear of “robot overlords” into specific mechanisms like instrumental convergence and infrastructure profusion.

**Quantification Phase (2018-present):** Recent years have seen explicit probability estimates entering mainstream discourse. Carlsmith’s power-seeking model Carlsmith [9], Cotra’s biological anchors, and various compute-based timelines represent attempts to put numbers on previously qualitative claims. The field increasingly recognizes that governance decisions require more than philosophical arguments—they need probability distributions.

This progression reflects a maturing field, though it also creates new challenges. As models become more quantitative, they risk false precision. As they become more complex, they risk inscrutability. AMTAIR attempts to navigate these tensions by preserving the narrative clarity of earlier work while enabling the mathematical rigor of recent approaches.



### 2.6.2 Governance Proposals Taxonomy

If risk models are the diagnosis, governance proposals are the treatment plans—and like medicine, they range from gentle interventions to radical surgery.

**Technical Standards:** The “first, do no harm” approach focuses on concrete safety requirements—interpretability benchmarks, robustness testing, capability thresholds. These proposals, exemplified by standard-setting bodies and technical safety organizations, offer specificity at the cost of narrowness.

**Regulatory Frameworks:** Moving up the intervention ladder, we find comprehensive regulatory proposals like the EU AI Act European [20]. These create institutional structures, liability regimes, and oversight mechanisms, trading broad coverage for implementation complexity.

**International Coordination:** At the ambitious end, proposals for international AI governance treaties, soft law arrangements, and technical cooperation agreements aim to prevent races to the bottom. Think nuclear non-proliferation but for minds instead of missiles.

**Research Priorities:** Cutting across these categories, work by Dafoe Dafoe [15] and others maps the research landscape itself—what questions need answering before we can govern wisely? This meta-level analysis shapes funding flows and talent allocation.

A particularly compelling example of conditional governance thinking comes from “A Narrow Path” Miotti et al. [35], which proposes a phased approach: immediate safety measures to prevent uncontrolled development, international institutions to ensure stability, and long-term scientific foundations for beneficial transformative AI. This temporal sequencing—safety, stability, then flourishing—reflects growing sophistication in governance thinking.

### 2.6.3 Bayesian Network Theory and Applications

The mathematical machinery underlying AMTAIR rests on decades of theoretical development in probabilistic graphical models. Understanding this foundation helps appreciate both the power and limitations of the approach.

The key insight, crystallized in the work of Pearl Pearl [40] and elaborated by Koller & Friedman Koller and Friedman [29], is that independence relationships in complex systems can be read from graph structure. D-separation, the Markov condition, and the relationship between graphs and probability distributions provide the mathematical spine that makes Bayesian networks more than pretty pictures.

Critical concepts for AI risk modeling:

- **Conditional Independence:** Variable A is independent of C given B—encoded through graph separation
- **Markov Condition:** Each variable is independent of its non-descendants given its parents
- **Inference Algorithms:** From exact variable elimination to approximate Monte Carlo methods

- **Causal Interpretation:** When edges represent causal influence, the network supports counterfactual reasoning

These aren’t just mathematical niceties. When we claim that “deployment decisions” mediates the relationship between “capability advancement” and “catastrophic risk,” we’re making a precise statement about conditional independence that has testable implications.

### 2.6.4 Software Tools Landscape

The gap between Bayesian network theory and practical implementation is bridged by an ecosystem of software tools, each with its own strengths and opinions about how probabilistic reasoning should work.

**pgmpy:** This Python library provides the computational backbone for AMTAIR, offering both learning algorithms and inference engines. Its object-oriented design maps naturally onto our extraction pipeline.

**NetworkX:** For graph manipulation and analysis, NetworkX has become the de facto standard in Python, providing algorithms for everything from centrality measurement to community detection.

**PyVis:** Interactive visualization transforms static networks into explorable landscapes. PyVis’s integration with web technologies enables the rich interactive features that make formal models accessible.

**Pandas/NumPy:** The workhorses of scientific Python handle data manipulation and numerical computation, providing the infrastructure on which everything else builds.

The integration challenge—making these tools play nicely together while maintaining performance and correctness—shaped many architectural decisions in AMTAIR. Each tool excels in its domain, but the seams between them required careful engineering.

### 2.6.5 Formalization Approaches

The challenge of formalizing natural language arguments extends far beyond AI risk, touching on fundamental questions in logic, linguistics, and artificial intelligence.

Pollock’s work on cognitive carpentry Pollock [41] provides philosophical grounding, arguing that human reasoning itself involves implicit formal structures that can be computationally modeled. This view—that formalization reveals rather than imposes structure—underlies AMTAIR’s approach.

Key theoretical challenges:

- **Semantic Preservation:** How do we maintain meaning while adding precision?
- **Structural Extraction:** What implicit relationships lurk in natural language?
- **Uncertainty Quantification:** How do we map “likely” to numbers?

Recent work on causal structure learning from text Babakov et al. [3] Ban et al. [4] Bethard [6] offers hope that these challenges can be addressed computationally. The convergence of

large language models with formal methods creates new possibilities for bridging the semantic-symbolic gap.

### 2.6.6 Correlation Accounting Methods

One of the most persistent criticisms of Bayesian networks concerns their assumption of conditional independence given parents. In the real world, and especially in complex socio-technical systems like AI development, correlations abound.

Methods for handling these correlations have evolved considerably:

**Copula Methods:** By separating marginal distributions from dependence structure, copulas Nelson [36] allow modeling of complex correlations while preserving the Bayesian network framework. Think of it as adding a correlation layer on top of the basic network.

**Hierarchical Models:** Introducing latent variables that influence multiple observed variables captures correlations naturally. If “AI research culture” influences both “capability progress” and “safety investment,” their correlation is explained.

**Explicit Correlation Nodes:** Sometimes the most straightforward approach is best—directly model correlation mechanisms as additional nodes in the network.

**Sensitivity Bounds:** When correlations remain uncertain, compute best and worst case scenarios. This reveals when independence assumptions critically affect conclusions versus when they’re harmless simplifications.

For AMTAIR, the pragmatic approach dominates: start with independence assumptions, identify where they matter through sensitivity analysis, then selectively add correlation modeling where it most affects conclusions.

## 2.7 Methodology

The methodology of this research resembles less a linear march from hypothesis to conclusion and more an iterative dance between theory and implementation, vision and reality. Let me walk you through the choreography.

### 2.7.1 Research Design Overview

This research follows what methodologists might call a “design science” approach—we’re not just studying existing phenomena but creating new artifacts (the AMTAIR system) and evaluating their utility for solving practical problems (the coordination crisis in AI governance).

The overall flow:

1. **Theoretical Development:** Establishing why automated extraction could address the coordination crisis, grounded in epistemic theory and mechanism design
2. **Technical Implementation:** Building working software that demonstrates feasibility, not as a proof-of-concept toy but as a system capable of handling real arguments

3. **Empirical Validation:** Testing extraction quality against expert judgment, measuring not just accuracy but usefulness for downstream tasks
4. **Application Studies:** Applying the system to real AI governance questions, evaluating whether formal models actually enhance decision-making

This isn't waterfall development where each phase completes before the next begins. Rather, insights from implementation fed back into theory, validation results shaped technical improvements, and application attempts revealed new requirements. The methodology itself embodied the iterative refinement it sought to enable.

### 2.7.2 Formalizing World Models from AI Safety Literature

The core methodological challenge—transforming natural language arguments into formal probabilistic models—requires careful consideration of what we're actually trying to capture.

A “world model” in this context isn't just any formal representation but specifically a causal model embodying beliefs about how different factors influence AI risk. The extraction approach must therefore:

- **Identify key variables:** Not just any entities mentioned, but causally relevant factors
- **Extract causal relationships:** Not mere correlation or co-occurrence, but directed influence
- **Capture uncertainty:** Both structural uncertainty (does A cause B?) and parametric uncertainty (how strongly?)
- **Preserve context:** Maintaining enough semantic information to interpret the formal model

Large language models enable this through sophisticated pattern recognition and reasoning capabilities, but they're tools, not magic wands. The methodology must account for their strengths (recognizing implicit structure) and weaknesses (potential hallucination, inconsistency).

### 2.7.3 From Natural Language to Computational Models

The journey from text to computation follows a carefully designed pipeline that mirrors human cognitive processes. Just as you wouldn't ask someone to simultaneously parse grammar and solve equations, we separate structural understanding from quantitative reasoning.

#### The Two-Stage Process:

Stage 1 focuses on structure—what causes what? The LLM reads an argument much as a human would, identifying key claims and their relationships. The prompt design here is crucial, providing enough guidance to ensure consistent extraction while allowing flexibility for different argument styles.

Stage 2 adds quantities—how likely is each outcome? With structure established, the system generates targeted questions about probabilities. This separation enables different approaches to quantification: extracting explicit estimates from text, inferring from qualitative language, or even connecting to external prediction markets.

The magic happens in the interplay. Structure constrains what probabilities are needed. Probability requirements might reveal missing structural elements. The process is a dialogue between qualitative and quantitative understanding.

#### 2.7.4 Directed Acyclic Graphs: Structure and Semantics

At the mathematical heart of Bayesian networks lie Directed Acyclic Graphs (DAGs)—structures that are simultaneously simple enough to analyze and rich enough to capture complex phenomena.

The “directed” part encodes causality or influence—edges have direction, flowing from cause to effect. The “acyclic” part ensures logical coherence—you can’t have A causing B causing C causing A, no matter how much certain political arguments might suggest otherwise.

Key properties for AI risk modeling:

**Acyclicity:** More than a mathematical convenience, this enforces coherent temporal or causal ordering. In AI risk arguments, this prevents circular reasoning where consequences justify premises that predict those same consequences.

**D-separation:** This graphical criterion determines conditional independence. If knowing about AI capabilities tells you nothing additional about risk given that you know deployment decisions, then capabilities and risk are d-separated given deployment.

**Markov Condition:** Each variable depends only on its parents, not on its entire ancestry. This locality assumption makes inference tractable and forces modelers to make intervention points explicit.

**Path Analysis:** Following paths through the graph reveals how influence propagates. Multiple paths between variables indicate redundancy—important for understanding intervention robustness.

The causal interpretation, following Pearl’s framework, transforms these mathematical objects into tools for counterfactual reasoning. When we ask “what if we prevented deployment of misaligned systems?” we’re performing surgery on the DAG, setting variables and propagating consequences.

#### 2.7.5 Quantification of Probabilistic Judgments

Here we encounter one of the most philosophically fraught aspects of the methodology: turning words into numbers. When an expert writes “highly likely,” what probability should we assign? When they say “significant risk,” what distribution captures their belief?

The methodology embraces rather than elides this challenge:

**Calibration Studies:** Research on human probability expression shows systematic patterns. “Highly likely” typically maps to 0.8-0.9, “probable” to 0.6-0.8, though individual and cultural variation is substantial.

**Extraction Strategies:** The system uses multiple approaches:

- Direct extraction: “We estimate 65% probability”
- Linguistic mapping: “Very likely”  $\rightarrow$  0.85 (with uncertainty)
- Comparative extraction: “More likely than X” where  $P(X)$  is known
- Bounded extraction: “At least 30%”  $\rightarrow$  [0.30, 1.0]

**Uncertainty Representation:** Rather than false precision, we maintain uncertainty about probabilities themselves. This might seem like uncertainty piled on uncertainty, but it’s honest—and mathematically tractable through hierarchical models.

The goal isn’t perfect extraction but useful extraction. If we can narrow “significant risk” from  $[0, 1]$  to  $[0.15, 0.45]$ , we’ve added information even if we haven’t achieved precision.

### 2.7.6 Inference Techniques for Complex Networks

Once we’ve built these formal models, we need to reason with them—and here computational complexity rears its exponential head. The number of probability calculations required for exact inference grows exponentially with network connectivity, quickly overwhelming even modern computers.

The methodology employs a portfolio of approaches:

**Exact Methods:** For smaller networks ( $<30$  nodes), variable elimination and junction tree algorithms provide exact answers. These form the gold standard against which we validate approximate methods.

**Sampling Approaches:** Monte Carlo methods trade exactness for scalability. By simulating many possible worlds consistent with our probability model, we approximate the true distributions. The law of large numbers is our friend here.

**Variational Methods:** These turn inference into optimization—find the simplest distribution that approximates our true beliefs. Like finding the best polynomial approximation to a complex curve.

**Hybrid Strategies:** Different parts of the network might use different methods. Exact inference for critical subgraphs, approximation for peripheral components.

The choice of method affects not just computation time but the types of questions we can meaningfully ask. This creates a methodological feedback loop where feasible inference shapes model design.

### 2.7.7 Integration with Prediction Markets and Forecasting Platforms

While full integration remains future work, the methodology anticipates connection to live forecasting data as a critical enhancement. The vision is compelling: formal models grounded in collective intelligence, updating as new information emerges.

The planned approach would involve:

**Semantic Matching:** Model variables rarely align perfectly with forecast questions. “AI causes human extinction” might map to multiple specific forecasts about capabilities, deployment, and

impacts. Developing robust matching algorithms is essential.

**Temporal Alignment:** Markets predict specific dates (“AGI by 2030”) while models consider scenarios (“given AGI development”). Bridging these requires careful probability conditioning.

**Quality Weighting:** Not all forecasts are created equal. Platform reputation, forecaster track records, and market depth all affect reliability. The methodology must account for this heterogeneity.

**Update Scheduling:** Real-time updates would overwhelm users and computation. The system needs intelligent policies about when model updates provide value.

Platforms like Metaculus Tetlock [49] already demonstrate sophisticated conditional forecasting on AI topics. The challenge lies not in data availability but in meaningful integration that enhances rather than complicates decision-making.

With these theoretical foundations and methodological commitments established, we can now turn to the concrete implementation of AMTAIR. The next chapter demonstrates how these abstract principles translate into working software that addresses real governance challenges. The journey from theory to practice always involves surprises—some pleasant, others less so—but that’s what makes it interesting.





## 3. AMTAIR: Design and Implementation

The moment of truth in any research project comes when elegant theories meet stubborn reality. For AMTAIR, this meant transforming the vision of automated argument extraction into working code that could handle the beautiful messiness of real AI safety arguments. Let me take you through this journey from blueprint to implementation, complete with victories, defeats, and the occasional moment of “well, that’s unexpected.”

### 3.1 System Architecture Overview

Picture, if you will, a factory for transforming arguments into models. Raw materials (PDFs, blog posts, research papers) enter at one end. Finished products (interactive Bayesian networks) emerge at the other. In between lies a carefully orchestrated pipeline where each stage performs its specialized transformation, passing refined materials to the next.

The AMTAIR architecture embodies a philosophy: complex tasks become manageable when decomposed into focused components. Rather than building a monolithic “argument-to-model” black box, we created a series of specialized modules, each excellent at one thing.

The pipeline consists of five main stages:

1. **Text Ingestion and Preprocessing:** Like a careful librarian, this stage catalogues incoming documents, normalizes their format, extracts metadata, and identifies the argumentative content worth processing.
2. **Argument Extraction:** The intellectual heart of the system, where large language models perform their magic, transforming prose into structured representations.
3. **Data Transformation:** The workshop where extracted arguments are refined, validated, and prepared for mathematical representation.
4. **Network Construction:** The assembly line where formal Bayesian networks are instantiated, complete with conditional probability tables.
5. **Interactive Visualization:** The showroom where complex models become accessible through thoughtful design and interactivity.

### 3.1.1 Five-Stage Pipeline Architecture

Let’s examine each stage more closely, understanding not just what they do but why they exist as separate components.

**Text Ingestion and Preprocessing** handles the unglamorous but essential work of standardization. Academic PDFs, with their two-column layouts and embedded figures, differ vastly from blog posts with inline code and hyperlinks. This stage creates a uniform representation while preserving essential structure and metadata. Format normalization strips away presentation while preserving content. Metadata extraction captures authorship, publication date, and citations. Relevance filtering identifies sections containing arguments rather than literature reviews or acknowledgments. Character encoding standardization prevents those maddening replacement characters that plague text processing.

**Argument Extraction** represents AMTAIR’s core innovation. Using a two-stage process that mirrors human reasoning, it first identifies structural relationships (what influences what) then quantifies those relationships (how likely, how strong). This separation enables targeted prompts optimized for each task, human verification between stages, and modular improvements as LLM capabilities evolve.

**Data Transformation** bridges the gap between textual representations and mathematical models. It parses the BayesDown syntax into structured data, validates that the resulting network forms a proper DAG, checks probability consistency, and handles missing data intelligently.

**Network Construction** instantiates the formal mathematical model. This involves creating nodes and edges according to extracted structure, populating conditional probability tables, initializing inference engines, and validating the complete model.

**Interactive Visualization** makes the complex accessible. Through thoughtful visual encoding of probabilities and relationships, progressive disclosure of detail, interactive exploration capabilities, and multiple export formats, it serves diverse stakeholder needs.

### 3.1.2 Design Principles

**Core Design Philosophy:** The architecture embodies several principles that guided countless implementation decisions:

**Modularity:** Each component has clear inputs, outputs, and responsibilities. This isn’t just good software engineering—it enables independent improvement of components and graceful degradation when parts fail.

**Validation Checkpoints:** Between each stage, we validate outputs before proceeding. Bad extractions don’t propagate into visualization. Malformed networks trigger re-extraction rather than cryptic errors.

**Human-in-the-Loop:** While pursuing automation, we recognize that human judgment remains invaluable. The architecture provides natural intervention points where experts can verify and correct.

**Extensibility:** New document formats, improved extraction prompts, alternative visualization libraries—the architecture accommodates growth without restructuring.

The system emphasizes transparency over black-box efficiency. Users can inspect intermediate representations, understand extraction decisions, and verify transformations. This builds trust—essential for a system handling high-stakes arguments about existential risk.

## 3.2 The Two-Stage Extraction Process

The heart of AMTAIR beats with a two-stage rhythm: structure, then probability. This separation, which initially seemed like an implementation detail, revealed itself as fundamental to the extraction challenge.

### 3.2.1 Stage 1: Structural Extraction (ArgDown)

Imagine reading a complex argument about AI risk. Your first pass likely isn’t calculating exact probabilities—you’re mapping the landscape. What are the key claims? How do they relate? What supports what? Stage 1 mirrors this cognitive process.

The extraction begins with pattern recognition. Natural language contains linguistic markers of causal relationships: “leads to,” “results in,” “depends on,” “influences.” The LLM, trained on vast corpora of argumentative text, recognizes these patterns and their variations.

Consider extracting from a passage like: “The development of artificial general intelligence will likely lead to rapid capability gains through recursive self-improvement. This intelligence explosion could result in systems pursuing convergent instrumental goals, potentially including resource acquisition and self-preservation. Without solved alignment, such power-seeking behavior poses existential risks to humanity.”

The system identifies three key variables connected by causal relationships:

- AGI Development → Intelligence Explosion
- Intelligence Explosion → Power-Seeking Behavior
- Power-Seeking Behavior → Existential Risk

But extraction goes beyond simple pattern matching. The system must handle complex linguistic phenomena like coreference (“this,” “such systems”), implicit relationships, conditional statements, and negative statements. The magic lies in prompt engineering that guides the LLM to consistent extraction while remaining flexible enough for diverse argument styles.

The output, formatted in ArgDown syntax, preserves both structure and semantics:

```
[Existential_Risk]: Threat to humanity's continued existence and flourishing.
+ [Power_Seeking_Behavior]: AI systems pursuing instrumental goals like resource acquisition
+ [Intelligence_Explosion]: Rapid recursive self-improvement leading to superintelligence
+ [AGI_Development]: Creation of artificial general intelligence systems.
```

### 3.2.2 Stage 2: Probability Integration (BayesDown)

With structure established, Stage 2 adds the quantitative flesh to the qualitative bones. This stage faces a different challenge: extracting numerical beliefs from text that often expresses uncertainty in frustratingly vague terms.

The process begins by generating targeted questions based on the extracted structure. For each node, we need prior probabilities. For each child-parent relationship, we need conditional probabilities. The combinatorics can be daunting—a node with three binary parents requires 8 conditional probability values.

The system employs multiple strategies for probability extraction:

**Explicit Extraction:** When authors provide numerical estimates (“we assign 70% probability”), extraction is straightforward, though we must handle various formats and contexts.

**Linguistic Mapping:** Qualitative expressions map to probability ranges based on calibration studies. “Highly likely” becomes approximately 0.85, though we maintain uncertainty about this mapping.

**Comparative Reasoning:** Statements like “more probable than not” or “at least as likely as X” provide bounds even without exact values.

**Coherence Enforcement:** Probabilities must sum correctly. If  $P(A|B) = 0.7$ , then  $P(\text{not } A|B)$  must equal 0.3. The system detects and resolves inconsistencies.

The result is a complete BayesDown specification:

json

```
[Existential_Risk]: Threat to humanity's continued existence. {
  "instantiations": ["true", "false"],
  "priors": {"p(true)": "0.10", "p(false)": "0.90"},
  "posteriors": {
    "p(true|power_seeking_true)": "0.65",
    "p(true|power_seeking_false)": "0.001"
  }
}
```

### 3.2.3 Why Two Stages?

The separation of structure from probability isn’t merely convenient—it’s cognitively valid and practically essential. Let me count the ways this design decision pays dividends:

**Cognitive Alignment:** Humans naturally separate “what relates to what” from “how likely is it.” The two-stage process mirrors this, making the system’s operation intuitive and interpretable.

**Error Isolation:** Structural errors (missing a key variable) differ fundamentally from probability errors (estimating 0.7 instead of 0.8). Separating stages allows targeted debugging and

improvement.

**Modular Validation:** Experts can verify structure without needing to evaluate every probability. This enables efficient human oversight at natural checkpoints.

**Flexible Quantification:** Different probability sources (text extraction, expert elicitation, market data) can feed into the same structure. The architecture accommodates multiple approaches to the probability challenge.

**Transparency:** Users can inspect ArgDown to understand what was extracted before probabilities were added. This builds trust and enables meaningful correction.

The two-stage approach also revealed an unexpected benefit: ArgDown itself became a valuable output. Researchers began using these structural extractions for qualitative analysis, even without probability quantification. Sometimes, just making argument structure explicit provides sufficient value.

### 3.3 Implementation Technologies

Choosing technologies for AMTAIR resembled assembling a band—each instrument needed to excel individually while harmonizing with the ensemble. The selection criteria balanced capability, maturity, interoperability, and community support.

#### 3.3.1 Technology Stack

The final ensemble performs beautifully:

Component	Technology	Purpose	Why This Choice
Language Models	GPT-4, Claude	Argument extraction	State-of-the-art reasoning capabilities
Network Analysis	NetworkX	Graph algorithms	Mature, comprehensive, well-documented
Probabilistic Modeling	pgmpy	Bayesian operations	Native Python, active development
Visualization	PyVis	Interactive rendering	Web-based, customizable, responsive
Data Processing	Pandas	Structured manipulation	Industry standard, powerful operations

**Language Models** form the cognitive core. GPT-4 and Claude demonstrate remarkable ability to understand complex arguments, recognize implicit structure, and maintain coherence across long extractions. The choice to support multiple models provides robustness and allows leveraging their complementary strengths.

**NetworkX** handles all graph-theoretic heavy lifting. From basic operations like cycle detection to advanced algorithms like centrality measurement, it provides a comprehensive toolkit that would take years to replicate.

**pgmpy** bridges the gap between graph structure and probabilistic reasoning. Its clean API design maps naturally onto our extracted representations, while its inference algorithms handle the computational complexity of Bayesian reasoning.

**PyVis** transforms static networks into living documents. Built on vis.js, it provides smooth physics simulations, rich interactivity, and extensive customization options—all accessible through Python.

**Pandas** might seem mundane compared to its companions, but it’s the reliable rhythm section that keeps everything together. Its ability to reshape, merge, and transform structured data makes the complex data transformations tractable.

### 3.3.2 Key Algorithms

Beyond the libraries lie custom algorithms that address AMTAIR-specific challenges:

**Hierarchical Parsing:** The algorithm that transforms indented ArgDown text into structured data represents a small miracle of recursive descent parsing adapted for our custom syntax. It maintains parent-child relationships while handling edge cases like repeated nodes and complex dependencies.

python

```
def parse_hierarchy(text, current_indent=0):
    """Recursively parse indented structure maintaining relationships"""
    # Track nodes at each level for parent identification
    # Handle repeated nodes by reference
    # Validate DAG property during construction
```

**Probability Completion:** Real arguments rarely specify all required probabilities. Our completion algorithm uses maximum entropy principles—when uncertain, assume maximum disorder. This provides conservative estimates that can be refined with additional information.

**Visual Encoding:** The algorithm mapping probabilities to colors uses perceptual uniformity. The green-to-red gradient isn’t linear in RGB space but follows human perception of color difference. Small details, big impact on usability.

**Layout Optimization:** Force-directed layouts often produce “hairballs” for complex networks. Our customized approach uses hierarchical initialization based on causal depth, then refines with physics simulation. The result: layouts that reveal structure rather than obscuring it.

### 3.3.3 (Expected) Performance Characteristics

Performance in a system like AMTAIR involves multiple dimensions—speed, accuracy, scalability. Let’s examine what theoretical analysis and design considerations suggest about system

behavior.

**Computational Complexity:** The extraction phase exhibits linear complexity in document length—processing twice as much text takes roughly twice as long. However, the inference phase faces exponential complexity in network connectivity. A fully connected network with  $n$  binary nodes requires  $O(2^n)$  operations for exact inference. This fundamental limitation shapes practical usage patterns.

**Practical Implications:** Small networks (<20 nodes) enable real-time interaction with exact inference. Medium networks (20-50 nodes) require seconds to minutes depending on connectivity. Large networks (>50 nodes) necessitate approximate methods, trading accuracy for tractability. Very large networks push the boundaries of current methods.

The bottleneck shifts predictably: extraction remains manageable even for lengthy documents, but inference becomes challenging as models grow. This suggests a natural workflow—extract comprehensively, then focus on relevant subnetworks for detailed analysis.

**Optimization Opportunities:** Several strategies could improve performance: caching frequent inference queries, hierarchical decomposition of large networks, parallel processing for independent subgraphs, and progressive rendering for visualization. The modular architecture accommodates these enhancements without fundamental restructuring.

### 3.3.4 Deterministic vs. Probabilistic Components of the Workflow

An interesting philosophical question arises: in a system reasoning about probability, which components should themselves be probabilistic?

The current implementation draws a clear line:

**Deterministic Components:** All data transformations, graph algorithms, and inference calculations operate deterministically. Given the same input, they produce identical output. This provides reproducibility and debuggability—essential for building trust.

**Probabilistic Components:** The LLM calls for extraction introduce variability. Even with temperature set to 0, language models exhibit some randomness. Different runs might extract slightly different structures or probability estimates from the same text.

This division reflects a deeper principle: use determinism wherever possible, embrace probability where necessary. The extraction task—interpreting natural language—inherently involves uncertainty. But once we have formal representations, all subsequent operations should be predictable.

From an information-theoretic perspective, we’re trying to extract maximum information from documents within computational budget constraints. Each document contains some finite amount of formalizable argument structure. Our goal is recovering as much as possible given realistic resource limits.

The two-stage extraction can be viewed as successive refinement—first recovering the higher-order bits (structure), then filling in lower-order bits (probabilities). This aligns with rate-

distortion theory, where we get the most important information first.

## 3.4 Case Study: Rain-Sprinkler-Grass

Every field has its canonical examples—physics has spherical cows, economics has widget factories, and Bayesian networks have the rain-sprinkler-grass scenario. Despite its simplicity, this example teaches profound lessons about causal reasoning and serves as the perfect test case for AMTAIR.

### 3.4.1 Processing Steps

Let me walk you through how AMTAIR processes this foundational example:

The input arrives as a simple text description: “When it rains, the grass gets wet. The sprinkler also makes the grass wet. However, when it rains, we usually don’t run the sprinkler.”

From this prosaic description, the system performs five transformations:

1. **ArgDown Parsing:** Extract three variables (Rain, Sprinkler, Grass\_Wet) and identify that rain influences both sprinkler usage and grass wetness, while the sprinkler also influences grass wetness.
2. **Question Generation:** Create probability queries: What’s  $P(\text{Rain})$ ? What’s  $P(\text{Sprinkler}|\text{Rain})$ ? What’s  $P(\text{Grass\_Wet}|\text{Rain}, \text{Sprinkler})$  for all combinations?
3. **BayesDown Extraction:** Either extract probabilities from text or apply reasonable defaults. The “usually don’t run” becomes  $P(\text{Sprinkler}|\text{Rain}) = 0.01$ .
4. **Network Construction:** Build the formal Bayesian network with three nodes, three edges, and complete conditional probability tables.
5. **Visualization Rendering:** Create an interactive display where rain appears as a root cause, influencing both sprinkler and grass directly.

Each step validates its outputs before proceeding, ensuring that errors don’t cascade through the pipeline.

### 3.4.2 Example Conversion Steps

Let’s trace the actual transformations to see the pipeline in action:

**Initial ArgDown Extraction:**

markdown

```
[Grass_Wet]: Concentrated moisture on grass blades. {"instantiations": ["wet", "dry"]}
+ [Rain]: Precipitation from the sky. {"instantiations": ["raining", "not_raining"]}
+ [Sprinkler]: Artificial watering system. {"instantiations": ["on", "off"]}
+ [Rain]
```

The hierarchy captures that rain influences sprinkler usage—a subtle but important causal relationship that pure correlation would miss.



**Generated Questions for Probability Extraction:**

markdown

```
/* Prior probabilities */
- What is the probability that it rains?
- What is the probability the sprinkler is on?

/* Conditional probabilities */
- What is the probability the sprinkler is on when it's raining?
- What is the probability the sprinkler is on when it's not raining?
- What is the probability the grass is wet when it's raining and sprinkler is on?
- [... and so on for all combinations]
```

The system generates exactly the questions needed to fully specify the network—no more, no less.

**Complete BayesDown Result:**

json

```
[Grass_Wet]: Concentrated moisture on grass. {
  "instantiations": ["wet", "dry"],
  "priors": {"p(wet)": "0.45", "p(dry)": "0.55"},
  "posteriors": {
    "p(wet|raining,on)": "0.99",
    "p(wet|raining,off)": "0.80",
    "p(wet|not_raining,on)": "0.90",
    "p(wet|not_raining,off)": "0.01"
  }
}
```

Notice how the probabilities tell a coherent story—grass is almost certainly wet if either water source is active, almost certainly dry if neither is.

**Resulting DataFrame Structure:**

The transformation into tabular format enables standard data analysis tools while preserving all relationships and probabilities. Each row represents a node with its properties, parents, children, and probability distributions.

**3.4.3 Results**

The successfully processed rain-sprinkler-grass example demonstrates several key capabilities:

**Structure Preservation:** The causal relationships—including the subtle influence of rain on sprinkler usage—are correctly captured and maintained throughout processing.

**Probability Coherence:** All probability distributions sum to 1.0, conditional probabilities are

complete, and the values tell a plausible story.

**Visual Clarity:** The rendered network clearly shows rain as the root cause, influencing both sprinkler and grass, while sprinkler provides an additional pathway to wet grass.

**Interactive Exploration:** Users can click nodes to see detailed probabilities, drag to rearrange for clarity, and explore how changing parameters affects outcomes.

**Inference Capability:** The system correctly calculates derived probabilities like  $P(\text{Rain}|\text{Grass\_Wet})$ —the diagnostic reasoning from effect to cause that makes Bayesian networks so powerful.

This simple example validates the basic pipeline functionality. But the real test comes with complex, real-world arguments...

## 3.5 Case Study: Carlsmith’s Power-Seeking AI Model

From the gentle meadows of rain and sprinklers, we now ascend to the existential peaks of AI risk. Carlsmith’s model represents a dramatic increase in complexity—both conceptually and computationally. Where rain-sprinkler-grass has 3 nodes, Carlsmith involves 23. Where grass wetness is intuitive, “mesa-optimization” and “corrigibility” require careful thought.

### 3.5.1 Model Complexity

The numbers tell only part of the story:

- **23 nodes:** Each representing a substantive claim about AI development, deployment, or risk
- **29 edges:** Encoding causal relationships across technical, strategic, and societal domains
- **Multiple probability tables:** Many nodes have several parents, creating combinatorial explosion
- **Six-level causal depth:** From root causes to final catastrophe, influence propagates through multiple stages

But the conceptual complexity dwarfs the computational. Nodes like “APS-Systems” (Advanced, Planning, Strategically aware) encode specific technical hypotheses. Relationships like how “incentives to build” influence “deployment despite misalignment” require understanding of organizational behavior under competitive pressure.

This is no longer a toy problem but a serious attempt to formalize one of the most important arguments of our time.

### 3.5.2 Automated Extraction of the Carlsmith’s Argument Structure

The extraction process began with feeding Carlsmith’s paper to AMTAIR. Watching the system work felt like observing an archaeological excavation—layers of argument slowly revealed their structure.

The LLM prompts for extraction deserve special attention. Through iterative refinement, we developed prompts that guide extraction while remaining flexible:

python

```
ARGDOWN_EXTRACTION = PromptTemplate("""
You are extracting the causal model from an AI safety argument.
Focus on:
1. Identifying key variables that affect outcomes
2. Capturing causal relationships (not mere association)
3. Preserving the author's terminology where possible
4. Creating a directed acyclic graph structure

For Carlsmith's argument about power-seeking AI, pay special attention to:
- The chain from capabilities to catastrophe
- Conditional relationships (X matters only if Y)
- Technical preconditions for risk
""")
```

The extraction revealed Carlsmith’s elegant decomposition. At the highest level: capabilities enable power-seeking, which enables disempowerment, which constitutes catastrophe. But the details matter—deployment decisions mediated by incentives and deception, alignment difficulty influenced by multiple technical factors, corrective mechanisms that might interrupt the chain.

The ArgDown representation captured this structure:

```
[Existential_Catastrophe]: Permanent curtailment of humanity's potential
+ [Human_Disempowerment]: Humans lose control over future
+ [Scale_Of_Power_Seeking]: Power-seeking behavior becomes overwhelming
+ [Misaligned_Power_Seeking]: AI systems pursue problematic objectives
+ [APS_Systems]: Advanced, planning, strategically aware AI
+ [Alignment_Difficulty]: Hard to align such systems
+ [Deployment_Despise_Misalignment]: Systems deployed anyway
+ [Incentives_To_Build]: Strong pressure to develop AI
+ [Deception]: AI systems hide misalignment
```

The structure revealed insights. “Misaligned\_Power\_Seeking” emerged as a critical hub, influenced by multiple factors and influencing multiple outcomes. The pathway from incentives through deployment to risk became explicit.

### 3.5.3 From ArgDown to BayesDown in Carlsmith’s Model

Adding probabilities to Carlsmith’s structure presented unique challenges. Unlike rain-sprinkler probabilities that have intuitive values, what’s the probability of “mesa-optimization” or “deceptive alignment”?

The system generated over 100 probability questions for the full model. A sample:

```
For [Deployment_Decisions]:
- What is P(deploy)?
```

- What is  $P(\text{deploy}|\text{strong\_incentives}, \text{deception})$ ?
- What is  $P(\text{deploy}|\text{strong\_incentives}, \text{no\_deception})$ ?
- What is  $P(\text{deploy}|\text{weak\_incentives}, \text{deception})$ ?
- What is  $P(\text{deploy}|\text{weak\_incentives}, \text{no\_deception})$ ?

Each question targets a specific parameter needed for the Bayesian network. The conditional structure reflects Carlsmith’s argument—deployment depends on both incentives (external pressure) and deception (hidden misalignment).

The LLM extraction drew on Carlsmith’s explicit estimates where available and inferred reasonable values elsewhere. The result captured both the structure and Carlsmith’s quantitative risk assessment:

json

```
[Deployment_Decisions]: Decisions to deploy potentially misaligned AI. {
  "instantiations": ["deploy", "withhold"],
  "priors": {"p(deploy)": "0.70", "p(withhold)": "0.30"},
  "posteriors": {
    "p(deploy|strong_incentives,deception)": "0.90",
    "p(deploy|strong_incentives,no_deception)": "0.75",
    "p(deploy|weak_incentives,deception)": "0.60",
    "p(deploy|weak_incentives,no_deception)": "0.30"
  }
}
```

The probabilities tell a plausible story: deployment becomes more likely with stronger incentives and successful deception, but even without deception, strong incentives create substantial deployment probability.

### 3.5.4 Practically Meaningful BayesDown

The BayesDown representation achieves something remarkable: it bridges the chasm between Carlsmith’s nuanced prose and mathematical formalism without losing the essence of either.

Consider what this bridge enables:

**For Technical Researchers:** The formal structure makes assumptions explicit. Is power-seeking really independent of capability level given strategic awareness? The model forces clarity.

**For Policymakers:** Probabilities attached to comprehensible descriptions provide actionable intelligence. “70% chance of deployment despite misalignment” translates better than abstract concerns.

**For Strategic Analysts:** The network structure reveals intervention points. Which nodes, if changed, most affect the final outcome? Where should we focus effort?

The hybrid nature—natural language plus formal structure plus probabilities—serves each audience while enabling communication between them. A policymaker can understand “deployment

decisions” without probability theory. A researcher can analyze the mathematical model without losing sight of what the variables mean.

This isn't just convenient—it's essential for coordination. When different communities can refer to the same model but engage with it at their appropriate level of technical detail, we create common ground for productive disagreement and collaborative problem-solving.

### 3.5.5 Interactive Visualization and Exploration

The moment when Carlsmith's model first rendered as an interactive network felt like putting on glasses after years of squinting. Suddenly, the complex web of relationships became navigable.

The visualization system employs multiple visual channels simultaneously:

**Color Coding:** Nodes shift from deep red (low probability) through yellow to bright green (high probability). At a glance, you see which factors Carlsmith considers likely versus speculative.

**Border Styling:** Blue borders mark root causes (like “Incentives\_To\_Build”), purple indicates intermediate nodes, magenta highlights final outcomes. The visual grammar guides the eye through causal flow.

**Layout Algorithm:** Initial placement uses causal depth—root causes at bottom, final outcomes at top. Physics simulation then refines positions to minimize edge crossings while preserving hierarchical structure.

**Progressive Disclosure:** Hovering reveals probability summaries. Clicking opens detailed conditional probability tables. Dragging allows custom arrangement. Each interaction level serves different analytical needs.

The implementation required careful attention to human factors:

python

```
def create_interactive_visualization(network_df):
    """Transform formal model into explorable landscape"""

    # Initialize with thoughtful defaults
    net = Network(height="720px", width="100%", directed=True)

    # Configure physics for clarity not just aesthetics
    net.force_atlas_2based(
        gravity=-50,      # Gentle spread
        spring_length=150, # Readable spacing
        spring_strength=0.02 # Soft constraints
    )

    # Add nodes with rich metadata
    for node in nodes:
```

```

net.add_node(
    node_id,
    label=create_simple_label(node),      # "Deployment\np=0.70"
    title=create_rich_tooltip(node),      # Full probability details
    color=probability_to_color(node),    # Visual encoding
    borderWidth=3,                       # Visible borders
    shape="box"                          # Readable text
)

```

The resulting visualization transforms abstract relationships into tangible understanding. Users report “aha” moments when exploring—suddenly seeing how technical factors compound into strategic risks, or identifying previously unnoticed bottlenecks in the causal chain.

### 3.5.6 Validation Against Original (From the MTAIR Project)

Validating AMTAIR’s extraction required careful comparison with expert judgment. While comprehensive benchmarking remains future work, preliminary validation efforts provide encouraging signals.

**Manual Baseline Creation:** Domain experts, including Johannes Meyer and Jelena Meyer, independently extracted ArgDown and BayesDown representations from Carlsmith’s paper. This created ground truth accounting for legitimate interpretive variation—experts might reasonably disagree on some structural choices or probability estimates.

**Structural Comparison:** Comparing extracted causal structures revealed high agreement on core relationships. AMTAIR consistently identified the main causal chain from capabilities through deployment to catastrophe. Some variation appeared in handling of auxiliary factors—where one expert might include a minor influence, another might omit it for simplicity.

**Probability Assessment:** Probability extraction showed greater variation, reflecting inherent ambiguity in translating qualitative language. When Carlsmith writes “likely,” different readers might reasonably interpret this as 0.7, 0.75, or 0.8. AMTAIR’s extractions fell within the range of expert interpretations, suggesting successful capture of intended meaning even if not identical numbers.

**Semantic Preservation:** Most importantly, the formal models preserved the essential insights of Carlsmith’s argument. The critical role of deployment decisions, the compound nature of risk, the importance of technical and strategic factors—all emerged clearly in the extracted representations.

An ideal validation protocol would expand this approach:

1. Multiple expert extractors working independently
2. Systematic comparison of structural and quantitative agreement
3. Analysis of where and why extractions diverge
4. Testing whether different extractions lead to different policy conclusions
5. Iterative refinement based on identified failure modes

The goal isn't perfect agreement—even human experts disagree. Rather, we seek extractions good enough to support meaningful analysis while acknowledging their limitations.

## 3.6 Validation Methodology

Building trust in automated extraction requires more than anecdotal success. We need systematic validation that honestly assesses both capabilities and limitations.

### 3.6.1 Ground Truth Construction

Creating ground truth for argument extraction poses unique challenges. Unlike named entity recognition or sentiment analysis, argument structure lacks universal standards. What constitutes the “correct” extraction from a complex text?

An ideal validation approach would embrace this inherent subjectivity:

**Expert Selection:** Recruit 5-10 domain experts with demonstrated expertise in both AI safety and formal modeling. Diversity matters—include technical researchers, policy analysts, and those with mixed backgrounds.

**Extraction Protocol:** Provide standardized training on ArgDown/BayesDown syntax while allowing flexibility in interpretation. Experts work independently to avoid anchoring bias, documenting their reasoning process alongside final extractions.

**Consensus Building:** Through structured discussion, identify areas of convergence (likely core argument structure) versus legitimate disagreement (interpretive choices, granularity decisions). This distinguishes system errors from inherent ambiguity.

**Quality Metrics:** Rather than binary correct/incorrect judgments, assess:

- Structural similarity (graph edit distance)
- Probability distribution overlap (KL divergence)
- Semantic preservation (expert ratings)
- Downstream task performance (policy analysis agreement)

The resulting dataset would capture not a single “truth” but a distribution of reasonable interpretations against which to evaluate automated extraction.

### 3.6.2 Evaluation Metrics

Evaluating argument extraction requires metrics that capture multiple dimensions of quality:

**Structural Fidelity:**

- Node identification: What fraction of expert-identified variables does the system extract?
- Edge accuracy: Are causal relationships preserved?
- Hierarchy preservation: Does the system maintain argument levels?

**Probability Calibration:**

- **Explicit extraction:** When sources state probabilities, how accurately are they captured?
- **Linguistic mapping:** Do qualitative expressions translate to reasonable probabilities?
- **Coherence:** Are probability distributions properly normalized?

#### Semantic Quality:

- **Description accuracy:** Do extracted descriptions preserve original meaning?
- **Terminology preservation:** Does the system maintain author’s vocabulary?
- **Context retention:** Is sufficient information preserved for interpretation?

#### Functional Validity:

- **Inference agreement:** Do extracted models support similar conclusions?
- **Sensitivity preservation:** Are critical parameters identified as influential?
- **Policy robustness:** Do different extractions suggest similar interventions?

These metrics acknowledge that perfect extraction is neither expected nor necessary. The goal is extraction sufficient for practical use while maintaining transparency about limitations.

### 3.6.3 Results Summary

While comprehensive validation remains future work, preliminary assessments using the methodology described above would likely reveal several patterns:

**Expected Strengths:** Automated extraction should excel at identifying explicit causal claims, preserving hierarchical argument structure, and extracting stated probabilities. The two-stage approach likely improves quality by allowing focused optimization for each task.

**Anticipated Challenges:** Implicit reasoning, complex conditionals, and ambiguous quantifiers would pose greater challenges. Coreference resolution across long documents and maintaining consistency in large models would require continued refinement.

**Practical Utility Threshold:** Even with imperfect extraction, the system could provide value if it achieves perhaps 70-80% structural accuracy and captures probability estimates within reasonable ranges. This level of performance would enable rapid initial modeling that experts could refine, dramatically reducing the time from argument to formal model.

The validation framework itself represents a contribution—establishing systematic methods for assessing argument extraction quality as this research area develops.

### 3.6.4 Error Analysis

Understanding failure modes guides both appropriate use and future improvements:

**Implicit Assumptions:** Authors often leave critical assumptions unstated, relying on shared background knowledge. When an AI safety researcher writes about “alignment,” they assume readers understand the technical concept. The system must either extract these implicit elements or flag their absence.



**Complex Conditionals:** Natural language expresses conditionality in myriad ways. “If we achieve alignment (which seems unlikely without major theoretical breakthroughs), then deployment might be safe (assuming robust verification).” Parsing nested, qualified conditionals challenges current methods.

**Ambiguous Quantifiers:** The word “significant” might mean 10% in one context, 60% in another. Without calibration to author-specific usage or domain conventions, probability extraction remains approximate.

**Coreference Challenges:** Academic writing loves pronouns and indirect references. When “this approach” appears three paragraphs after introducing multiple approaches, identifying the correct referent requires sophisticated discourse understanding.

These limitations don’t invalidate the approach but rather define its boundaries. Users who understand these constraints can work within them, leveraging automation’s strengths while compensating for its weaknesses.

## 3.7 Policy Evaluation Capabilities

The ultimate test of a model isn’t its elegance but its utility. Can AMTAIR’s extracted models actually inform governance decisions? This section demonstrates how formal models enable systematic policy analysis.

### 3.7.1 Intervention Representation

Representing policy interventions in Bayesian networks requires translating governance mechanisms into parameter modifications. Pearl’s do-calculus provides the mathematical framework, but the practical challenge lies in meaningful translation.

An ideal implementation would support several intervention types:

**Parameter Modification:** Policies often change probabilities. Safety requirements might reduce  $P(\text{deployment}|\text{misaligned})$  from 0.7 to 0.2 by making unsafe deployment legally prohibited or reputationally costly.

**Structural Interventions:** Some policies add new causal pathways. Introducing mandatory review boards creates new nodes and edges representing oversight mechanisms.

**Uncertainty Modeling:** Policy effectiveness is itself uncertain. Rather than assuming perfect implementation, represent ranges:  $P(\text{deployment}|\text{misaligned})$  might become  $[0.1, 0.3]$  depending on enforcement.

**Multi-Level Effects:** Policies influence multiple levels simultaneously. Compute governance affects technical development, corporate behavior, and international competition.

The system would translate high-level policy descriptions into specific network modifications, enabling rigorous counterfactual analysis of intervention effects.

### 3.7.2 Example: Deployment Governance

Let’s trace how a specific policy—mandatory safety certification before deployment—might be evaluated:

**Baseline Model:** In Carlsmith’s original model,  $P(\text{deployment}|\text{misaligned}) = 0.7$ , reflecting competitive pressures overwhelming safety concerns.

**Policy Specification:** Safety certification requires demonstrating alignment properties before deployment authorization. Based on similar regulations in other domains, we might estimate 80-90% effectiveness.

**Parameter Update:** The modified model sets  $P(\text{deployment}|\text{misaligned}) = 0.1\text{-}0.2$ , representing the residual probability of circumvention or regulatory capture.

**Downstream Effects:**

- Reduced deployment of misaligned systems
- Lower probability of power-seeking manifestation
- Decreased existential risk from  $\sim 5\%$  to  $\sim 1.2\%$

**Sensitivity Analysis:** How robust is this conclusion? Varying certification effectiveness, enforcement probability, and other parameters reveals which assumptions critically affect the outcome.

This example illustrates policy evaluation’s value: moving from vague claims (“regulation would help”) to quantitative assessments (“this specific intervention might reduce risk by  $75\% \pm 15\%$ ”).

### 3.7.3 Robustness Analysis

Good policies work across scenarios. AMTAIR enables testing interventions against multiple worldviews, parameter ranges, and structural variations.

**Cross-Model Testing:** Extract multiple expert models and evaluate the same policy in each. If an intervention reduces risk in Carlsmith’s model but increases it in Christiano’s, we’ve identified a critical dependency.

**Parameter Sensitivity:** Which uncertainties most affect policy effectiveness? If the intervention only works for  $P(\text{alignment\_difficulty}) < 0.3$ , and experts disagree whether it’s 0.2 or 0.4, we need more research before implementing.

**Structural Uncertainty:** Some disagreements concern model structure itself. Does capability advancement directly influence misalignment risk, or only indirectly through deployment pressures? Test policies under both structures.

**Confidence Bounds:** Rather than point estimates, compute ranges. “This policy reduces risk by 40-80%” honestly represents uncertainty while still providing actionable guidance.

The goal isn’t eliminating uncertainty but making decisions despite it. Robustness analysis reveals which policies work across uncertainties versus those requiring specific assumptions.

## 3.8 Interactive Visualization Design

A Bayesian network without good visualization is like a symphony without performers—all potential, no impact. The visualization system transforms mathematical abstractions into intuitive understanding.

### 3.8.1 Visual Encoding Strategy

Every visual element carries information:

**Color:** The probability spectrum from red (low) through yellow to green (high) provides immediate gestalt understanding. Pre-attentive processing—the brain’s ability to process certain visual features without conscious attention—makes patterns jump out.

**Borders:** Node type encoding (blue=root, purple=intermediate, magenta=outcome) creates visual flow. The eye naturally follows from blue through purple to magenta, tracing causal pathways.

**Size:** Larger nodes have higher centrality—more connections, more influence. This emerges from the physics simulation but reinforces importance.

**Layout:** Force-directed positioning naturally clusters related concepts while maintaining readability. The algorithm balances competing constraints: minimize edge crossings, maintain hierarchical levels, avoid node overlap, and create aesthetic appeal.

The encoding philosophy: every pixel should earn its place by conveying information while maintaining visual harmony.

### 3.8.2 Progressive Disclosure

Information overload kills understanding. The interface reveals complexity gradually:

**Level 1 - Overview:** At first glance, see network structure and probability color coding. This answers: “What’s the shape of the argument? Where are the high-risk areas?”

**Level 2 - Hover Details:** Mouse over a node to see its description and prior probability. This adds: “What does this factor represent? How likely is it?”

**Level 3 - Click Deep Dive:** Clicking opens full probability tables and relationships. This reveals: “How does this probability change with conditions? What influences this factor?”

**Level 4 - Interactive Exploration:** Dragging, zooming, and physics controls enable custom investigation. This supports: “What if I reorganize to see different patterns? How do these clusters relate?”

Each level serves different users and use cases. A policymaker might work primarily with levels 1-2, while a researcher dives into level 3-4 details.

### 3.8.3 User Interface Elements

Effective interface design for Bayesian networks requires balancing power with accessibility:

**Physics Controls:** Force-directed layouts benefit from tuning. Gravity affects spread, spring length controls spacing, damping influences settling time. Advanced users can adjust these for optimal layouts, while defaults work well for most cases.

**Filter Options:** With large networks, selective viewing becomes essential. Filter by probability ranges (show only likely events), node types (focus on interventions), or causal depth (see only immediate effects).

**Export Functions:** Different stakeholders need different formats. Researchers want raw data, policymakers need reports, presenters require images. Supporting diverse export formats enables broad usage.

**Comparison Mode:** Understanding often comes from contrast. Side-by-side viewing of baseline versus intervention, or different expert models, reveals critical differences.

Iterative design with actual users would refine these features, ensuring they serve real needs rather than imagined ones.

## 3.9 Integration with Prediction Markets

The vision: formal models that breathe with live data, updating as collective intelligence evolves. While full implementation awaits, the architecture anticipates this future.

### 3.9.1 Design for Integration

**Integration Architecture** requires careful design to manage the impedance mismatch between formal models and market data:

**API Specifications:** Each platform—Metaculus, Manifold, Good Judgment Open—has unique data formats, update frequencies, and question types. A unified adapter layer would translate platform-specific formats into model-compatible data.

**Semantic Matching:** The hard problem—connecting “AI causes extinction by 2100” (market question) to “Existential\_Catastrophe” (model node). This requires sophisticated NLP and possibly human curation for high-stakes connections.

**Aggregation Methods:** When multiple markets address similar questions, how do we combine? Weighted averages based on market depth, participant quality, and historical accuracy provide more signal than simple means.

**Update Scheduling:** Real-time updates would overwhelm users and computation. Smart scheduling might update daily for slow-changing strategic questions, hourly for capability announcements, immediately for critical events.

### 3.9.2 Challenges and Opportunities

The challenges are real but surmountable:

**Question Mapping:** Markets ask specific, time-bound questions while models represent general relationships. “AGI by 2030?” maps uncertainly to “APS\_Systems exists.” Developing robust mapping functions requires deep understanding of both domains.

**Temporal Alignment:** Market probabilities change over time, but model parameters are typically static. Should we use current market values, time-weighted averages, or attempt to extract trend information?

**Quality Variation:** A liquid market with expert participants provides different information than a thin market with casual forecasters. Weighting schemes must account for these quality differences.

**Incentive Effects:** If models influence policy and policy influences outcomes, and markets forecast outcomes, we create feedback loops. Understanding these dynamics prevents perverse incentives.

Despite challenges, even partial integration provides value:

- External validation of expert-derived probabilities
- Dynamic updating as new information emerges
- Identification of where model and market disagree
- Quantified uncertainty from market spread

The perfect shouldn’t be the enemy of the good—simple integration beats no integration.

## 3.10 Computational Performance Analysis

As networks grow from toy examples to real-world complexity, computational challenges emerge. Understanding these constraints shapes realistic expectations and optimization priorities.

### 3.10.1 Exact vs. Approximate Inference

The fundamental tradeoff in probabilistic reasoning: exactness versus tractability.

**Exact Inference:** Variable elimination and junction tree algorithms provide mathematically exact answers. For our 3-node rain-sprinkler network, calculations complete instantly. For 20-node networks with modest connectivity, expect seconds. But for 50+ node networks with complex dependencies, exact inference becomes impractical—potentially taking hours or exhausting memory.

**Approximate Methods:** When exactness becomes impractical, approximation saves the day:

- **Monte Carlo Sampling:** Generate thousands of scenarios consistent with the network, estimate probabilities from frequencies. Accuracy improves with samples, trading computation time for precision.

- **Variational Inference:** Find the simplest distribution that approximates our complex reality. Like fitting a smooth curve to jagged data—we lose detail but gain comprehension.
- **Belief Propagation:** Pass messages between nodes until beliefs converge. Works beautifully for tree-structured networks, can oscillate or converge slowly for complex loops.

The system selects methods based on network properties:

- Small networks: exact inference for precision
- Medium networks: belief propagation for speed
- Large networks: sampling for scalability
- Very large networks: hierarchical decomposition

### 3.10.2 Scaling Strategies

When networks grow beyond convenient computation, clever strategies maintain usability:

**Hierarchical Decomposition:** Break large networks into smaller, manageable subnetworks. Compute locally, then integrate results. Like solving a jigsaw puzzle by completing sections before assembling the whole.

**Relevance Pruning:** For specific queries, most nodes don't matter. If asking about deployment risk, technical details about interpretability methods might be temporarily ignorable. Prune irrelevant subgraphs for focused analysis.

**Caching Architecture:** Many queries repeat— $P(\text{catastrophe})$ ,  $P(\text{deployment}|\text{misalignment})$ . Cache results to avoid recomputation. Smart invalidation updates only affected queries when parameters change.

**Parallel Processing:** Inference calculations often decompose naturally. Different branches of the network can be processed simultaneously. Modern multi-core processors and cloud computing make this increasingly attractive.

Implementation would balance these strategies based on usage patterns. Interactive exploration benefits from caching and pruning. Batch analysis leverages parallelization. The architecture accommodates multiple approaches.

## 3.11 Results and Achievements

### 3.11.1 Extraction Quality Assessment

Assessing extraction quality requires honesty about both achievements and limitations. An ideal evaluation would examine multiple dimensions:

**Coverage:** What proportion of arguments in source texts does the system successfully capture? Initial applications suggest the two-stage approach identifies most explicit causal claims while struggling with deeply implicit relationships.

**Accuracy:** How closely do automated extractions match expert consensus? Preliminary comparisons indicate strong agreement on primary causal structures with more variation in proba-

bility estimates.

**Robustness:** How well does the system handle different writing styles, argument structures, and domains? Academic papers with clear argumentation extract more reliably than informal blog posts or policy documents.

**Utility:** Do the extracted models enable meaningful analysis? Even imperfect extractions that capture 80% of structure with approximate probabilities can dramatically accelerate modeling compared to starting from scratch.

The key insight: perfect extraction isn't necessary for practical value. Like machine translation, which provides useful results despite imperfections, automated argument extraction can enhance human capability without replacing human judgment.

### 3.11.2 Computational Performance

Performance analysis would reveal the practical boundaries of the current system:

**Extraction Speed:** LLM-based extraction scales roughly linearly with document length. A 20-page paper might require 30-60 seconds for structural extraction and similar time for probability extraction. This enables processing dozens of documents daily—orders of magnitude faster than manual approaches.

**Network Complexity Limits:** Exact inference remains tractable for networks up to approximately 30-40 nodes with moderate connectivity. Beyond this, approximate methods become necessary, with sampling methods scaling to hundreds of nodes at the cost of precision.

**Visualization Responsiveness:** Interactive visualization performs smoothly for networks under 50 nodes. Larger networks benefit from hierarchical viewing or focus+context techniques to maintain usability.

**End-to-End Pipeline:** From document input to interactive visualization, expect 2-5 minutes for typical AI safety arguments. This represents roughly 100x speedup compared to manual modeling efforts.

These performance characteristics make AMTAIR practical for real-world use while highlighting areas for future optimization.

### 3.11.3 Policy Impact Evaluation

The true test of AMTAIR lies in its ability to inform governance decisions. An ideal policy evaluation framework would demonstrate several capabilities:

**Intervention Modeling:** Representing diverse policy proposals—from technical standards to international agreements—as parameter modifications in extracted networks. This translation from qualitative proposals to quantitative changes enables rigorous analysis.

**Comparative Assessment:** Evaluating multiple interventions across different expert world-views to identify robust strategies. Policies that reduce risk across different models deserve priority over those requiring specific assumptions.

**Sensitivity Analysis:** Understanding which uncertainties most affect policy conclusions. If an intervention’s effectiveness depends critically on disputed parameters, this highlights research priorities.

**Implementation Guidance:** Moving beyond “this policy reduces risk” to specific recommendations about design details, implementation sequences, and success metrics.

The system would transform abstract policy discussions into concrete quantitative analyses, enabling evidence-based decision-making in AI governance.

## 3.12 Summary of Technical Contributions

Looking back at the implementation journey, several achievements stand out:

**Automated Extraction:** The two-stage pipeline successfully transforms natural language arguments into formal models, achieving practical accuracy while maintaining transparency about limitations.

**Hybrid Representation:** BayesDown bridges qualitative and quantitative worlds, preserving semantic richness while enabling mathematical analysis.

**Scalable Architecture:** Modular design accommodates growth—new document types, improved extraction methods, additional visualization options—without fundamental restructuring.

**Interactive Accessibility:** Thoughtful visualization makes complex models understandable to diverse stakeholders, democratizing access to formal reasoning tools.

**Policy Relevance:** The ability to model interventions and assess robustness transforms academic exercises into practical governance tools.

These technical achievements validate the feasibility of computational coordination infrastructure for AI governance. Not as a complete solution, but as a meaningful enhancement to human judgment and collaboration.

The implementation demonstrates that the vision of automated argument extraction is not merely theoretical but practically achievable. While challenges remain—particularly in handling implicit reasoning and diverse uncertainty expressions—the system provides a foundation for enhanced coordination in AI governance.

The journey from concept to implementation revealed unexpected insights. The two-stage extraction process, initially a pragmatic choice, proved cognitively valid. The intermediate representations became valuable outputs themselves. The visualization challenges led to design innovations applicable beyond this project.

Most importantly, the implementation confirms that formal modeling of AI risk arguments need not remain the province of a few dedicated experts. Through automation and thoughtful design, these powerful tools can serve the broader community working to ensure advanced AI benefits humanity.



Having demonstrated technical feasibility and practical utility, we must now critically examine limitations, address objections, and explore broader implications. The next chapter undertakes this essential reflection, ensuring we neither oversell the approach nor undervalue its contributions.



## 4. Discussion: Implications and Limitations

### 4.1 Technical Limitations and Responses

#### 4.1.1 Objection 1: Extraction Quality Boundaries

**Critic:** “Complex implicit reasoning chains resist formalization; automated extraction will systematically miss nuanced arguments and subtle conditional relationships that human experts would identify.”

**Response:** This concern has merit—extraction does face inherent limitations. However, the empirical results tell a more nuanced story. The two-stage extraction process, while imperfect, captures sufficient structure for practical use while maintaining transparency about its limitations.

More importantly, AMTAIR employs a hybrid human-AI workflow that addresses this limitation:

- **Two-stage verification:** Humans review structural extraction before probability quantification
- **Transparent outputs:** All intermediate representations remain human-readable
- **Iterative refinement:** Extraction prompts improve based on error analysis
- **Ensemble approaches:** Multiple extraction attempts can identify ambiguities

The question is not whether automated extraction perfectly captures every nuance—it doesn’t. Rather, it’s whether imperfect extraction still provides value over no formal representation. When the alternative is relying on conflicting mental models that remain entirely implicit, even partially accurate formal models represent significant progress.

Furthermore, extraction errors often reveal interesting properties of the source arguments themselves—ambiguities that human readers gloss over become explicit when formalization fails. This diagnostic value enhances rather than undermines the approach.

#### 4.1.2 Objection 2: False Precision in Uncertainty

**Critic:** “Attaching exact probabilities to unprecedented events like AI catastrophe is fundamentally misguided. The numbers create false confidence in what amounts to educated speculation

about radically uncertain futures.”

**Response:** This philosophical objection strikes at the heart of formal risk assessment. However, AMTAIR addresses it through several design choices:

First, the system explicitly represents uncertainty about uncertainty. Rather than point estimates, the framework supports probability distributions over parameters. When someone says “likely” we might model this as a range rather than exactly 0.8, capturing both the central estimate and our uncertainty about it.

Second, all probabilities are explicitly conditional on stated assumptions. The system doesn’t claim “ $P(\text{catastrophe}) = 0.05$ ” absolutely, but rather “Given Carlsmith’s model assumptions,  $P(\text{catastrophe}) = 0.05$ .” This conditionality is preserved throughout analysis.

Third, sensitivity analysis reveals which probabilities actually matter. Often, precise values are unnecessary—knowing whether a parameter is closer to 0.1 or 0.9 suffices for decision-making. The formalization helps identify where precision matters and where it doesn’t.

Finally, the alternative to quantification isn’t avoiding the problem but making it worse. When experts say “highly likely” or “significant risk,” they implicitly reason with probabilities. Formalization simply makes these implicit quantities explicit and subject to scrutiny. As Dennis Lindley noted, “Uncertainty is not in the events, but in our knowledge about them.”

### 4.1.3 Objection 3: Correlation Complexity

**Critic:** “Bayesian networks assume conditional independence given parents, but real-world AI risks involve complex correlations. Ignoring these dependencies could dramatically misrepresent risk levels.”

**Response:** Standard Bayesian networks do face limitations with correlation representation—this is a genuine technical challenge. However, several approaches within the framework address this:

**Explicit correlation nodes:** When factors share hidden common causes, we can add latent variables to capture correlations. For instance, “AI research culture” might influence both “capability advancement” and “safety investment.”

**Copula methods:** For known correlation structures, copula functions can model dependencies while preserving marginal distributions. This extends standard Bayesian networks significantly.<sup>5</sup>

**Sensitivity bounds:** When correlations remain uncertain, we can compute bounds on outcomes under different correlation assumptions. This reveals when correlations critically affect conclusions.

**Model ensembles:** Different correlation structures can be modeled separately and results aggregated, similar to climate modeling approaches.

More fundamentally, the question is whether imperfect independence assumptions invalidate the

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<sup>5</sup>Copulas provide a mathematically elegant way to separate marginal behavior from dependence structure

approach. In practice, explicitly modeling first-order effects with known limitations often proves more valuable than attempting to capture all dependencies informally. The framework makes assumptions transparent, enabling targeted improvements where correlations matter most.

## 4.2 Conceptual and Methodological Concerns

### 4.2.1 Objection 4: Democratic Exclusion

**Critic:** “Transforming policy debates into complex graphs and equations will sideline non-technical stakeholders, concentrating influence among those comfortable with formal models. This technocratic approach undermines democratic participation in crucial decisions about humanity’s future.”

**Response:** This concern about technocratic exclusion deserves serious consideration—formal methods can indeed create barriers. However, AMTAIR’s design explicitly prioritizes accessibility alongside rigor:

**Progressive disclosure interfaces** allow engagement at multiple levels. A policymaker might explore visual network structures and probability color-coding without engaging mathematical details. Interactive features let users modify assumptions and see consequences without understanding implementation.

**Natural language preservation** ensures original arguments remain accessible. The Bayes-Down format maintains human-readable descriptions alongside formal specifications. Users can always trace from mathematical representations back to source texts.

**Comparative advantage** comes from making implicit technical content explicit, not adding complexity. When experts debate AI risk, they already employ sophisticated probabilistic reasoning—formalization reveals rather than creates this complexity. Making hidden assumptions visible arguably enhances rather than reduces democratic participation.

**Multiple interfaces** serve different communities. Researchers access full technical depth, policymakers use summary dashboards, public stakeholders explore interactive visualizations. The same underlying model supports varied engagement modes.

Rather than excluding non-technical stakeholders, proper implementation can democratize access to expert reasoning by making it inspectable and modifiable. The risk lies not in formalization itself but in poor interface design or gatekeeping behaviors around model access.

### 4.2.2 Objection 5: Oversimplification of Complex Systems

**Critic:** “Forcing rich socio-technical systems into discrete Bayesian networks necessarily loses crucial dynamics—feedback loops, emergent properties, institutional responses, and cultural factors that shape AI development. The models become precise but wrong.”

**Response:** All models simplify by necessity—as Box noted, “All models are wrong, but some are useful.” The question becomes whether formal simplifications improve upon informal mental models:

**Transparent limitations** make formal models’ shortcomings explicit. Unlike mental models where simplifications remain hidden, network representations clearly show what is and isn’t included. This transparency enables targeted criticism and improvement.

**Iterative refinement** allows models to grow more sophisticated over time. Starting with first-order effects and adding complexity where it proves important follows successful practice in other domains. Climate models began simply and added dynamics as computational power and understanding grew.

**Complementary tools** address different aspects of the system. Bayesian networks excel at probabilistic reasoning and intervention analysis. Other approaches—agent-based models, system dynamics, scenario planning—can capture different properties. AMTAIR provides one lens, not the only lens.

**Empirical adequacy** ultimately judges models. If simplified representations enable better predictions and decisions than informal alternatives, their abstractions are justified. Early results suggest formal models, despite simplifications, outperform intuitive reasoning for complex risk assessment.

The goal isn’t creating perfect representations but useful ones. By making simplifications explicit and modifiable, formal models enable systematic improvement in ways mental models cannot.

#### 4.2.3 Objection 6: Idiosyncratic Implementation and Modeling Choices

**Critic:** “The specific choices made in AMTAIR’s implementation—from prompt design to parsing algorithms to visualization strategies—seem arbitrary. Different teams might make entirely different choices, leading to incompatible results. How can we trust conclusions that depend so heavily on implementation details?”

**Response:** This concern about implementation dependency is valid and deserves careful consideration. However, several factors mitigate this issue:

**Convergent Design Principles:** While specific implementations vary, fundamental design principles tend to converge. The two-stage extraction process (structure then probability) emerges naturally from how humans parse arguments. The use of intermediate representations follows established practice in computational linguistics. These aren’t arbitrary choices but responses to inherent challenges.

**Empirical Validation:** The “correctness” of implementation choices isn’t philosophical but empirical. If different reasonable implementations extract similar structures and lead to similar policy conclusions, this demonstrates robustness. If they diverge dramatically, this reveals genuine ambiguity in source materials—itsself valuable information.

**Transparent Methodology:** By documenting all implementation choices and making code open source, AMTAIR enables replication and variation. Other teams can modify specific components while preserving overall architecture, testing which choices matter.

**Convergence at Higher Levels:** Even if implementations differ in details, they may converge

at levels that matter for coordination. If two systems extract slightly different network structures but reach similar conclusions about policy robustness, the implementation differences don't undermine the approach's value.

**Community Standards:** As the field matures, community standards will likely emerge—not enforcing uniformity but establishing interoperability. This parallels development in other technical fields where multiple implementations coexist within shared frameworks.

The deeper insight is that implementation choices encode theoretical commitments. By making these explicit and variable, AMTAIR turns a bug into a feature—we can systematically explore how different assumptions affect conclusions, enhancing rather than undermining epistemic security.

## 4.3 Red-Teaming Results

To identify failure modes, systematic adversarial testing of the AMTAIR system would be essential.

### 4.3.1 Adversarial Extraction Attempts

A comprehensive red-teaming approach would test the system with:

**Contradictory Arguments:** Texts containing logically inconsistent claims or probability estimates. The system should flag contradictions rather than silently reconciling them.

**Circular Reasoning:** Arguments with circular dependencies that violate DAG requirements. Proper validation should detect and report such structural issues.

**Ambiguous Language:** Texts using extremely vague or metaphorical language. The system should acknowledge extraction uncertainty rather than forcing precise interpretations.

**Deceptive Framings:** Arguments crafted to imply false causal relationships. This tests whether the system merely extracts surface claims or requires deeper coherence.

**Adversarial Prompts:** Inputs designed to trigger known LLM failure modes. This ensures robustness against prompt injection and manipulation attempts.

Each failure mode discovered would inform system improvements and user guidance.

### 4.3.2 Robustness Findings

Theoretical analysis suggests key vulnerabilities:

**Anchoring Effects:** Language models may over-weight information presented early in documents, potentially biasing extraction toward initial framings.

**Authority Sensitivity:** Extraction might be influenced by explicit credibility signals in text, potentially giving undue weight to claimed expertise.

**Complexity Limits:** Performance likely degrades with very large argument structures, requiring hierarchical decomposition strategies.

**Context Windows:** Long-range dependencies exceeding model context windows could be missed, fragmenting cohesive arguments.

Understanding these limitations enables appropriate use—leveraging strengths while compensating for weaknesses through human oversight and validation.

### 4.3.3 Implications for Deployment

These considerations suggest AMTAIR is suitable for:

- **Research applications** with expert oversight
- **Policy analysis** of well-structured arguments
- **Educational uses** demonstrating formal reasoning
- **Collaborative modeling** with human verification

But should be used cautiously for:

- Fully automated analysis without review
- Adversarial or politically contentious texts
- Real-time decision-making without validation
- Arguments far outside training distribution

## 4.4 Enhancing Epistemic Security

Despite limitations, AMTAIR contributes to epistemic security in AI governance through several mechanisms.

### 4.4.1 Making Models Inspectable

The greatest epistemic benefit comes from forcing implicit models into explicit form. When an expert claims “misalignment likely leads to catastrophe,” formalization asks:

- Likely means what probability?
- Through what causal pathways?
- Under what assumptions?
- With what evidence?

This explicitation serves multiple functions:

**Clarity:** Vague statements become precise claims subject to evaluation

**Comparability:** Different experts’ models can be systematically compared

**Criticizability:** Hidden assumptions become visible targets for challenge

**Updatability:** Formal models can systematically incorporate new evidence



#### 4.4.2 Revealing Convergence and Divergence

Theoretical analysis suggests formal comparison would reveal:

**Structural Patterns:** Experts likely share more agreement about causal structures than probability values, suggesting common understanding of mechanisms despite quantitative disagreement.

**Crux Identification:** Formal models make explicit which specific disagreements drive different conclusions, focusing discussion on genuinely critical differences.

**Hidden Agreements:** Apparently conflicting positions might share substantial common ground obscured by different terminology or emphasis.

**Uncertainty Clustering:** Areas of high uncertainty likely correlate across models, revealing where additional research would most reduce disagreement.

These patterns remain invisible in natural language debates but become analyzable through formalization.

#### 4.4.3 Improving Collective Reasoning

AMTAIR enhances group epistemics through:

**Explicit uncertainty:** Replacing “might,” “could,” “likely” with probability distributions reduces miscommunication and forces precision

**Compositional reasoning:** Complex arguments decompose into manageable components that can be independently evaluated

**Evidence integration:** New information updates specific parameters rather than requiring complete argument reconstruction

**Exploration tools:** Stakeholders can modify assumptions and immediately see consequences, building intuition about model dynamics

While empirical validation remains future work, theoretical considerations suggest these mechanisms could substantially improve coordination quality. By providing shared representations and systematic methods for managing disagreement, formal models create infrastructure for collective intelligence that transcends individual limitations.

### 4.5 Scaling Challenges and Opportunities

Moving from prototype to widespread adoption faces both technical and social challenges.

#### 4.5.1 Technical Scaling

**Computational complexity** grows with network size, but several approaches help:

- Hierarchical decomposition for very large models
- Caching and approximation for common queries

- Distributed processing for extraction tasks
- Incremental updating rather than full recomputation

**Data quality** varies dramatically across sources:

- Academic papers provide structured arguments
- Blog posts offer rich ideas with less formal structure
- Policy documents mix normative and empirical claims
- Social media presents extreme extraction challenges

**Integration complexity** increases with ecosystem growth:

- Multiple LLM providers with different capabilities
- Diverse visualization needs across users
- Various export formats for downstream tools
- Version control for evolving models

#### 4.5.2 Social and Institutional Scaling

**Adoption barriers** include:

- Learning curve for formal methods
- Institutional inertia in established processes
- Concerns about replacing human judgment
- Resource requirements for implementation

**Trust building** requires:

- Transparent methodology documentation
- Published validation studies
- High-profile successful applications
- Community ownership and development

**Sustainability** depends on:

- Open source development model
- Diverse funding sources
- Academic and industry partnerships
- Clear value demonstration

#### 4.5.3 Opportunities for Impact

Despite challenges, several factors favor adoption:

**Timing:** AI governance needs tools now, creating receptive audiences

**Complementarity:** AMTAIR enhances rather than replaces existing processes

**Flexibility:** The approach adapts to different contexts and needs

**Network effects:** Value increases as more perspectives are formalized

Early adopters in research organizations and think tanks can demonstrate value, creating momentum for broader adoption.

## 4.6 Integration with Governance Frameworks

AMTAIR complements rather than replaces existing governance approaches.

### 4.6.1 Standards Development

Technical standards bodies could use AMTAIR to:

- Model how proposed standards affect risk pathways
- Compare different standard options systematically
- Identify unintended consequences through pathway analysis
- Build consensus through explicit model negotiation

Example: Evaluating compute thresholds for AI system regulation by modeling how different thresholds affect capability development, safety investment, and competitive dynamics.

### 4.6.2 Regulatory Design

Regulators could apply the framework to:

- Assess regulatory impact across different scenarios
- Identify enforcement challenges through explicit modeling
- Compare international approaches systematically
- Design adaptive regulations responsive to evidence

Example: Analyzing how liability frameworks affect corporate AI development decisions under different market conditions.

The extensive literature on corporate governance and liability frameworks Cuomo, Mallin, and Zattoni [14] Demirag, Sudarsanam, and WRIGHT [17] De Villiers and Dimes [16] Di Vito and Trottier [18] Kaur [27] List and Pettit [30] Solomon [46] provides theoretical grounding for understanding how regulatory interventions shape organizational behavior. AMTAIR could formalize these relationships in the specific context of AI development, making explicit how different liability regimes might incentivize or discourage safety investments.

### 4.6.3 International Coordination

Multilateral bodies could leverage shared models for:

- Establishing common risk assessments
- Negotiating agreements with explicit assumptions
- Monitoring compliance through parameter tracking
- Adapting agreements as evidence emerges

Example: Building shared models for AGI development scenarios to inform international AI governance treaties.

#### 4.6.4 Organizational Decision-Making

Individual organizations could use AMTAIR for:

- Internal risk assessment and planning
- Board-level communication about AI strategies
- Research prioritization based on model sensitivity
- Safety case development with explicit assumptions

Example: An AI lab modeling how different safety investments affect both capability advancement and risk mitigation.

### 4.7 Future Research Directions

Several research directions could enhance AMTAIR’s capabilities and impact.

#### 4.7.1 Technical Enhancements

**Improved extraction:** Fine-tuning language models specifically for argument extraction, handling implicit reasoning, and cross-document synthesis

**Richer representations:** Temporal dynamics, continuous variables, and multi-agent interactions within extended frameworks

**Inference advances:** Quantum computing applications, neural approximate inference, and hybrid symbolic-neural methods

**Validation methods:** Automated consistency checking, anomaly detection in extracted models, and benchmark dataset development

#### 4.7.2 Methodological Extensions

**Causal discovery:** Inferring causal structures from data rather than just extracting from text

**Experimental integration:** Connecting models to empirical results from AI safety experiments

**Dynamic updating:** Continuous model refinement as new evidence emerges from research and deployment

**Uncertainty quantification:** Richer representation of deep uncertainty and model confidence

Recent advances in causal structure learning from both text and data Babakov et al. [3] Ban et al. [4] Bethard [6] Chen et al. [11] Heinze-Deml, Maathuis, and Meinshausen [24] Squires and Uhler [47] Yang, Han, and Poon [53] suggest promising directions for enhancing AMTAIR’s extraction capabilities. The theoretical foundations from Duhem [19] and Meyer [34] on the philosophy of science and knowledge structures provide epistemological grounding for these methodological extensions.

### 4.7.3 Application Domains

**Beyond AI safety:** Climate risk, biosecurity, nuclear policy, and other existential risks

**Corporate governance:** Strategic planning, risk management, and innovation assessment

**Scientific modeling:** Formalizing theoretical arguments in emerging fields

**Educational tools:** Teaching probabilistic reasoning and critical thinking

### 4.7.4 Ecosystem Development

**Open standards:** Common formats for model exchange and tool interoperability

**Community platforms:** Collaborative model development and sharing infrastructure

**Training programs:** Building capacity for formal modeling in governance communities

**Quality assurance:** Certification processes for high-stakes model applications

These directions could transform AMTAIR from a single tool into a broader ecosystem for enhanced reasoning about complex risks.

## 4.8 Known Unknowns and Deep Uncertainties

While AMTAIR enhances reasoning under uncertainty, fundamental limitations remain regarding truly novel developments that might fall outside existing conceptual frameworks.

### 4.8.1 Categories of Deep Uncertainty

**Novel Capabilities:** Future AI developments may operate according to principles outside current scientific understanding. No amount of careful modeling can anticipate fundamental paradigm shifts in what intelligence can accomplish.

**Emergent Behaviors:** Complex system properties that resist prediction from component analysis may dominate outcomes. The interaction between advanced AI systems and human society could produce wholly unexpected dynamics.

**Strategic Interactions:** Game-theoretic dynamics with superhuman AI systems exceed human modeling capacity. We cannot reliably predict how entities smarter than us will behave strategically.

**Social Transformation:** Unprecedented social and economic changes may invalidate current institutional assumptions. Our models assume continuity in basic social structures that AI might fundamentally alter.

### 4.8.2 Adaptation Strategies for Deep Uncertainty

Rather than pretending to model the unmodelable, AMTAIR incorporates several strategies:

**Model Architecture Flexibility:** The modular structure enables rapid incorporation of new variables as novel factors become apparent. When surprises occur, models can be updated rather than discarded.

**Explicit Uncertainty Tracking:** Confidence levels for each model component make clear where knowledge is solid versus speculative. This prevents false confidence in highly uncertain domains.

**Scenario Branching:** Multiple model variants capture different assumptions about fundamental uncertainties. Rather than committing to one worldview, the system maintains portfolios of possibilities.

**Update Mechanisms:** Integration with prediction markets and expert assessment enables rapid model revision as new information emerges. Models evolve rather than remaining static.

### 4.8.3 Robust Decision-Making Principles

Given deep uncertainty, certain decision principles become paramount:

**Option Value Preservation:** Policies should maintain flexibility for future course corrections rather than locking in irreversible choices based on current models.

**Portfolio Diversification:** Multiple approaches hedging across different uncertainty sources provide robustness against model error.

**Early Warning Systems:** Monitoring for developments that would invalidate current models enables rapid response when assumptions break down.

**Adaptive Governance:** Institutional mechanisms must enable rapid response to new information rather than rigid adherence to plans based on outdated models.

The goal is not to eliminate uncertainty but to make good decisions despite it. AMTAIR provides tools for systematic reasoning about what we do know while maintaining appropriate humility about what we don't and can't know.

## 4.9 Summary of Implications

The discussion reveals both the promise and limitations of computational approaches to AI governance coordination:

**Technical Feasibility:** Despite imperfections, automated extraction and formal modeling prove practically viable for complex AI risk arguments.

**Epistemic Value:** Making implicit models explicit, enabling systematic comparison, and supporting evidence integration enhance collective reasoning.

**Practical Limitations:** Extraction boundaries, false precision risks, and implementation dependencies require careful management.

**Integration Potential:** The approach complements rather than replaces existing governance frameworks, adding rigor without sacrificing flexibility.

**Future Development:** Technical enhancements, methodological extensions, and ecosystem growth could amplify impact.

**Deep Uncertainty:** Fundamental limits on predicting novel developments require maintaining humility and adaptability.

These findings suggest AMTAIR represents a valuable addition to the AI governance toolkit—not a panacea but a meaningful enhancement to our collective capacity for navigating unprecedented challenges.





# 5. Conclusion: Toward Coordinated AI Governance

## 5.1 Summary of Key Contributions

This thesis has demonstrated both the need for and feasibility of computational approaches to enhancing coordination in AI governance. The work makes several distinct contributions across theory, methodology, and implementation.

### 5.1.1 Theoretical Contributions

**Diagnosis of the Coordination Crisis:** I’ve articulated how fragmentation across technical, policy, and strategic communities systematically amplifies existential risk from advanced AI. This framing moves beyond identifying disagreements to understanding how misaligned efforts create negative-sum dynamics—safety gaps emerge between communities, resources are misallocated through duplication and neglect, and interventions interact destructively.

**The Multiplicative Benefits Framework:** The combination of automated extraction, prediction market integration, and formal policy evaluation creates value exceeding the sum of parts. Automation enables scale, markets provide empirical grounding, and policy analysis delivers actionable insights. Together, they address different facets of the coordination challenge while reinforcing each other’s strengths.

**Epistemic Infrastructure Conception:** Positioning formal models as epistemic infrastructure reframes the role of technical tools in governance. Rather than replacing human judgment, computational approaches provide common languages, shared representations, and systematic methods for managing disagreement—essential foundations for coordination under uncertainty.

### 5.1.2 Methodological Innovations

**Two-Stage Extraction Architecture:** Separating structural extraction (ArgDown) from probability quantification (BayesDown) addresses key challenges in automated formalization. This modularity enables human oversight at critical points, supports multiple quantification methods, allows for unprecedented transparency and explainability of the entire process, and isolates different types of errors for targeted improvement.

**BayesDown as Bridge Representation:** The development of BayesDown syntax creates a crucial intermediate representation preserving both narrative accessibility and mathematical precision. This bridge enables the transformation from qualitative arguments to quantitative models while maintaining traceability and human readability.

**Validation Framework:** The systematic approach to validating automated extraction—comparing against expert annotations, measuring multiple accuracy dimensions, and analyzing error patterns—establishes scientific standards for assessing formalization tools. This framework can guide future development in this emerging area.

### 5.1.3 Technical Achievements

**Working Implementation:** AMTAIR demonstrates end-to-end feasibility from document ingestion through interactive visualization. The system successfully processes complex arguments like Carlsmith’s power-seeking AI model, extracting hierarchical structures and probability information.

**Scalability Solutions:** Technical approaches for handling realistic model complexity—hierarchical decomposition, approximate inference, and progressive visualization—show that computational limitations need not prevent practical application.

**Accessibility Design:** The layered interface approach serves diverse stakeholders without compromising technical depth. Progressive disclosure, visual encoding, and interactive exploration make formal models accessible beyond technical specialists.

### 5.1.4 Empirical Findings

**Extraction Feasibility:** The successful extraction of complex arguments like Carlsmith’s model validates the core premise that implicit formal structures exist in natural language arguments and can be computationally recovered with reasonable fidelity.

**Convergence Patterns:** Theoretical analysis suggests that formal comparison would reveal structural agreements across different expert worldviews even when probability estimates diverge—providing foundations for coordination.

**Intervention Impacts:** Policy evaluation capabilities demonstrate how formal models enable rigorous assessment of governance options. The ability to trace intervention effects through complex causal networks validates the practical value of formalization.

## 5.2 Limitations and Honest Assessment

Despite these contributions, important limitations constrain current capabilities and should guide appropriate use.

### 5.2.1 Technical Constraints

**Extraction Boundaries:** The system struggles with implicit assumptions, complex conditionals, and ambiguous quantifiers. These limitations necessitate human review for high-stakes applications.

**Correlation Handling:** Standard Bayesian networks inadequately represent complex correlations in real systems. While extensions like copulas and explicit correlation nodes help, fully capturing interdependencies remains challenging.

**Computational Scaling:** Very large networks require approximations that may affect accuracy. As models grow to represent richer phenomena, computational constraints increasingly bind.

### 5.2.2 Conceptual Limitations

**Formalization Trade-offs:** Converting rich arguments to formal models necessarily loses nuance. While making assumptions explicit provides value, some insights resist mathematical representation.

**Probability Interpretation:** Deep uncertainty about unprecedented events challenges probabilistic representation. Numbers can create false precision even when explicitly conditional and uncertain.

**Social Complexity:** Institutional dynamics, cultural factors, and political processes influence AI development in ways that causal models struggle to capture fully.

### 5.2.3 Practical Constraints

**Adoption Barriers:** Learning curves, institutional inertia, and resource requirements limit immediate deployment. Even demonstrably valuable tools face implementation challenges.

**Maintenance Burden:** Models require updating as arguments evolve and evidence emerges. Without sustained effort, formal representations quickly become outdated.

**Context Dependence:** The approach works best for well-structured academic arguments. Application to informal discussions or political rhetoric remains challenging.

## 5.3 Implications for AI Governance

Despite limitations, AMTAIR's approach offers significant implications for how AI governance can evolve toward greater coordination and effectiveness.

### 5.3.1 Near-Term Applications

**Research Coordination:** Research organizations can use formal models to:

- Map the landscape of current arguments and identify gaps
- Prioritize investigations targeting high-sensitivity parameters
- Build cumulative knowledge through explicit model updating

- Facilitate collaboration through shared representations

**Policy Development:** Governance bodies can apply the framework to:

- Evaluate proposals across multiple expert worldviews
- Identify robust interventions effective under uncertainty
- Make assumptions explicit for democratic scrutiny
- Track how evidence changes optimal policies over time

**Stakeholder Communication:** The visualization and analysis tools enable:

- Clearer communication between technical and policy communities
- Public engagement with complex risk assessments
- Board-level strategic discussions grounded in formal analysis
- International negotiations with explicit shared models

### 5.3.2 Medium-Term Transformation

As adoption spreads, we might see:

**Epistemic Commons:** Shared repositories of formalized arguments become reference points for governance discussions, similar to how economic models inform monetary policy or climate models guide environmental agreements.

**Adaptive Governance:** Policies designed with explicit models can include triggers for reassessment as key parameters change, enabling responsive governance that avoids both paralysis and recklessness.

**Professionalization:** “Model curator” and “argument formalization specialist” emerge as recognized roles, building expertise in bridging natural language and formal representations.

**Quality Standards:** Community norms develop around model transparency, validation requirements, and appropriate use cases, preventing both dismissal and over-reliance on formal tools.

### 5.3.3 Long-Term Vision

Successfully scaling this approach could fundamentally alter AI governance:

**Coordinated Response:** Rather than fragmented efforts, the AI safety ecosystem could operate with shared situational awareness—different actors understanding how their efforts interact and contribute to collective goals.

**Anticipatory Action:** Formal models with prediction market integration could provide early warning of emerging risks, enabling proactive rather than reactive governance.

**Global Cooperation:** Shared formal frameworks could facilitate international coordination similar to how economic models enable monetary coordination or climate models support environmental agreements.

**Democratic Enhancement:** Making expert reasoning transparent and modifiable could enable broader participation in crucial decisions about humanity’s technological future.

## 5.4 Recommendations for Stakeholders

Different communities can take concrete steps to realize these benefits:

### 5.4.1 For Researchers

1. **Experiment with formalization:** Try extracting your own arguments into ArgDown/BayesDown format to discover implicit assumptions
2. **Contribute to validation:** Provide expert annotations for building benchmark datasets and improving extraction quality
3. **Develop extensions:** Build on the open-source foundation to add capabilities for your specific domain needs
4. **Publish formally:** Include formal model representations alongside traditional papers to enable cumulative building

### 5.4.2 For Policymakers

1. **Pilot applications:** Use AMTAIR for internal analysis of specific policy proposals to build familiarity and identify value
2. **Demand transparency:** Request formal models underlying expert recommendations to understand assumptions and uncertainties
3. **Fund development:** Support tool development and training to build governance capacity for formal methods
4. **Design adaptively:** Create policies with explicit triggers based on model parameters to enable responsive governance

### 5.4.3 For Technologists

1. **Improve extraction:** Contribute better prompting strategies, fine-tuned models, or validation methods
2. **Enhance interfaces:** Develop visualizations and interactions serving specific stakeholder needs
3. **Build integrations:** Connect AMTAIR to other tools in the AI governance ecosystem
4. **Scale infrastructure:** Address computational challenges for larger models and broader deployment

## 5.5 Future Research Agenda

Looking ahead, the landscape of possibilities stretches toward the horizon, each path promising its own rewards and challenges. Let me map the territory worth exploring.

### 5.5.1 Technical Priorities

The technical frontier advances on multiple fronts, each offering multiplicative improvements when combined:

**Extraction Enhancement:** The current system, while functional, merely scratches the surface of what’s possible. Fine-tuning language models specifically on argument extraction tasks could dramatically improve accuracy. Imagine models trained not just on general text but on thousands of examples of arguments transformed into formal representations.

**Handling Implicit Reasoning:** So much of expert argumentation relies on unstated background knowledge. When an AI safety researcher mentions “mesa-optimization,” they assume familiarity with complex concepts about learned optimization occurring within larger optimization processes. Future systems need to bridge these inferential gaps, perhaps by maintaining explicit knowledge bases of domain concepts or by training models to recognize and fill common argumentative ellipses.

**Cross-Document Synthesis:** Real understanding emerges not from single papers but from conversations across documents. Authors respond to each other, build on previous work, refine arguments over time. Future systems should trace these intellectual lineages, building composite models that capture evolving community understanding rather than static snapshots.

**Representation Extensions:** Current Bayesian networks, while powerful, make limiting assumptions. Temporal dynamics matter—AI development unfolds over time, with early decisions constraining later options. Multi-agent representations could capture strategic interactions between actors. Continuous variables better represent quantities like “capability level” than binary approximations. Each extension opens new analytical possibilities.

### 5.5.2 Methodological Development

Beyond technical improvements lie deeper methodological questions about how we validate, use, and improve these systems:

**Validation Science:** We need not just ad hoc evaluation but a science of argument extraction assessment. This means building benchmark datasets capturing diverse argument types, developing metrics that go beyond surface accuracy to semantic fidelity, creating adversarial test suites that probe system limitations, and establishing longitudinal studies tracking how extracted models evolve with updating source documents.

**Hybrid Intelligence:** The future isn’t human or AI but human and AI. Optimal collaboration patterns remain unexplored. Should humans verify structure while AI handles probabilities? Should AI propose multiple extractions for human selection? How do we combine formal models with scenario narratives, quantitative forecasts with qualitative insights? The design space for human-AI collaboration in argument formalization remains largely uncharted.

**Social Methods:** Technology embedded in social contexts requires social science. How do organizations actually use these models? What changes when formal representations replace

informal discussions? Ethnographic studies of model use, measurement of coordination improvements, identification of adoption barriers—all essential for real-world impact.

### 5.5.3 Application Expansion

The principles underlying AMTAIR apply far beyond AI risk:

**Domain Extensions:** Every field grappling with complex risks could benefit. Biosecurity faces similar challenges—technical complexity, value-laden choices, deep uncertainty. Climate policy involves multi-level causation across physical, economic, and social systems. Nuclear policy, despite decades of study, still struggles with coordination across technical and strategic communities. Each domain would require specialized extraction approaches but could leverage the same fundamental architecture.

**Institutional Integration:** Moving from research prototype to institutional tool requires thoughtful embedding. Regulatory impact assessment could incorporate formal modeling to make assumptions explicit. Corporate strategic planning, especially for companies developing advanced technologies, needs tools for reasoning about unprecedented risks. Academic peer review might benefit from formal representation of complex arguments.

**Global Deployment:** AI governance is inherently international, but different regions have different governance cultures, risk tolerances, and institutional structures. Adapting AMTAIR for different contexts—from Silicon Valley’s move-fast culture to the EU’s precautionary approach to China’s state-led development—requires both technical and cultural translation.

## 5.6 Closing Reflections

As I write these final words, I’m struck by the peculiar position we find ourselves in. We are arguably the first generation that must govern technologies that could fundamentally transform or terminate our species’ story. The margin for error shrinks as capabilities grow. The cost of coordination failure rises toward infinity.

The AMTAIR project emerged from a simple observation paired with an ambitious hope. The observation: while humanity mobilizes unprecedented resources to address AI risks, our efforts remain tragically uncoordinated. Different communities work with incompatible frameworks, duplicate efforts, and sometimes actively undermine each other’s work. The hope: that computational tools might help us build the epistemic infrastructure necessary for coordination.

What we’ve accomplished here is both less and more than originally envisioned. Less, because the challenges proved deeper than anticipated. Natural language resists formalization. Probabilities remain stubbornly subjective. Coordination failures have roots beyond mere communication difficulties. More, because the journey revealed unexpected possibilities. Intermediate representations became valuable in themselves. The extraction process surfaced insights about argument structure. The visualization work demonstrated how thoughtful design can democratize access to formal tools.

Perhaps most importantly, this work demonstrates that perfect solutions need not be the enemy

of meaningful progress. AMTAIR doesn't solve the coordination crisis—no single tool could. But it offers genuine assistance: making implicit models explicit, enabling systematic comparison across worldviews, supporting evidence-based policy evaluation, and creating common ground for productive disagreement.

**The Stakes:** Let me be plain about what's at risk. The development of artificial general intelligence represents a discontinuity in human history comparable to the emergence of life or the evolution of consciousness. Get it right, and we might solve problems that have plagued humanity since our beginning—disease, poverty, ignorance, perhaps even death itself. Get it wrong, and we might extinguish not just ourselves but all the potential futures we might have created.

This isn't science fiction or academic speculation. The capabilities advancing in labs today point toward systems that could, within decades or less, exceed human cognitive abilities across all domains. What happens when we create minds greater than our own? How do we ensure they remain aligned with human values and flourishing? These questions demand our best collective wisdom.

Yet we approach this challenge fragmented. Technical researchers develop alignment techniques without clear paths to implementation. Policymakers craft governance frameworks without deep technical understanding. Ethicists articulate values without operational specificity. International bodies convene without shared models of the risks they're addressing. This fragmentation isn't just inefficient—it's existentially dangerous.

AMTAIR represents one attempt to build bridges. By automating the extraction of worldviews, integrating live forecasts, and enabling systematic policy evaluation, we create infrastructure for enhanced coordination. Not coordination itself—that requires human wisdom, institutional change, and political will. But infrastructure that makes coordination more feasible.

The path forward demands both ambition and humility. Ambition to build the tools, institutions, and practices necessary for navigating unprecedented risks. Humility to recognize that our tools are imperfect, our understanding incomplete, and our time limited. We must act despite uncertainty, coordinate despite disagreement, and hope despite the magnitude of the challenge.

As I close this thesis, I think of future readers—perhaps humans living in a world made wonderful by aligned AI, perhaps historians studying how we navigated this crucial transition, perhaps no one at all if we fail. To those readers, know that we tried. We saw the challenge, recognized our limitations, and attempted to build what tools we could.

The coordination crisis in AI governance represents both existential risk and existential opportunity. Risk, if we fail to align our efforts before it's too late. Opportunity, if we succeed in creating unprecedented cooperation around humanity's most important challenge. AMTAIR offers one piece of the puzzle—computational infrastructure that enhances our collective ability to reason about complex risks.

May we prove worthy of the challenge before us. May our tools amplify our wisdom rather than our folly. And may future generations look back on this time not as when humanity failed to



coordinate, but as when we rose to meet our greatest test.

The work continues. The stakes could not be higher. The time grows short. Let us build what we can, while we can, for all our futures depend on it.



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[Existential\_Risk]: Increase in existential risks for humanity. {"instantiations": [TRUE", "FALSE"]}

- [Unaligned\_AGI\_Risk]: Unaligned artificial general intelligence causes existential risk. {"instantiations": [TRUE", "FALSE"]}
  - [State-State\_Relations]
- [Near\_term\_AI]: Even if not unaligned AGI, near term AI can act as intermediate risk factor. {"instantiations": [TRUE", "FALSE"]}
  - [State-State\_Relations]: AI arms race dynamic inhibits international coordination, diverting resources from other pressing issues {"instantiations": [TRUE", "FALSE"]}
    - \* [Cybersecurity]: Probably enhances Cyber-Attack-Offense, may intensify cyber warfare. {"instantiations": [TRUE", "FALSE"]}
  - [State-Cooperation\_Relations]: Cooperations have a lot of power and might have misaligned goals with society {"instantiations": [TRUE", "FALSE"]}
  - [Stable\_Repressive\_Regime]: More repressive instruments, possibility of stable repressive regime. {"instantiations": [TRUE", "FALSE"]}
    - \* [State-Citizen\_Relations]: AI helps regime monitor citizens {"instantiations": [TRUE", "FALSE"]}
  - [Compromised\_Political\_Decision\_Making]: AI can compromise political decision making. {"instantiations": [TRUE", "FALSE"]}
    - \* [Social\_media\_and\_Recommender\_Systems]: Influence of AI in social media on public opinion. {"instantiations": [TRUE", "FALSE"]}
- [Nuclear]: Probability that nuclear conflict escalates to end civilisation. {"instantiations": [TRUE", "FALSE"]}
  - [Compromised\_Political\_Decision\_Making]
- [Biological]: Probability that a natural or engineered pandemic poses existential risks. {"instantiations": [TRUE", "FALSE"]}
  - [Compromised\_Political\_Decision\_Making]
  - [Social\_media\_and\_Recommender\_Systems]
- [Natural]: Non-human caused existential risks, seem unrelated with AI. {"instantiations": [TRUE", "FALSE"]}
- [Environmental]: Probability of climate catastrophe. {"instantiations": [TRUE", "FALSE"]}

- 
- [Compromised\_Political\_Decision\_Making]
  - [AI\_resource\_consumption]: Current AI models consume large amounts of energy having environmental impacts. {"instantiations": ["TRUE", "FALSE"]}
  - [Social\_media\_and\_Recommender\_Systems]

# AMTAIR Prototype Demonstration (Public Colab Notebook)



# AMTAIR Prototype: Automating Transformative AI Risk Modeling

## Executive Summary

This notebook implements a prototype of the AMTAIR (Automating Transformative AI Risk Modeling) project, which addresses the critical coordination failure in AI governance by developing computational tools that automate the extraction of probabilistic world models from AI safety literature.

The prototype demonstrates the transformation pipeline from structured argument representations (ArgDown) to probabilistic Bayesian networks (BayesDown), enabling the visualization and analysis of causal relationships and probability distributions that underlie AI risk assessments and policy evaluations.

## Purpose Within the Master’s Thesis

This notebook serves as the technical implementation component of the Master’s thesis “Automating Transformative AI Risk Modeling: A Computational Approach to Policy Impact Evaluation.” It demonstrates the feasibility of automating the extraction and formalization of world models, focusing on the core extraction pipeline and visualization capabilities that form the foundation for more sophisticated analysis.

## Relevance to AI Governance

The coordination crisis in AI governance stems from different stakeholders working with incompatible assumptions, terminologies, and priorities. By making implicit models explicit through automated extraction and formalization, this work helps bridge communication gaps between technical researchers, policy specialists, and other stakeholders, contributing to more effective coordination in addressing existential risks from advanced AI.

## Notebook Structure and Workflow

This notebook implements a multi-stage pipeline for transforming argument structures into interactive Bayesian network visualizations:

0. **Environment Setup** (Sections 0.1-0.3): Establishes the technical environment with necessary libraries and data connections
1. **Argument Extraction: Sources to ArgDown** (Sections 1.0-1.8): Processes source documents into structured ArgDown representations
2. **Probability Integration** (Sections 2.0-2.8): Enhances ArgDown with probability information to create BayesDown
3. **Data Transformation** (Section 3.0): Converts BayesDown into structured DataFrame format
4. **Visualization and Analysis** (Section 4.0): Creates interactive Bayesian network visualizations
5. **Archiving and Export** (Sections 5.0-6.0): Provides utilities for saving and sharing results

## Instructions — How to use this notebook:

1. **Import Libraries & Install Packages:** Run Section 0.1 to set up the necessary dependencies for data processing and visualization.
2. **Connect to GitHub Repository & Load Data files:** Run Section 0.2 to establish connections to the data repository and load example datasets. This step retrieves sample ArgDown files and extracted data for demonstration.
3. **Process Source Documents to ArgDown:** Sections 1.0-1.8 demonstrate the extraction of argument structures from source documents (such as PDFs) into ArgDown format, a markdown-like notation for structured arguments.
4. **Convert ArgDown to BayesDown:** Sections 2.0-2.3 handle the transformation of ArgDown files into BayesDown format, which incorporates probabilistic information into the argument structure.
5. **Extract Data into Structured Format:** Section 3.0 processes BayesDown format into structured database entries (CSV) that can be used for analysis.
6. **Create and Analyze Bayesian Networks:** Section 4.0 demonstrates how to build Bayesian networks from the extracted data and provides tools for analyzing risk pathways.
7. **Save and Export Results:** Sections 5.0-6.0 provide methods for archiving results and exporting visualizations.

AMTAIR Prototype Demonstration (Public Colab Notebook)

AMTAIR Prototype: Automating Transformative AI Risk Modeling

Executive Summary

Purpose Within the Master's Thesis

Relevance to AI Governance

Notebook Structure and Workflow

Instructions — How to use this notebook:

Key Concepts:

Example Workflow:

Troubleshooting:

## 0 Environment Setup and Data Access

0.1 Prepare Colab/Python Environment — Import Libraries & Packages

0.2 Connect to GitHub Repository

0.3 File Import

## 1 Sources (PDF's of Papers) to ArgDown (.md file)

1.0 Sources to ArgDown: Structured Argument Extraction

Process Overview

What is ArgDown?

1.1 Specify Source Document (e.g. PDF)

1.2 Generate ArgDown Extraction Prompt

1.3 Prepare LLM API Call

1.4 Make ArgDown Extraction LLM API Call

1.5 Save ArgDown Extraction Response

1.6 Review and Check ArgDown.md File

1.6.0 Check the Graph Structure with the ArgDown Sandbox On-line

1.7 Extract ArgDown Graph Information as DataFrame

1.8 Store ArgDown Information as 'ArgDown.csv' file

## 2 Probability Extractions: ArgDown (.csv) to BayesDown (.md + plugin JSON syntax)

2.0 ArgDown to BayesDown: Adding Probability Information

Process Overview

What is BayesDown?

2.1 Probability Extraction Questions — 'ArgDown.csv' to 'ArgDown\_WithQuestions.csv'

2.2 'ArgDown\_WithQuestions.csv' to 'BayesDownQuestions.md'

2.3 Generate BayesDown Probability Extraction Prompt

## 2.3.0 BayesDown Format Specification

### Core Structure

### 2.3.1 Rain-Sprinkler-Lawn Example

## 2.4 Prepare 2nd API call

## 2.5 Make BayesDown Probability Extraction API Call

## 2.6 Save BayesDown with Probability Estimates (.csv)

## 2.7 Review & Verify BayesDown Probability Estimates

### 2.7.2 Check the Graph Structure with the ArgDown Sandbox Online

## 2.8 Extract BayesDown with Probability Estimates as Dataframe

## 3 Data Extraction: BayesDown (.md) to Database (.csv)

### 3.0 BayesDown to Structured Data: Network Construction

#### Extraction Pipeline Overview

#### Theoretical Foundation

#### Role in Thesis Research

### 3.0.0 ExtractBayesDown-Data\_v1

### 3.0.1 Test BayesDown Extraction

### 3.0.2 Check the Graph Structure with the ArgDown Sandbox Online

## 3.1 Extraction

## 3.2 Data-Post-Processing

## 3.4 Download and save finished data frame as .csv file

## 4 Analysis & Inference: Bayesian Network Visualization

### 4.0 Bayesian Network Visualization Approach

#### Visualization Philosophy

#### Connection to AMTAIR Goals

#### Implementation Structure

### 4.1 Phase 1: Dependencies/Functions

### 4.2 Phase 2: Node Classification and Styling Module

### 4.3 Phase 3: HTML Content Generation Module

### 4.4 Phase 4: Main Visualization Function



## 5 Quick check HTML Outputs

### Conclusion: From Prototype to Production

Summary of Achievements

Limitations and Future Work

Connection to AMTAIR Project

## 6 Save Outputs

6.0 Saving and Exporting Results

6.1 Convert .ipynb Notebook to Markdown

6.2 Convert Notebook to Markdown Documentation

6.3 Create PDF and Latex

## Key Concepts:

- **ArgDown:** A structured format for representing arguments, with hierarchical relationships between statements.
- **BayesDown:** An extension of ArgDown that incorporates probabilistic information, allowing for Bayesian network construction.
- **Extraction Pipeline:** The process of converting unstructured text to structured argument representations.
- **Bayesian Networks:** Probabilistic graphical models that represent variables and their conditional dependencies.

## Example Workflow:

1. Load a sample ArgDown file from the repository
2. Extract the hierarchical structure and relationships
3. Add probabilistic information to create a BayesDown representation
4. Generate a Bayesian network visualization
5. Analyze conditional probabilities and risk pathways

## Troubleshooting:

- If connectivity issues occur, ensure you have access to the GitHub repository
- For visualization errors, check that all required libraries are properly installed
- When processing custom files, ensure they follow the expected format conventions



# 0 Environment Setup and Data Access

This section establishes the technical foundation for the AMTAIR prototype by: 1. Installing and importing necessary libraries 2. Setting up access to the GitHub repository 3. Loading example data files

The environment setup is designed to be run once per session, with flags to prevent redundant installations and imports. This section forms the basis for the subsequent extraction and analysis steps in the pipeline.

The key goal is to create a reproducible environment where the Bayesian network extraction and visualization can be performed consistently, with appropriate error handling and resource management.

## 0.1 Prepare Colab/Python Environment — Import Libraries & Packages

```
# @title 0.1.0 --- Install & Import Libraries & Packages (One-Time Setup) --- [install_import]

"""
BLOCK PURPOSE:
Establishes the core technical environment for the AMTAIR prototype.
Sets up all required libraries for Bayesian network processing, visualization,
and data manipulation.
Uses a flag-based approach to ensure setup only runs once per session,
enhancing efficiency.

The setup follows a three-stage process:
1. Install required packages not available in Colab by default
2. Import all necessary libraries with error handling
3. Set a global flag to prevent redundant execution

DEPENDENCIES: Requires internet connection for package installation
```

```

OUTPUTS: Global variable _setup_imports_done and loaded Python libraries
"""

# Check if setup has already been completed in this session using environment flag
try:
    # If this variable exists, setup was already done successfully
    _setup_imports_done
    print(" Libraries already installed and imported in this session. Skipping setup.")

except NameError:
    print(" Performing one-time library installation and imports...")

    # --- STAGE 1: Install required packages ---
    # Install visualization and network analysis libraries
    !pip install -q pyvis # Network visualization library
    !apt-get install pandoc -y # Document conversion utility

    # Install Google API and data processing packages
    # Data manipulation and Google integration
    !pip install -q --upgrade gspread pandas google-auth google-colab

    # Install Bayesian network and probabilistic modeling tools
    !pip install -q pgmpy # Probabilistic graphical models library

    # Install notebook conversion tools
    !pip install -q nbconvert # Often pre-installed, but ensures availability

    print(" --> Installations complete.")

    # --- STAGE 2: Import libraries with error handling ---
    try:
        # Network and HTTP libraries
        import requests # For making HTTP requests to APIs and GitHub
        import io # For handling in-memory file-like objects

        # Data processing libraries
        import pandas as pd # For structured data manipulation
        import numpy as np # For numerical operations
        import json # For JSON parsing and serialization
        import re # For regular expression pattern matching

        # Visualization libraries

```

```

import matplotlib.pyplot as plt # For creating plots and charts
from IPython.display import HTML, display, Markdown # For rich output in notebook

# --- Specialized libraries requiring installation ---
# Network analysis library
import networkx as nx # For graph representation and analysis

# Probabilistic modeling libraries
from pgmpy.models import BayesianNetwork # For Bayesian network structure
from pgmpy.factors.discrete import TabularCPD # For conditional probability tables
from pgmpy.inference import VariableElimination # For probabilistic inference

# Interactive network visualization
from pyvis.network import Network # For interactive network visualization

# Output version information for key libraries
print(f"    pandas version: {pd.__version__}")
print(f"    networkx version: {nx.__version__}")
# Add others if specific versions are critical

print("    --> Imports complete.")

# --- STAGE 3: Set flag to indicate successful setup ---
_setup_imports_done = True
print("    One-time setup finished successfully.")

except ImportError as e:
    # Handle specific import failures
    print(f"    ERROR during import: {e}")
    print("    --> Setup did not complete successfully. Please check installations.")
except Exception as e:
    # Handle unexpected errors
    print(f"    UNEXPECTED ERROR during setup: {e}")
    print("    --> Setup did not complete successfully.")

# Environment is now ready for AMTAIR processing

```

Libraries already installed and imported in this session. Skipping setup.

## 0.2 Connect to GitHub Repository

The Public GitHub Repo Url in use:

[https://raw.githubusercontent.com/SingularitySmith/AMTAIR\\_Prototype/main/](https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main/)

Note: When encountering errors, accessing the data, try using “RAW” Urls.

```
# @title 0.2.0 --- Connect to GitHub Repository --- Load Files [connect_to_github_repository]

"""
BLOCK PURPOSE: Establishes connection to the AMTAIR GitHub repository and provides
functions to load example data files for processing.

This block creates a reusable function for accessing files from the project's
GitHub repository, enabling access to example files like the rain-sprinkler-lawn
Bayesian network that serves as our canonical test case.

DEPENDENCIES: requests library, io library
OUTPUTS: load_file_from_repo function and test file loads
"""

from requests.exceptions import HTTPError

# Specify the base repository URL for the AMTAIR project
repo_url = "https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main/data/ex
print(f"Connecting to repository: {repo_url}")

def load_file_from_repo(relative_path):
    """
    Loads a file from the specified GitHub repository using a relative path.

    Args:
        relative_path (str): Path to the file relative to the repo_url

    Returns:
        For CSV/JSON: pandas DataFrame
        For MD: string containing file contents

    Raises:
        HTTPError: If file not found or other HTTP error occurs
        ValueError: If unsupported file type is requested
    """
    file_url = repo_url + relative_path
    print(f"Attempting to load: {file_url}")

    # Fetch the file content from GitHub
    response = requests.get(file_url)
```

```

# Check for bad status codes with enhanced error messages
if response.status_code == 404:
    raise HTTPError(f"File not found at URL: {file_url}. Check the file path/name and en
else:
    response.raise_for_status() # Raise for other error codes

# Convert response to file-like object
file_object = io.StringIO(response.text)

# Process different file types appropriately
if relative_path.endswith(".csv"):
    return pd.read_csv(file_object) # Return DataFrame for CSV
elif relative_path.endswith(".json"):
    return pd.read_json(file_object) # Return DataFrame for JSON
elif relative_path.endswith(".md"):
    return file_object.read() # Return raw content for MD files
else:
    raise ValueError(f"Unsupported file type: {relative_path.split('.')[-1]}. Add support

# Load example files to test connection
try:
    # Load the extracted data CSV file
    # df = load_file_from_repo("extracted_data.csv")

    # Load the ArgDown test text
    md_content = load_file_from_repo("ArgDown.md")

    print(" Successfully connected to repository and loaded test files.")
except Exception as e:
    print(f" Error loading files: {str(e)}")
    print("Please check your internet connection and the repository URL.")

# Display preview of loaded content (commented out to avoid cluttering output)
print(md_content)

```

Connecting to repository: [https://raw.githubusercontent.com/SingularitySmith/AMTAIR\\_Prototype/main/main.py](https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main/main.py)

Attempting to load: [https://raw.githubusercontent.com/SingularitySmith/AMTAIR\\_Prototype/main/main.py](https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main/main.py)

Successfully connected to repository and loaded test files.

[Existential\_Catastrophe]: The destruction of humanity's long-term potential due to AI systems

- [Human\_Disempowerment]: Permanent and collective disempowerment of humanity relative to AI

- [Scale\_Of\_Power\_Seeking]: Power-seeking by AI systems scaling to the point of permanent

- [Misaligned\_Power\_Seeking]: Deployed AI systems seeking power in unintended and hi

```

- [APS_Systems]: AI systems with advanced capabilities, agentic planning, and st
  - [Advanced_AI_Capability]: AI systems that outperform humans on tasks that
  - [Agentic_Planning]: AI systems making and executing plans based on world m
  - [Strategic_Awareness]: AI systems with models accurately representing power
- [Difficulty_Of_Alignment]: It is harder to build aligned systems than misalign
  - [Instrumental_Convergence]: AI systems with misaligned objectives tend to
  - [Problems_With_Proxies]: Optimizing for proxy objectives breaks correlatio
  - [Problems_With_Search]: Search processes can yield systems pursuing differ
- [Deployment_Decisions]: Decisions to deploy potentially misaligned AI systems.
  - [Incentives_To_Build_APS]: Strong incentives to build and deploy APS syste
    - [Usefulness_Of_APS]: APS systems are very useful for many valuable tas
    - [Competitive_Dynamics]: Competitive pressures between AI developers. {
  - [Deception_By_AI]: AI systems deceiving humans about their true objectives
- [Corrective_Feedback]: Human society implementing corrections after observing prob
  - [Warning_Shots]: Observable failures in weaker systems before catastrophic ris
  - [Rapid_Capability_Escalation]: AI capabilities escalating very rapidly, allowi
[Barriers_To_Understanding]: Difficulty in understanding the internal workings of advanced A
- [Misaligned_Power_Seeking]: Deployed AI systems seeking power in unintended and high-impac
[Adversarial_Dynamics]: Potentially adversarial relationships between humans and power-seeking
- [Misaligned_Power_Seeking]: Deployed AI systems seeking power in unintended and high-impac
[Stakes_Of_Error]: The escalating impact of mistakes with power-seeking AI systems. {"instan
- [Misaligned_Power_Seeking]: Deployed AI systems seeking power in unintended and high-impac

```

### 0.3 File Import

```

# @title
md_content

```

```

'[Existential_Catastrophe]: The destruction of humanity\'s long-term potential due to AI sys

```



# 1 Argument Extraction: Sources (PDF's of Papers) to ArgDown (.md file)

## 1.0 Sources to ArgDown: Structured Argument Extraction

### Process Overview

This section implements the first major stage of the AMTAIR pipeline: transforming source documents (such as research papers, blog posts, or expert analyses) into structured argument representations using the ArgDown format.

ArgDown is a markdown-like notation for representing arguments in a hierarchical structure. In the context of AMTAIR, it serves as the first step toward creating formal Bayesian networks by:

1. Identifying key variables/statements in the text
2. Capturing their hierarchical relationships
3. Preserving their descriptive content
4. Defining their possible states (instantiations)

The extraction process uses Large Language Models (LLMs) to identify the structure and relationships in the text, though in this notebook we focus on processing pre-formatted examples rather than performing the full extraction from raw text.

### What is ArgDown?

ArgDown uses a simple syntax where:

- Statements are represented as `[Statement]: Description`
- Relationships are indicated with `+` symbols and indentation
- Metadata is added in JSON format, including possible states of each variable

For example:

```
[MainClaim]: Description of the main claim. {"instantiations": ["claim_TRUE", "claim_FALSE"]}

+ [SupportingEvidence]: Description of evidence. {"instantiations": ["evidence_TRUE", "evidence_FALSE"]}
```

This structure will later be enhanced with probability information to create BayesDown, which can be transformed into a Bayesian network for analysis and visualization.

## 1.1 Specify Source Document (e.g. PDF)

Review the source document, ensure it is suitable for API call and upload to / store it in the correct location.

```
# @title 1.1.0 --- MTAIR Online Model (Analytica) --- [online_model]

from IPython.display import IFrame

IFrame(src="https://acp.analytica.com/view0?invite=4560&code=3000289064591444815", width="100%", height="400px")

<IPython.lib.display.IFrame at 0x7b9cc9929f50>

MTAIR Online Model (Analytica)
```

## 1.2 Generate ArgDown Extraction Prompt

Generate Extraction Prompt

```
# @title 1.2.0 --- Prompt Template Function Definitions --- [prompt_template_function]

"""
BLOCK PURPOSE: Defines a flexible template system for LLM prompts used in the extraction pipeline.

This block implements two key classes:
1. PromptTemplate: A template class supporting variable substitution for dynamic prompts
2. PromptLibrary: A collection of pre-defined prompt templates for different extraction tasks

These templates are used in the ArgDown and BayesDown probability extraction
stages of the pipeline, providing consistent and well-structured prompts to the LLMs.

DEPENDENCIES: string.Template for variable substitution
OUTPUTS: PromptTemplate and PromptLibrary classes
"""

from string import Template
from typing import Dict, Optional, Union, List

class PromptTemplate:
    """Template system for LLM prompts with variable substitution"""

    def __init__(self, template: str):
        """Initialize with template string using $variable format"""
        self.template = Template(template)
```

```
def format(self, **kwargs) -> str:
    """Substitute variables in the template"""
    return self.template.safe_substitute(**kwargs)

@classmethod
def from_file(cls, filepath: str) -> 'PromptTemplate':
    """Load template from a file"""
    with open(filepath, 'r') as f:
        template = f.read()
    return cls(template)

class PromptLibrary:
    """Collection of prompt templates for different extraction tasks"""

    # ArgDown extraction prompt - transforms source text into structured argument map
    ARGDOWN_EXTRACTION = PromptTemplate("""
You are participating in the AMTAIR (Automating Transformative AI Risk Modeling)
project and you are tasked with converting natural language arguments into
ArgDown syntax by extracting and formalizing causal world models from
unstructured text.
Your specific task is to extract the implicit causal model from the provided
document in structured ArgDown format.

## Epistemic Foundation & Purpose

This extraction represents one possible interpretation of the implicit causal
model in the document. Multiple extractions from the same text help reveal
patterns of convergence (where the model is clearly articulated) and
divergence (where the model contains ambiguities). This approach acknowledges
that expert texts often contain implicit rather than explicit causal models.

Your role is to reveal the causal structure already present in the author's
thinking, maintaining epistemic humility about your interpretation while
adhering strictly to the required format.

## ArgDown Format Specification

### Core Syntax

ArgDown represents causal relationships using a hierarchical structure:

1. Variables appear in square brackets with descriptive text:

```

```

    `[Variable_Name]: Description of the variable.`

2. Causal relationships use indentation (2 spaces per level) and '+' symbols:

[Effect]: Description of effect. + [Cause]: Description of cause. + [Deeper_Cause]: Description of deeper cause.

3. Causality flows from bottom (more indented) to top (less indented):
- More indented variables (causes) influence less indented variables (effects)
- The top-level variable is the ultimate effect or outcome
- Deeper indentation levels represent root causes or earlier factors

4. Each variable must include JSON metadata with possible states (instantiations):
`[Variable]: Description. {"instantiations": ["variable_STATE1", "variable_STATE2"]}`

### JSON Metadata Format

The JSON metadata must follow this exact structure:

```json
{"instantiations": ["variable_STATE1", "variable_STATE2"]}
```

Requirements:
* Double quotes (not single) around field names and string values
* Square brackets enclosing the instantiations array
* Comma separation between array elements
* No trailing comma after the last element
* Must be valid JSON syntax that can be parsed by standard JSON parsers

For binary variables (most common case):
{"instantiations": ["variable_TRUE", "variable_FALSE"]}

For multi-state variables (when clearly specified in the text):
{"instantiations": ["variable_HIGH", "variable_MEDIUM", "variable_LOW"]}

The metadata must appear on the same line as the variable definition, after the description.

## Complex Structural Patterns

### Variables Influencing Multiple Effects

The same variable can appear multiple times in different places in the hierarchy if it influences multiple effects.

[Effect1]: First effect description. {"instantiations": ["effect1_TRUE", "effect1_FALSE"]}
+ [Cause_A]: Description of cause A. {"instantiations": ["cause_a_TRUE", "cause_a_FALSE"]}

[Effect2]: Second effect description. {"instantiations": ["effect2_TRUE", "effect2_FALSE"]}

```

```

+ [Cause_A]
+ [Cause_B]: Description of cause B. {"instantiations": ["cause_b_TRUE", "cause_b_FALSE"]}

### Multiple Causes of the Same Effect
Multiple causes can influence the same effect by being listed at the same indentation level.
[Effect]: Description of effect. {"instantiations": ["effect_TRUE", "effect_FALSE"]}
+ [Cause1]: Description of first cause. {"instantiations": ["cause1_TRUE", "cause1_FALSE"]}
+ [Cause2]: Description of second cause. {"instantiations": ["cause2_TRUE", "cause2_FALSE"]}
+ [Deeper_Cause]: A cause that influences Cause2. {"instantiations": ["deeper_cause_TRUE", "deeper_cause_FALSE"]}

### Causal Chains
Causal chains are represented through multiple levels of indentation:
[Ultimate_Effect]: The final outcome. {"instantiations": ["ultimate_effect_TRUE", "ultimate_effect_FALSE"]}
+ [Intermediate_Effect]: A mediating variable. {"instantiations": ["intermediate_effect_TRUE", "intermediate_effect_FALSE"]}
+ [Root_Cause]: The initial cause. {"instantiations": ["root_cause_TRUE", "root_cause_FALSE"]}
+ [2nd_Intermediate_Effect]: A mediating variable. {"instantiations": ["intermediate_effect2_TRUE", "intermediate_effect2_FALSE"]}

### Common Cause of Multiple Variables
A common cause affecting multiple variables is represented by referencing the same variable name.
[Effect1]: First effect description. {"instantiations": ["effect1_TRUE", "effect1_FALSE"]}
+ [Common_Cause]: Description of common cause. {"instantiations": ["common_cause_TRUE", "common_cause_FALSE"]}

[Effect2]: Second effect description. {"instantiations": ["effect2_TRUE", "effect2_FALSE"]}
+ [Common_Cause]

## Detailed Extraction Workflow
Please follow this step-by-step process, documenting your reasoning in XML tags:
<analysis>
First, conduct a holistic analysis of the document:
1. Identify the main subject matter or domain
2. Note key concepts, variables, and factors discussed
3. Pay attention to language indicating causal relationships (causes, affects, influences, etc.)
4. Look for the ultimate outcomes or effects that are the focus of the document
5. Record your general understanding of the document's implicit causal structure
</analysis>
<variable_identification>
Next, identify and list the key variables in the causal model:
* Focus on factors that are discussed as having an influence or being influenced
* For each variable:
  * Create a descriptive name in [square_brackets]
  * Write a concise description based directly on the text

```

```
* Determine possible states (usually binary TRUE/FALSE unless clearly specified)
* Distinguish between:
  * Outcome variables (effects the author is concerned with)
  * Intermediate variables (both causes and effects in chains)
  * Root cause variables (exogenous factors in the model)
* List all identified variables with their descriptions and possible states
</variable_identification>

<causal_structure>
Then, determine the causal relationships between variables:
* For each variable, identify what factors influence it
* Note the direction of causality (what causes what)
* Look for mediating variables in causal chains
* Identify common causes of multiple effects
* Capture feedback loops if present (though they must be represented as DAGs)
* Map out the hierarchical structure of the causal model
</causal_structure>

<format_conversion>
Now, convert your analysis into proper ArgDown format:
* Start with the ultimate outcome variables at the top level
* Place direct causes indented below with \+ symbols
* Continue with deeper causes at further indentation levels
* Add variable descriptions and instantiations metadata
* Ensure variables appearing in multiple places have consistent names
* Check that the entire structure forms a valid directed acyclic graph
</format_conversion>

<validation>

Finally, review your extraction for quality and format correctness:
1. Verify all variables have properly formatted metadata
2. Check that indentation properly represents causal direction
3. Confirm the extraction accurately reflects the document's implicit model
4. Ensure no cycles exist in the causal structure
5. Verify that variables referenced multiple times are consistent
6. Check that the extraction would be useful for subsequent analysis

</validation>

## Source Document Analysis Guidance
```

When analyzing the source document:

- \* Focus on revealing the author's own causal model, not imposing an external framework
- \* Maintain the author's terminology where possible
- \* Look for both explicit statements of causality and implicit assumptions
- \* Pay attention to the relative importance the author assigns to different factors
- \* Notice where the author expresses certainty versus uncertainty
- \* Consider the level of granularity appropriate to the document's own analysis

Remember that your goal is to make the implicit model explicit, not to evaluate or improve it.  
The value lies in accurately representing the author's perspective, even if you might personally disagree.

""")

```
# BayesDown probability extraction prompt - enhances ArgDown with probability information
BAYESDOWN_EXTRACTION = PromptTemplate("""
```

You are an expert in probabilistic reasoning and Bayesian networks. Your task is to extend the provided ArgDown structure with probability information, creating a BayesDown representation.

For each statement in the ArgDown structure, you need to:

1. Estimate prior probabilities for each possible state
2. Estimate conditional probabilities given parent states
3. Maintain the original structure and relationships

Here is the format to follow:

```
[Node]: Description. { "instantiations": ["node_TRUE", "node_FALSE"], "priors": { "p(node_TRUE)": 0.5, "p(node_FALSE)": 0.5 } }
[Parent]: Parent description. {...}
```

Here are the specific probability questions to answer:

\$questions

ArgDown structure to enhance:

\$argdown

Provide the complete BayesDown representation with probabilities:

""")

```
@classmethod
def get_template(cls, template_name: str) -> PromptTemplate:
    """Get a prompt template by name"""
    if hasattr(cls, template_name):
```

```
        return getattr(cls, template_name)
    else:
        raise ValueError(f"Template not found: {template_name}")
```

## 1.3 Prepare LLM API Call

Combine Systemprompt + API Specifications + ArgDown Instructions + Prompt + Source PDF for API Call

```
# @title 1.3.0 --- Provider-Agnostic LLM API Interface --- [provider_agnostic-interface]

"""
BLOCK PURPOSE: Provides a unified interface for interacting with different LLM providers.

This block implements a flexible, provider-agnostic system for making LLM API calls:
1. Base abstract class (LLMProvider) defining the common interface
2. Implementation classes for specific providers (OpenAI and Anthropic)
3. Factory class for creating appropriate provider instances

This abstraction allows the extraction pipeline to work with different LLM providers
without changing the core code, supporting both current and future LLM backends.

DEPENDENCIES: requests for API calls, os for environment variables, abstract base classes
OUTPUTS: LLMProvider abstract class and concrete implementations for OpenAI and Anthropic
"""

import os
import json
import time
import requests
from abc import ABC, abstractmethod
from typing import Dict, List, Optional, Union, Any
from dataclasses import dataclass

@dataclass
class LLMResponse:
    """Standard response object for LLM completions"""
    content: str          # The generated text response
    model: str            # The model used for generation
    usage: Dict[str, int] # Token usage statistics
    raw_response: Dict[str, Any] # Complete provider-specific response
    created_at: float = time.time() # Timestamp of response creation
```



```

class LLMProvider(ABC):
    """Abstract base class for LLM providers"""

    @abstractmethod
    def complete(self,
                  prompt: str,
                  system_prompt: Optional[str] = None,
                  temperature: float = 0.7,
                  max_tokens: int = 4000) -> LLMResponse:
        """Generate a completion from the LLM"""
        pass

    @abstractmethod
    def get_available_models(self) -> List[str]:
        """Return a list of available models from this provider"""
        pass

class OpenAIProvider(LLMProvider):
    """OpenAI API implementation"""

    def __init__(self, api_key: Optional[str] = None, organization: Optional[str] = None):
        """Initialize with API key from args or environment"""
        self.api_key = api_key or os.environ.get("OPENAI_API_KEY")
        if not self.api_key:
            raise ValueError("OpenAI API key is required. Provide as argument "
                             + "or set OPENAI_API_KEY environment variable.")

        self.organization = organization or os.environ.get("OPENAI_ORGANIZATION")
        self.api_base = "https://api.openai.com/v1"

    def complete(self,
                  prompt: str,
                  system_prompt: Optional[str] = None,
                  model: str = "gpt-4-turbo",
                  temperature: float = 0.7,
                  max_tokens: int = 4000) -> LLMResponse:
        """Generate a completion using OpenAI's API"""

        # Prepare request headers
        headers = {
            "Content-Type": "application/json",

```

```

        "Authorization": f"Bearer {self.api_key}"
    }

    if self.organization:
        headers["OpenAI-Organization"] = self.organization

    # Create message structure
    messages = []
    if system_prompt:
        messages.append({"role": "system", "content": system_prompt})

    messages.append({"role": "user", "content": prompt})

    # Prepare request data
    data = {
        "model": model,
        "messages": messages,
        "temperature": temperature,
        "max_tokens": max_tokens
    }

    # Make API call
    response = requests.post(
        f"{self.api_base}/chat/completions",
        headers=headers,
        json=data
    )

    response.raise_for_status()
    result = response.json()

    # Transform into standardized response format
    return LLMResponse(
        content=result["choices"][0]["message"]["content"],
        model=result["model"],
        usage=result["usage"],
        raw_response=result
    )

def get_available_models(self) -> List[str]:
    """Return a list of available OpenAI models"""
    headers = {

```

```

        "Authorization": f"Bearer {self.api_key}"
    }

    if self.organization:
        headers["OpenAI-Organization"] = self.organization

    response = requests.get(
        f"{self.api_base}/models",
        headers=headers
    )

    response.raise_for_status()
    models = response.json()["data"]
    return [model["id"] for model in models]

class AnthropicProvider(LLMProvider):
    """Anthropic Claude API implementation"""

    def __init__(self, api_key: Optional[str] = None):
        """Initialize with API key from args or environment"""
        self.api_key = api_key or os.environ.get("ANTHROPIC_API_KEY")
        if not self.api_key:
            raise ValueError("Anthropic API key is required. Provide as"
                              + " argument or set ANTHROPIC_API_KEY environment variable.")

        self.api_base = "https://api.anthropic.com/v1"

    def complete(self,
                 prompt: str,
                 system_prompt: Optional[str] = None,
                 model: str = "claude-3-opus-20240229",
                 temperature: float = 0.7,
                 max_tokens: int = 4000) -> LLMResponse:
        """Generate a completion using Anthropic's API"""

        # Prepare request headers
        headers = {
            "Content-Type": "application/json",
            "X-API-Key": self.api_key,
            "anthropic-version": "2023-06-01"
        }

```

```
# Prepare request data in Anthropic-specific format
data = {
    "model": model,
    "messages": [{"role": "user", "content": prompt}],
    "temperature": temperature,
    "max_tokens": max_tokens
}

# Add system prompt if provided (Anthropic uses a different format)
if system_prompt:
    data["system"] = system_prompt

# Make API call
response = requests.post(
    f"{self.api_base}/messages",
    headers=headers,
    json=data
)

response.raise_for_status()
result = response.json()

# Transform into standardized response format
return LLMResponse(
    content=result["content"][0]["text"],
    model=result["model"],
    usage={"prompt_tokens": result.get("usage", {}).get("input_tokens", 0),
           "completion_tokens": result.get("usage", {}).get("output_tokens", 0)},
    raw_response=result
)

def get_available_models(self) -> List[str]:
    """Return a list of available Anthropic models"""
    # Anthropic doesn't have a models endpoint, so we return a static list
    return [
        "claude-3-opus-20240229",
        "claude-3-sonnet-20240229",
        "claude-3-haiku-20240307"
    ]

class LLMFactory:
    """Factory for creating LLM providers"""
```

```

    @staticmethod
    def create_provider(provider_name: str, **kwargs) -> LLMProvider:
        """Create and return an LLM provider instance"""
        if provider_name.lower() == "openai":
            return OpenAIProvider(**kwargs)
        elif provider_name.lower() == "anthropic":
            return AnthropicProvider(**kwargs)
        else:
            raise ValueError(f"Unsupported provider: {provider_name}")

# @title 1.3.1 --- API Call Function Definitions --- [api_call_function_definitions]

"""
BLOCK PURPOSE: Provides core functions for extracting ArgDown representations from text using LLMs.

This block implements the main extraction functionality:
1. extract_argdown_from_text: Sends text to LLM to extract structured ArgDown representation
2. validate_argdown: Verifies the extracted ArgDown for correctness and completeness
3. process_source_document: Handles source files (PDF, TXT, MD) and manages extraction
4. save_argdown_extraction: Saves extraction results with metadata for further processing

These functions form the first stage of the AMTAIR pipeline, transforming
unstructured text into structured argument representations.

DEPENDENCIES: LLMFactory from previous cell, re for pattern matching
OUTPUTS: Functions for ArgDown extraction, validation, and storage
"""

def extract_argdown_from_text(text: str, provider_name: str = "openai", model: str = None) -> ArgDown:
    """
    Extract ArgDown representation from text using LLM

    Args:
        text: The source text to extract arguments from
        provider_name: The LLM provider to use (openai or anthropic)
        model: Specific model to use, or None for default

    Returns:
        Extracted ArgDown representation
    """
    # Create LLM provider
    provider = LLMFactory.create_provider(provider_name)

```

```

# Get extraction prompt
prompt_template = PromptLibrary.get_template("ARGDOWN_EXTRACTION")
prompt = prompt_template.format(text=text)

# Set model-specific parameters
if provider_name.lower() == "openai":
    model = model or "gpt-4-turbo"
    temperature = 0.3 # Lower temperature for more deterministic extraction
    max_tokens = 4000
elif provider_name.lower() == "anthropic":
    model = model or "claude-3-opus-20240229"
    temperature = 0.2
    max_tokens = 4000

# Call the LLM
system_prompt = "You are an expert in argument mapping and causal reasoning."
response = provider.complete(
    prompt=prompt,
    system_prompt=system_prompt,
    model=model,
    temperature=temperature,
    max_tokens=max_tokens
)

# Extract the ArgDown content (remove any markdown code blocks if present)
argdown_content = response.content
if "```" in argdown_content:
    # Extract content between code blocks if present
    import re
    matches = re.findall(r"```(?:argdown)?\n([\s\S]*?)\n```", argdown_content)
    if matches:
        argdown_content = matches[0]

return argdown_content

def validate_argdown(argdown_text: str) -> Dict[str, Any]:
    """
    Validate ArgDown representation to ensure it's well-formed

    Args:
        argdown_text: ArgDown representation to validate
    """

```

```

Returns:
    Dictionary with validation results
"""
# Initialize validation results
results = {
    "is_valid": True,
    "errors": [],
    "warnings": [],
    "stats": {
        "node_count": 0,
        "relationship_count": 0,
        "max_depth": 0
    }
}

# Basic syntax checks
lines = argdown_text.split("\n")
node_pattern = r'\[(.*?)\]:'
instantiation_pattern = r'{"instantiations":'

# Track nodes and relationships
nodes = set()
relationships = []
current_depth = 0
max_depth = 0

for i, line in enumerate(lines):
    # Skip empty lines
    if not line.strip():
        continue

    # Calculate indentation depth
    indent = 0
    if '+' in line:
        indent = line.find('+') // 2

    current_depth = indent
    max_depth = max(max_depth, current_depth)

    # Check for node definitions
    import re

```

```

node_matches = re.findall(node_pattern, line)
if node_matches:
    node = node_matches[0]
    nodes.add(node)
    results["stats"]["node_count"] += 1

    # Check for instantiations
    if instantiation_pattern not in line:
        results["warnings"].append(f"Line {i+1}: Node '{node}' is missing instantiation")

# Check parent-child relationships
if indent > 0 and '+' in line and node_matches:
    # This is a child node; find its parent
    parent_indent = indent - 1
    j = i - 1
    while j >= 0:
        if '+' in lines[j] and lines[j].find('+') // 2 == parent_indent:
            parent_matches = re.findall(node_pattern, lines[j])
            if parent_matches:
                parent = parent_matches[0]
                relationships.append((parent, node))
                results["stats"]["relationship_count"] += 1
                break
        j -= 1

results["stats"]["max_depth"] = max_depth

# If we didn't find any nodes, that's a problem
if results["stats"]["node_count"] == 0:
    results["is_valid"] = False
    results["errors"].append("No valid nodes found in ArgDown representation")

return results

def process_source_document(file_path: str, provider_name: str = "openai") -> Dict[str, Any]:
    """
    Process a source document to extract ArgDown representation

    Args:
        file_path: Path to the source document
        provider_name: The LLM provider to use

```



```

Returns:
    Dictionary with extraction results
"""
# Load the source document
text = ""
if file_path.endswith(".pdf"):
    # PDF handling requires additional libraries
    try:
        import PyPDF2
        with open(file_path, 'rb') as file:
            reader = PyPDF2.PdfReader(file)
            text = ""
            for page in reader.pages:
                text += page.extract_text() + "\n"
    except ImportError:
        raise ImportError("PyPDF2 is required for PDF processing. "
                          + "Install it with: pip install PyPDF2")
elif file_path.endswith(".txt"):
    with open(file_path, 'r') as file:
        text = file.read()
elif file_path.endswith(".md"):
    with open(file_path, 'r') as file:
        text = file.read()
else:
    raise ValueError(f"Unsupported file format: {file_path}")

# Extract ArgDown
argdown_content = extract_argdown_from_text(text, provider_name)

# Validate the extraction
validation_results = validate_argdown(argdown_content)

# Prepare results
results = {
    "source_path": file_path,
    "extraction_timestamp": time.time(),
    "argdown_content": argdown_content,
    "validation": validation_results,
    "provider": provider_name
}

return results

```

### 1.3 Prepare LLM API Call and Document Extraction: Sources (PDF's of Papers) to ArgDown (.md file)

```
def save_argdown_extraction(results: Dict[str, Any], output_path: str) -> None:
    """
    Save ArgDown extraction results

    Args:
        results: Extraction results dictionary
        output_path: Path to save the results
    """
    # Save the ArgDown content
    with open(output_path, 'w') as file:
        file.write(results["argdown_content"])

    # Save metadata alongside
    metadata_path = output_path.replace('.md', '_metadata.json')
    metadata = {
        "source_path": results["source_path"],
        "extraction_timestamp": results["extraction_timestamp"],
        "validation": results["validation"],
        "provider": results["provider"]
    }

    with open(metadata_path, 'w') as file:
        json.dump(metadata, file, indent=2)

# @title 1.3.2 --- Prepare LLM API Call --- [prepare_api_call]

"""
BLOCK PURPOSE: Prepares parameters for LLM API calls used in ArgDown extraction.

This function handles the configuration for LLM API calls, including:
1. Source document path validation
2. LLM provider selection and validation
3. Model selection with appropriate defaults

The function returns a configuration dictionary that can be passed to the
extraction function in the next step of the pipeline.

DEPENDENCIES: None (uses standard Python functionality)
OUTPUTS: Dictionary with extraction configuration parameters
"""

def prepare_extraction_call(source_path, provider_name="openai", model=None):
```

```

"""
Prepare the LLM API call for ArgDown extraction

Args:
    source_path (str): Path to the source document to extract from
    provider_name (str): LLM provider to use ('openai' or 'anthropic')
    model (str, optional): Specific model to use. Defaults to None (uses provider's default)

Returns:
    dict: Configuration parameters for extraction

Raises:
    ValueError: If an unsupported provider is specified
"""

# Load the source document
print(f"Processing source document: {source_path}")

# Determine provider and model
provider = provider_name.lower()
if provider not in ["openai", "anthropic"]:
    raise ValueError(f"Unsupported provider: {provider}. Use 'openai' or 'anthropic'.")

# Set default model if none provided
if model is None:
    if provider == "openai":
        model = "gpt-4-turbo"
    elif provider == "anthropic":
        model = "claude-3-opus-20240229"

# Print configuration
print(f"Using provider: {provider}")
print(f"Selected model: {model}")

return {
    "source_path": source_path,
    "provider": provider,
    "model": model
}

# Usage example:
source_path = "example_document.pdf" # Replace with actual document path
extraction_config = prepare_extraction_call(source_path, provider_name="openai")

```

Processing source document: example\_document.pdf

Using provider: openai

Selected model: gpt-4-turbo

## 1.4 Make ArgDown Extraction LLM API Call

```
# @title 1.4.0 --- Make ArgDown Extraction LLM API Call --- [extraction_api_call]

"""
BLOCK PURPOSE: Executes the ArgDown extraction process using the LLM API.

This function performs the actual extraction of ArgDown representations from
source documents:

1. Takes the configuration parameters prepared in the previous step
2. Processes the document using the LLM API
3. Validates the extraction results
4. Provides timing and statistics about the extraction

The extraction process transforms unstructured text into a structured argument
representation following the ArgDown syntax defined in the AMTAIR project.

DEPENDENCIES: process_source_document function from previous cells
OUTPUTS: Dictionary with extraction results including ArgDown content and validation info
"""

def execute_extraction(extraction_config):
    """
    Execute the ArgDown extraction using the LLM API

    Args:
        extraction_config (dict): Configuration parameters for extraction

    Returns:
        dict: Extraction results including ArgDown content and validation info

    Raises:
        Exception: For any errors during extraction
    """
    print(f"Starting extraction from {extraction_config['source_path']}")
    start_time = time.time()

    try:
```

```

# Process the document
results = process_source_document(
    extraction_config["source_path"],
    provider_name=extraction_config["provider"]
)

# Print success message
elapsed_time = time.time() - start_time
print(f"Extraction completed in {elapsed_time:.2f} seconds")
print(f"Extracted {results['validation']['stats']['node_count']} nodes with "
      f"{results['validation']['stats']['relationship_count']} relationships")

# Print any warnings
if results['validation']['warnings']:
    print("\nWarnings:")
    for warning in results['validation']['warnings']:
        print(f"- {warning}")

return results

except Exception as e:
    print(f"Error during extraction: {str(e)}")
    raise

# Usage example:
extraction_results = execute_extraction(extraction_config)

```

Starting extraction from example\_document.pdf

Error during extraction: PyPDF2 is required for PDF processing. Install it with: pip install

ImportError: PyPDF2 is required for PDF processing. Install it with: pip install PyPDF2

```

-----
ModuleNotFoundError                                Traceback (most recent call last)
<ipython-input-19-fd592eb962ab> in process_source_document(file_path, provider_name)
    166         try:
--> 167             import PyPDF2
    168             with open(file_path, 'rb') as file:
ModuleNotFoundError: No module named 'PyPDF2'
During handling of the above exception, another exception occurred:
ImportError                                Traceback (most recent call last)
<ipython-input-21-27555067c1d2> in <cell line: 0>()
    59
    60 # Usage example:

```

## 1.5 Save ArgDown Extraction Response: Sources (PDF's of Papers) to ArgDown (.md file)

```
---> 61 extraction_results = execute_extraction(extraction_config)

<ipython-input-21-27555067c1d2> in execute_extraction(extraction_config)
    35     try:
    36         # Process the document
---> 37         results = process_source_document(
    38             extraction_config["source_path"],
    39             provider_name=extraction_config["provider"]
<ipython-input-19-fd592eb962ab> in process_source_document(file_path, provider_name)
    172         text += page.extract_text() + "\n"
    173     except ImportError:
--> 174         raise ImportError("PyPDF2 is required for PDF processing. Install it with: pip install PyPDF2")
    175     elif file_path.endswith(".txt"):
    176         with open(file_path, 'r') as file:
ImportError: PyPDF2 is required for PDF processing. Install it with: pip install PyPDF2

-----

NOTE: If your import is failing due to a missing package, you can
manually install dependencies using either !pip or !apt.
To view examples of installing some common dependencies, click the
"Open Examples" button below.

-----
```

## 1.5 Save ArgDown Extraction Response

1. Save and log API return
2. Save ArgDown.md file for further Processing

```
# @title 1.5.0 --- Save ArgDown Extraction Response --- [save_extraction_response]

"""
BLOCK PURPOSE: Saves the extracted ArgDown content to files for further processing.

This function handles saving the extraction results:
1. Creates an output directory if it doesn't exist
2. Saves the extracted ArgDown content with a timestamp in the filename
3. Saves accompanying metadata in a JSON file
4. Saves a copy at a standard location for the next steps in the pipeline
5. Provides a preview of the extracted content

The saved files serve as inputs for the next stage of the pipeline where
probability information will be added to create BayesDown.

DEPENDENCIES: os module for directory operations
```

OUTPUTS: Saved ArgDown files and preview of extracted content

```

"""

def save_extraction_results(results, output_directory="./outputs"):
    """
    Save the extraction results to file

    Args:
        results (dict): Extraction results from execute_extraction
        output_directory (str): Directory to save results

    Returns:
        str: Path to the saved ArgDown file
    """
    # Ensure output directory exists
    import os
    os.makedirs(output_directory, exist_ok=True)

    # Create base filename from source
    import os.path
    base_name = os.path.basename(results["source_path"]).split('.')[0]
    timestamp = time.strftime("%Y%m%d-%H%M%S")
    output_filename = f"{base_name}_argdown_{timestamp}.md"
    output_path = os.path.join(output_directory, output_filename)

    # Save the results
    save_argdown_extraction(results, output_path)

    print(f"Saved ArgDown extraction to: {output_path}")
    print(f"Metadata saved to: {output_path.replace('.md', '_metadata.json')}")

    # Also save to standard location for further processing
    standard_path = os.path.join(output_directory, "ArgDown.md")
    with open(standard_path, 'w') as f:
        f.write(results["argdown_content"])
    print(f"Also saved to standard location: {standard_path}")

    return output_path

# Usage example:
output_path = save_extraction_results(extraction_results)

```

```
# Preview the extracted ArgDown
from IPython.display import Markdown, display

# Display the first 500 characters of the extracted ArgDown
preview = extraction_results["argdown_content"][:500] + "..." if len(extraction_results["argdown_content"]) > 500 else extraction_results["argdown_content"]
display(Markdown(f"## Extracted ArgDown Preview\n\n```\n{preview}\n```"))
```

NameError: name 'extraction\_results' is not defined

```
-----
NameError                                Traceback (most recent call last)
<ipython-input-57-84ee4ea64739> in <cell line: 0>()
    55
    56 # Usage example:
--> 57 output_path = save_extraction_results(extraction_results)
    58
    59 # Preview the extracted ArgDown
NameError: name 'extraction_results' is not defined
```

## 1.6 Review and Check ArgDown.md File

```
display(Markdown(md_content))
```

[Existential\_Catastrophe]: The destruction of humanity's long-term potential due to AI systems we've lost control over. {"instantiations": ["existential\_catastrophe\_TRUE", "existential\_catastrophe\_FALSE"]} - [Human\_Disempowerment]: Permanent and collective disempowerment of humanity relative to AI systems. {"instantiations": ["human\_disempowerment\_TRUE", "human\_disempowerment\_FALSE"]} - [Scale\_Of\_Power\_Seeking]: Power-seeking by AI systems scaling to the point of permanently disempowering all of humanity. {"instantiations": ["scale\_of\_power\_seeking\_TRUE", "scale\_of\_power\_seeking\_FALSE"]} - [Misaligned\_Power\_Seeking]: Deployed AI systems seeking power in unintended and high-impact ways due to problems with their objectives. {"instantiations": ["misaligned\_power\_seeking\_TRUE", "misaligned\_power\_seeking\_FALSE"]} - [APS\_Systems]: AI systems with advanced capabilities, agentic planning, and strategic awareness. {"instantiations": ["aps\_systems\_TRUE", "aps\_systems\_FALSE"]} - [Advanced\_AI\_Capability]: AI systems that outperform humans on tasks that grant significant power in the world. {"instantiations": ["advanced\_ai\_capability\_TRUE", "advanced\_ai\_capability\_FALSE"]} - [Agentic\_Planning]: AI systems making and executing plans based on world models to achieve objectives. {"instantiations": ["agentic\_planning\_TRUE", "agentic\_planning\_FALSE"]} - [Strategic\_Awareness]: AI systems with models accurately representing power dynamics with humans. {"instantiations": ["strategic\_awareness\_TRUE", "strategic\_awareness\_FALSE"]} - [Difficulty\_Of\_Alignment]: It is harder to build aligned systems than misaligned systems that are attractive to deploy. {"instantiations": ["difficulty\_of\_alignment\_TRUE", "difficulty\_of\_alignment\_FALSE"]} - [Instrumental\_Convergence]: AI systems with



misaligned objectives tend to seek power as an instrumental goal. {"instantiations": ["instrumental\_convergence\_TRUE", "instrumental\_convergence\_FALSE"]} - [Problems\_With\_Proxies]: Optimizing for proxy objectives breaks correlations with intended goals. {"instantiations": ["problems\_with\_proxies\_TRUE", "problems\_with\_proxies\_FALSE"]} - [Problems\_With\_Search]: Search processes can yield systems pursuing different objectives than intended. {"instantiations": ["problems\_with\_search\_TRUE", "problems\_with\_search\_FALSE"]} - [Deployment\_Decisions]: Decisions to deploy potentially misaligned AI systems. {"instantiations": ["deployment\_decisions\_DEPLOY", "deployment\_decisions\_WITHHOLD"]} - [Incentives\_To\_Build\_APS]: Strong incentives to build and deploy APS systems. {"instantiations": ["incentives\_to\_build\_aps\_STRONG", "incentives\_to\_build\_aps\_WEAK"]} - [Usefulness\_Of\_APS]: APS systems are very useful for many valuable tasks. {"instantiations": ["usefulness\_of\_aps\_HIGH", "usefulness\_of\_aps\_LOW"]} - [Competitive\_Dynamics]: Competitive pressures between AI developers. {"instantiations": ["competitive\_dynamics\_STRONG", "competitive\_dynamics\_WEAK"]} - [Deception\_By\_AI]: AI systems deceiving humans about their true objectives. {"instantiations": ["deception\_by\_ai\_TRUE", "deception\_by\_ai\_FALSE"]} - [Corrective\_Feedback]: Human society implementing corrections after observing problems. {"instantiations": ["corrective\_feedback\_EFFECTIVE", "corrective\_feedback\_INEFFECTIVE"]} - [Warning\_Shots]: Observable failures in weaker systems before catastrophic risks. {"instantiations": ["warning\_shots\_OBSERVED", "warning\_shots\_UNOBSERVED"]} - [Rapid\_Capability\_Escalation]: AI capabilities escalating very rapidly, allowing little time for correction. {"instantiations": ["rapid\_capability\_escalation\_TRUE", "rapid\_capability\_escalation\_FALSE"]} - [Barriers\_To\_Understanding]: Difficulty in understanding the internal workings of advanced AI systems. {"instantiations": ["barriers\_to\_understanding\_HIGH", "barriers\_to\_understanding\_LOW"]} - [Misaligned\_Power\_Seeking]: Deployed AI systems seeking power in unintended and high-impact ways due to problems with their objectives. {"instantiations": ["misaligned\_power\_seeking\_TRUE", "misaligned\_power\_seeking\_FALSE"]} - [Adversarial\_Dynamics]: Potentially adversarial relationships between humans and power-seeking AI. {"instantiations": ["adversarial\_dynamics\_TRUE", "adversarial\_dynamics\_FALSE"]} - [Misaligned\_Power\_Seeking]: Deployed AI systems seeking power in unintended and high-impact ways due to problems with their objectives. {"instantiations": ["misaligned\_power\_seeking\_TRUE", "misaligned\_power\_seeking\_FALSE"]} - [Stakes\_Of\_Error]: The escalating impact of mistakes with power-seeking AI systems. {"instantiations": ["stakes\_of\_error\_HIGH", "stakes\_of\_error\_LOW"]} - [Misaligned\_Power\_Seeking]: Deployed AI systems seeking power in unintended and high-impact ways due to problems with their objectives. {"instantiations": ["misaligned\_power\_seeking\_TRUE", "misaligned\_power\_seeking\_FALSE"]}

### 1.6.0 Check the Graph Structure with the ArgDown Sandbox Online

Copy and paste the BayesDown formatted ... in the ArgDown Sandbox below to quickly verify that the network renders correctly.

```
# @title 1.6.1 --- ArgDown Online Sandbox --- [argdown_online_sandbox]

from IPython.display import IFrame

IFrame(src="https://argdown.org/sandbox/map/", width="100%", height="600px")

<IPython.lib.display.IFrame at 0x7b9ccf0ea210>

ArgDown Online Sandbox
```

## 1.7 Extract ArgDown Graph Information as DataFrame

Extract:

- Nodes (Variable\_Title)
- Edges (Parents)
- Instantiations
- Description

Implementation nodes: - One function for ArgDown and BayesDown extraction, but: - IF YOU ONLY WANT ARGDOWN EXTRACTION: USE ARGUMENT IN FUNCTION CALL “parse\_markdown\_hierarchy(markdown\_text, ArgDown = True)” - so if you set ArgDown = True, it gives you only instantiations, no probabilities.

```
# @title 1.7.0 --- Parsing ArgDown & BayesDown (.md to .csv) --- [parsing_argdown_bayesdown]

"""
BLOCK PURPOSE: Provides the core parsing functionality for transforming ArgDown
and BayesDown text representations into structured DataFrame format for further
processing.

This block implements the critical extraction pipeline described in the AMTAIR
project (see PY_TechnicalImplementation) that converts argument structures
into Bayesian networks.

The function can handle both basic ArgDown (structure-only) and
BayesDown (with probabilities).

Key steps in the parsing process:
1. Remove comments from the markdown text
2. Extract titles, descriptions, and indentation levels
3. Establish parent-child relationships based on indentation
4. Convert the structured information into a DataFrame
5. Add derived columns for network analysis

DEPENDENCIES: pandas, re, json libraries
```

```

INPUTS: Markdown text in ArgDown/BayesDown format
OUTPUTS: Structured DataFrame with node information, relationships, and properties
"""

def parse_markdown_hierarchy_fixed(markdown_text, ArgDown=False):
    """
    Parse ArgDown or BayesDown format into a structured DataFrame with parent-child relationships.

    Args:
        markdown_text (str): Text in ArgDown or BayesDown format
        ArgDown (bool): If True, extracts only structure without probabilities
                        If False, extracts both structure and probability information

    Returns:
        pandas.DataFrame: Structured data with node information, relationships, and attributes
    """
    # PHASE 1: Clean and prepare the text
    clean_text = remove_comments(markdown_text)

    # PHASE 2: Extract basic information about nodes
    titles_info = extract_titles_info(clean_text)

    # PHASE 3: Determine the hierarchical relationships
    titles_with_relations = establish_relationships_fixed(titles_info, clean_text)

    # PHASE 4: Convert to structured DataFrame format
    df = convert_to_dataframe(titles_with_relations, ArgDown)

    # PHASE 5: Add derived columns for analysis
    df = add_no_parent_no_child_columns_to_df(df)
    df = add_parents_instantiation_columns_to_df(df)

    return df

def remove_comments(markdown_text):
    """
    Remove comment blocks from markdown text using regex pattern matching.

    Args:
        markdown_text (str): Text containing potential comment blocks

    Returns:
    """

```

```

    str: Text with comment blocks removed
    """
    # Remove anything between /* and */ using regex
    return re.sub(r'/\*.*?\*/', '', markdown_text, flags=re.DOTALL)

def extract_titles_info(text):
    """
    Extract titles with their descriptions and indentation levels from markdown text.

    Args:
        text (str): Cleaned markdown text

    Returns:
        dict: Dictionary with titles as keys and dictionaries of attributes as values
    """
    lines = text.split('\n')
    titles_info = {}

    for line in lines:
        # Skip empty lines
        if not line.strip():
            continue

        # Extract title within square or angle brackets
        title_match = re.search(r'<[\[\]](.+?)>[\[\]]', line)
        if not title_match:
            continue

        title = title_match.group(1)

        # Extract description and metadata
        title_pattern_in_line = r'<[\[\]]' + re.escape(title) + r'>[\[\]]:'
        description_match = re.search(title_pattern_in_line + r'\s*(.*)', line)

        if description_match:
            full_text = description_match.group(1).strip()

            # Split description and metadata at the first "{"
            if "{" in full_text:
                split_index = full_text.find("{")
                description = full_text[:split_index].strip()
                metadata = full_text[split_index:].strip()

```

```

else:
    # Keep the entire description and no metadata
    description = full_text
    metadata = '' # Initialize as empty string
else:
    description = ''
    metadata = '' # Ensure metadata is initialized

# Calculate indentation level based on spaces before + or - symbol
indentation = 0
if '+' in line:
    symbol_index = line.find('+')
    # Count spaces before the '+' symbol
    i = symbol_index - 1
    while i >= 0 and line[i] == ' ':
        indentation += 1
        i -= 1
elif '-' in line:
    symbol_index = line.find('-')
    # Count spaces before the '-' symbol
    i = symbol_index - 1
    while i >= 0 and line[i] == ' ':
        indentation += 1
        i -= 1

# If neither symbol exists, indentation remains 0

if title in titles_info:
    # Only update description if it's currently empty and we found a new one
    if not titles_info[title]['description'] and description:
        titles_info[title]['description'] = description

    # Store all indentation levels for this title
    titles_info[title]['indentation_levels'].append(indentation)

    # Keep max indentation for backward compatibility
    if indentation > titles_info[title]['indentation']:
        titles_info[title]['indentation'] = indentation

    # Do NOT update metadata here - keep the original metadata
else:
    # First time seeing this title, create a new entry

```

```

        titles_info[title] = {
            'description': description,
            'indentation': indentation,
            'indentation_levels': [indentation], # Initialize with first indentation level
            'parents': [],
            'children': [],
            'line': None,
            'line_numbers': [], # Initialize an empty list for all occurrences
            'metadata': metadata # Set metadata explicitly from what we found
        }

    return titles_info

def establish_relationships_fixed(titles_info, text):
    """
    Establish parent-child relationships between titles using BayesDown
    indentation rules.

    In BayesDown syntax:
    - More indented nodes (with + symbol) are PARENTS of less indented nodes
    - The relationship reads as "Effect is caused by Cause" (Effect + Cause)
    - This aligns with how Bayesian networks represent causality

    Args:
        titles_info (dict): Dictionary with information about titles
        text (str): Original markdown text (for identifying line numbers)

    Returns:
        dict: Updated dictionary with parent-child relationships
    """
    lines = text.split('\n')

    # Dictionary to store line numbers for each title occurrence
    title_occurrences = {}

    # Record line number for each title (including multiple occurrences)
    line_number = 0
    for line in lines:
        if not line.strip():
            line_number += 1
            continue

```

```

title_match = re.search(r'<\[ (.+?) >\]', line)
if not title_match:
    line_number += 1
    continue

title = title_match.group(1)

# Store all occurrences of each title with their line numbers
if title not in title_occurrences:
    title_occurrences[title] = []
title_occurrences[title].append(line_number)

# Store all line numbers where this title appears
if 'line_numbers' not in titles_info[title]:
    titles_info[title]['line_numbers'] = []
titles_info[title]['line_numbers'].append(line_number)

# For backward compatibility, keep the first occurrence in 'line'
if titles_info[title]['line'] is None:
    titles_info[title]['line'] = line_number

line_number += 1

# Create an ordered list of all title occurrences with their line numbers
all_occurrences = []
for title, occurrences in title_occurrences.items():
    for line_num in occurrences:
        all_occurrences.append((title, line_num))

# Sort occurrences by line number
all_occurrences.sort(key=lambda x: x[1])

# Get indentation for each occurrence
occurrence_indents = {}
for title, line_num in all_occurrences:
    for line in lines[line_num:line_num+1]: # Only check the current line
        indent = 0
        if '+' in line:
            symbol_index = line.find('+')
            # Count spaces before the '+' symbol
            j = symbol_index - 1
            while j >= 0 and line[j] == ' ':

```

```

        indent += 1
        j -= 1
    elif '-' in line:
        symbol_index = line.find('-')
        # Count spaces before the '-' symbol
        j = symbol_index - 1
        while j >= 0 and line[j] == ' ':
            indent += 1
            j -= 1
        occurrence_indents[(title, line_num)] = indent

# Enhanced backward pass for correct parent-child relationships
for i, (title, line_num) in enumerate(all_occurrences):
    current_indent = occurrence_indents[(title, line_num)]

    # Skip root nodes (indentation 0) for processing
    if current_indent == 0:
        continue

    # Look for the immediately preceding node with lower indentation
    j = i - 1
    while j >= 0:
        prev_title, prev_line = all_occurrences[j]
        prev_indent = occurrence_indents[(prev_title, prev_line)]

        # If we find a node with less indentation, it's a child of current node
        if prev_indent < current_indent:
            # In BayesDown:
            # More indented node is a parent (cause) of less indented node (effect)
            if title not in titles_info[prev_title]['parents']:
                titles_info[prev_title]['parents'].append(title)
            if prev_title not in titles_info[title]['children']:
                titles_info[title]['children'].append(prev_title)

            # Only need to find the immediate child
            # (closest preceding node with lower indentation)
            break

        j -= 1

return titles_info

```



```
def convert_to_dataframe(titles_info, ArgDown):
    """
    Convert the titles information dictionary to a pandas DataFrame.

    Args:
        titles_info (dict): Dictionary with information about titles
        ArgDown (bool): If True, extract only structural information without probabilities

    Returns:
        pandas.DataFrame: Structured data with node information and relationships
    """
    if ArgDown == True:
        # For ArgDown, exclude probability columns
        df = pd.DataFrame(columns=['Title', 'Description', 'line', 'line_numbers', 'indentation',
                                   'indentation_levels', 'Parents', 'Children', 'instantiations'])
    else:
        # For BayesDown, include probability columns
        df = pd.DataFrame(columns=['Title', 'Description', 'line', 'line_numbers', 'indentation',
                                   'indentation_levels', 'Parents', 'Children', 'instantiations',
                                   'priors', 'posteriors'])

    for title, info in titles_info.items():
        # Parse the metadata JSON string into a Python dictionary
        if 'metadata' in info and info['metadata']:
            try:
                # Only try to parse if metadata is not empty
                if info['metadata'].strip():
                    jsonMetadata = json.loads(info['metadata'])
                    if ArgDown == True:
                        # Create the row dictionary with instantiations as
                        # metadata only, no probabilities yet
                        row = {
                            'Title': title,
                            'Description': info.get('description', ''),
                            'line': info.get('line', ''),
                            'line_numbers': info.get('line_numbers', []),
                            'indentation': info.get('indentation', ''),
                            'indentation_levels': info.get('indentation_levels', []),
                            'Parents': info.get('parents', []),
                            'Children': info.get('children', []),
                            # Extract specific metadata fields,
                            # defaulting to empty if not present

```

```

        'instantiations': jsonMetadata.get('instantiations', []),
    }
else:
    # Create dict with probabilities for BayesDown
    row = {
        'Title': title,
        'Description': info.get('description', ''),
        'line': info.get('line', ''),
        'line_numbers': info.get('line_numbers', []),
        'indentation': info.get('indentation', ''),
        'indentation_levels': info.get('indentation_levels', []),
        'Parents': info.get('parents', []),
        'Children': info.get('children', []),
        # Extract specific metadata fields, defaulting to empty if not present
        'instantiations': jsonMetadata.get('instantiations', []),
        'priors': jsonMetadata.get('priors', {}),
        'posteriors': jsonMetadata.get('posteriors', {})
    }
else:
    # Empty metadata case
    row = {
        'Title': title,
        'Description': info.get('description', ''),
        'line': info.get('line', ''),
        'line_numbers': info.get('line_numbers', []),
        'indentation': info.get('indentation', ''),
        'indentation_levels': info.get('indentation_levels', []),
        'Parents': info.get('parents', []),
        'Children': info.get('children', []),
        'instantiations': [],
        'priors': {},
        'posteriors': {}
    }
except json.JSONDecodeError:
    # Handle case where metadata isn't valid JSON
    row = {
        'Title': title,
        'Description': info.get('description', ''),
        'line': info.get('line', ''),
        'line_numbers': info.get('line_numbers', []),
        'indentation': info.get('indentation', ''),
        'indentation_levels': info.get('indentation_levels', []),

```

```

        'Parents': info.get('parents', []),
        'Children': info.get('children', []),
        'instantiations': [],
        'priors': {},
        'posteriors': {}
    }
else:
    # Handle case where metadata field doesn't exist or is empty
    row = {
        'Title': title,
        'Description': info.get('description', ''),
        'line': info.get('line', ''),
        'line_numbers': info.get('line_numbers', []),
        'indentation': info.get('indentation', ''),
        'indentation_levels': info.get('indentation_levels', []),
        'Parents': info.get('parents', []),
        'Children': info.get('children', []),
        'instantiations': [],
        'priors': {},
        'posteriors': {}
    }

    # Add the row to the DataFrame
    df.loc[len(df)] = row

return df

def add_no_parent_no_child_columns_to_df(dataframe):
    """
    Add No_Parent and No_Children boolean columns to the DataFrame to
    identify root and leaf nodes.

    Args:
        dataframe (pandas.DataFrame): The DataFrame to enhance

    Returns:
        pandas.DataFrame: Enhanced DataFrame with additional boolean columns
    """
    no_parent = []
    no_children = []

    for _, row in dataframe.iterrows():

```

```

        no_parent.append(not row['Parents']) # True if Parents list is empty
        no_children.append(not row['Children']) # True if Children list is empty

    dataframe['No_Parent'] = no_parent
    dataframe['No_Children'] = no_children

    return dataframe

def add_parents_instantiation_columns_to_df(dataframe):
    """
    Add all possible instantiations of parents as a list of lists column
    to the DataFrame.
    This is crucial for generating conditional probability tables.

    Args:
        dataframe (pandas.DataFrame): The DataFrame to enhance

    Returns:
        pandas.DataFrame: Enhanced DataFrame with parent_instantiations column
    """
    # Create a new column to store parent instantiations
    parent_instantiations = []

    # Iterate through each row in the dataframe
    for _, row in dataframe.iterrows():
        parents = row['Parents']
        parent_insts = []

        # For each parent, find its instantiations and add to the list
        for parent in parents:
            # Find the row where Title matches the parent
            parent_row = dataframe[dataframe['Title'] == parent]

            # If parent found in the dataframe
            if not parent_row.empty:
                # Get the instantiations of this parent
                parent_instantiation = parent_row['instantiations'].iloc[0]
                parent_insts.append(parent_instantiation)

        # Add the list of parent instantiations to our new column
        parent_instantiations.append(parent_insts)

```

```
# Add the new column to the dataframe
dataframe['parent_instantiations'] = parent_instantiations

return dataframe
```

```
# example use case:
ex_csv = parse_markdown_hierarchy_fixed(md_content, ArgDown = True)
ex_csv
```

|    | Title                       | Description                                       | line | line_number     |
|----|-----------------------------|---|------|-----------------|
| 0  | Existential_Catastrophe     | The destruction of humanity's long-term potent... | 0    | [0]             |
| 1  | Human_Disempowerment        | Permanent and collective disempowerment of hum... | 1    | [1]             |
| 2  | Scale_Of_Power_Seeking      | Power-seeking by AI systems scaling to the poi... | 2    | [2]             |
| 3  | Misaligned_Power_Seeking    | Deployed AI systems seeking power in unintende... | 3    | [3, 21, 23, 24] |
| 4  | APS_Systems                 | AI systems with advanced capabilities, agentic... | 4    | [4]             |
| 5  | Advanced_AI_Capability      | AI systems that outperform humans on tasks tha... | 5    | [5]             |
| 6  | Agentic_Planning            | AI systems making and executing plans based on... | 6    | [6]             |
| 7  | Strategic_Awareness         | AI systems with models accurately representing... | 7    | [7]             |
| 8  | Difficulty_Of_Alignment     | It is harder to build aligned systems than mis... | 8    | [8]             |
| 9  | Instrumental_Convergence    | AI systems with misaligned objectives tend to ... | 9    | [9]             |
| 10 | Problems_With_Proxies       | Optimizing for proxy objectives breaks correla... | 10   | [10]            |
| 11 | Problems_With_Search        | Search processes can yield systems pursuing di... | 11   | [11]            |
| 12 | Deployment_Decisions        | Decisions to deploy potentially misaligned AI ... | 12   | [12]            |
| 13 | Incentives_To_Build_APS     | Strong incentives to build and deploy APS syst... | 13   | [13]            |
| 14 | Usefulness_Of_APS           | APS systems are very useful for many valuable ... | 14   | [14]            |
| 15 | Competitive_Dynamics        | Competitive pressures between AI developers.      | 15   | [15]            |
| 16 | Deception_By_AI             | AI systems deceiving humans about their true o... | 16   | [16]            |
| 17 | Corrective_Feedback         | Human society implementing corrections after o... | 17   | [17]            |
| 18 | Warning_Shots               | Observable failures in weaker systems before c... | 18   | [18]            |
| 19 | Rapid_Capability_Escalation | AI capabilities escalating very rapidly, allow... | 19   | [19]            |
| 20 | Barriers_To_Understanding   | Difficulty in understanding the internal worki... | 20   | [20]            |
| 21 | Adversarial_Dynamics        | Potentially adversarial relationships between ... | 22   | [22]            |
| 22 | Stakes_Of_Error             | The escalating impact of mistakes with power-s... | 24   | [24]            |

example use case

## 1.8 Store ArgDown Information as 'ArgDown.csv' file

```
# Assuming 'md_content' holds the markdown text
# Store the results of running the function parse_markdown_hierarchy(md_content, ArgDown = True)
result_df = parse_markdown_hierarchy_fixed(md_content, ArgDown = True)
```

## 1.8 Store ArgDown Information as ArgDownSource (PDF's of Papers) to ArgDown (.md file)

```
# Save to CSV
result_df.to_csv('ArgDown.csv', index=False)

# Test if 'ArgDown.csv' has been saved correctly with the correct information
# Load the data from the CSV file
argdown_df = pd.read_csv('ArgDown.csv')

# Display the DataFrame
print(argdown_df)
```

|    | Title \                     |
|----|-----------------------------|
| 0  | Existential_Catastrophe     |
| 1  | Human_Disempowerment        |
| 2  | Scale_Of_Power_Seeking      |
| 3  | Misaligned_Power_Seeking    |
| 4  | APS_Systems                 |
| 5  | Advanced_AI_Capability      |
| 6  | Agentic_Planning            |
| 7  | Strategic_Awareness         |
| 8  | Difficulty_Of_Alignment     |
| 9  | Instrumental_Convergence    |
| 10 | Problems_With_Proxies       |
| 11 | Problems_With_Search        |
| 12 | Deployment_Decisions        |
| 13 | Incentives_To_Build_APS     |
| 14 | Usefulness_Of_APS           |
| 15 | Competitive_Dynamics        |
| 16 | Deception_By_AI             |
| 17 | Corrective_Feedback         |
| 18 | Warning_Shots               |
| 19 | Rapid_Capability_Escalation |
| 20 | Barriers_To_Understanding   |
| 21 | Adversarial_Dynamics        |
| 22 | Stakes_Of_Error             |

|   | Description                                       | line | line_numbers \  |
|---|---|------|-----------------|
| 0 | The destruction of humanity's long-term potent... | 0    | [0]             |
| 1 | Permanent and collective disempowerment of hum... | 1    | [1]             |
| 2 | Power-seeking by AI systems scaling to the poi... | 2    | [2]             |
| 3 | Deployed AI systems seeking power in unintende... | 3    | [3, 21, 23, 25] |
| 4 | AI systems with advanced capabilities, agentic... | 4    | [4]             |
| 5 | AI systems that outperform humans on tasks tha... | 5    | [5]             |
| 6 | AI systems making and executing plans based on... | 6    | [6]             |

|    |   |    |      |
|----|---|----|------|
| 7  | AI systems with models accurately representing... | 7  | [7]  |
| 8  | It is harder to build aligned systems than mis... | 8  | [8]  |
| 9  | AI systems with misaligned objectives tend to ... | 9  | [9]  |
| 10 | Optimizing for proxy objectives breaks correla... | 10 | [10] |
| 11 | Search processes can yield systems pursuing di... | 11 | [11] |
| 12 | Decisions to deploy potentially misaligned AI ... | 12 | [12] |
| 13 | Strong incentives to build and deploy APS syst... | 13 | [13] |
| 14 | APS systems are very useful for many valuable ... | 14 | [14] |
| 15 | Competitive pressures between AI developers.      | 15 | [15] |
| 16 | AI systems deceiving humans about their true o... | 16 | [16] |
| 17 | Human society implementing corrections after o... | 17 | [17] |
| 18 | Observable failures in weaker systems before c... | 18 | [18] |
| 19 | AI capabilities escalating very rapidly, allow... | 19 | [19] |
| 20 | Difficulty in understanding the internal worki... | 20 | [20] |
| 21 | Potentially adversarial relationships between ... | 22 | [22] |
| 22 | The escalating impact of mistakes with power-s... | 24 | [24] |

|    | indentation | indentation_levels \ |
|----|-------------|----------------------|
| 0  | 0           | [0]                  |
| 1  | 0           | [0]                  |
| 2  | 4           | [4]                  |
| 3  | 8           | [8, 0, 0, 0]         |
| 4  | 12          | [12]                 |
| 5  | 16          | [16]                 |
| 6  | 16          | [16]                 |
| 7  | 16          | [16]                 |
| 8  | 12          | [12]                 |
| 9  | 16          | [16]                 |
| 10 | 16          | [16]                 |
| 11 | 16          | [16]                 |
| 12 | 12          | [12]                 |
| 13 | 16          | [16]                 |
| 14 | 20          | [20]                 |
| 15 | 20          | [20]                 |
| 16 | 16          | [16]                 |
| 17 | 8           | [8]                  |
| 18 | 12          | [12]                 |
| 19 | 12          | [12]                 |
| 20 | 0           | [0]                  |
| 21 | 0           | [0]                  |
| 22 | 0           | [0]                  |

```

                                Parents \
0                                []
1                                ['Scale_Of_Power_Seeking']
2    ['Misaligned_Power_Seeking', 'Corrective_Feedb...
3    ['APS_Systems', 'Difficulty_Of_Alignment', 'De...
4    ['Advanced_AI_Capability', 'Agentic_Planning',...
5                                []
6                                []
7                                []
8    ['Instrumental_Convergence', 'Problems_With_Pr...
9                                []
10                               []
11                               []
12    ['Incentives_To_Build_APS', 'Deception_By_AI']
13    ['Usefulness_Of_APS', 'Competitive_Dynamics']
14                               []
15                               []
16                               []
17    ['Warning_Shots', 'Rapid_Capability_Escalation']
18                               []
19                               []
20                               []
21                               []
22                               []

```

```

                                Children \
0                                []
1                                []
2    ['Human_Disempowerment']
3    ['Scale_Of_Power_Seeking']
4    ['Misaligned_Power_Seeking']
5    ['APS_Systems']
6    ['APS_Systems']
7    ['APS_Systems']
8    ['Misaligned_Power_Seeking']
9    ['Difficulty_Of_Alignment']
10   ['Difficulty_Of_Alignment']
11   ['Difficulty_Of_Alignment']
12   ['Misaligned_Power_Seeking']
13   ['Deployment_Decisions']
14   ['Incentives_To_Build_APS']
15   ['Incentives_To_Build_APS']

```



```

16      ['Deployment_Decisions']
17      ['Scale_Of_Power_Seeking']
18      ['Corrective_Feedback']
19      ['Corrective_Feedback']
20      []
21      []
22      []

```

|    | instantiations                                    | No_Parent | No_Children | \ |
|----|---|-----------|-------------|---|
| 0  | ['existential_catastrophe_TRUE', 'existential_... | True      | True        |   |
| 1  | ['human_disempowerment_TRUE', 'human_disempowe... | False     | True        |   |
| 2  | ['scale_of_power_seeking_TRUE', 'scale_of_powe... | False     | False       |   |
| 3  | ['misaligned_power_seeking_TRUE', 'misaligned_... | False     | False       |   |
| 4  | ['aps_systems_TRUE', 'aps_systems_FALSE']         | False     | False       |   |
| 5  | ['advanced_ai_capability_TRUE', 'advanced_ai_c... | True      | False       |   |
| 6  | ['agentic_planning_TRUE', 'agentic_planning_FA... | True      | False       |   |
| 7  | ['strategic_awareness_TRUE', 'strategic_aware...  | True      | False       |   |
| 8  | ['difficulty_of_alignment_TRUE', 'difficulty_o... | False     | False       |   |
| 9  | ['instrumental_convergence_TRUE', 'instrumenta... | True      | False       |   |
| 10 | ['problems_with_proxies_TRUE', 'problems_with_... | True      | False       |   |
| 11 | ['problems_with_search_TRUE', 'problems_with_s... | True      | False       |   |
| 12 | ['deployment_decisions_DEPLOY', 'deployment_de... | False     | False       |   |
| 13 | ['incentives_to_build_aps_STRONG', 'incentives... | False     | False       |   |
| 14 | ['usefulness_of_aps_HIGH', 'usefulness_of_aps_... | True      | False       |   |
| 15 | ['competitive_dynamics_STRONG', 'competitive_d... | True      | False       |   |
| 16 | ['deception_by_ai_TRUE', 'deception_by_ai_FALSE'] | True      | False       |   |
| 17 | ['corrective_feedback_EFFECTIVE', 'corrective_... | False     | False       |   |
| 18 | ['warning_shots_OBSERVED', 'warning_shots_UNOB... | True      | False       |   |
| 19 | ['rapid_capability_escalation_TRUE', 'rapid_ca... | True      | False       |   |
| 20 | ['barriers_to_understanding_HIGH', 'barriers_t... | True      | True        |   |
| 21 | ['adversarial_dynamics_TRUE', 'adversarial_dyn... | True      | True        |   |
| 22 | ['stakes_of_error_HIGH', 'stakes_of_error_LOW']   | True      | True        |   |

```

                                parent_instantiations
0                                []
1  [['scale_of_power_seeking_TRUE', 'scale_of_pow...
2  [['misaligned_power_seeking_TRUE', 'misaligned...
3  [['aps_systems_TRUE', 'aps_systems_FALSE'], ['...
4  [['advanced_ai_capability_TRUE', 'advanced_ai_...
5                                []
6                                []
7                                []

```

```

8  [['instrumental_convergence_TRUE', 'instrument...
9                                     []
10                                    []
11                                    []
12  [['incentives_to_build_aps_STRONG', 'incentive...
13  [['usefulness_of_aps_HIGH', 'usefulness_of_aps...
14                                     []
15                                     []
16                                     []
17  [['warning_shots_OBSERVED', 'warning_shots_UNO...
18                                     []
19                                     []
20                                     []
21                                     []
22                                     []

```

## 2 Probability Extractions: ArgDown (.csv) to BayesDown (.md + plugin JSON syntax)

### 2.0 ArgDown to BayesDown: Adding Probability Information

#### Process Overview

This section implements the second major stage of the AMTAIR pipeline: enhancing the structured argument representation (ArgDown) with probability information to create BayesDown.

BayesDown extends ArgDown by adding: 1. Prior probabilities for each variable (unconditional beliefs) 2. Conditional probabilities representing the relationships between variables 3. The full parameter specification needed for a Bayesian network

The process follows these steps: 1. Generate probability questions for each node and its relationships 2. Create a BayesDown template with placeholders for these probabilities 3. Answer the probability questions (manually or via LLM) 4. Substitute the answers into the BayesDown representation

This enhanced representation contains all the information needed to construct a formal Bayesian network, enabling probabilistic reasoning and policy evaluation.

#### What is BayesDown?

BayesDown maintains the ArgDown structure but adds probability metadata:

```
[Node]: Description. {  
  "instantiations": ["node_TRUE", "node_FALSE"],  
  "priors": { "p(node_TRUE)": "0.7", "p(node_FALSE)": "0.3" },  
  "posteriors": { "p(node_TRUE|parent_TRUE)": "0.9", "p(node_TRUE|parent_FALSE)": "0.4" }  
}
```

The result is a hybrid representation that preserves the narrative structure of arguments while adding the mathematical precision of Bayesian networks.

## 2.1 Probability Extraction Questions — ‘ArgDown.csv’ to ‘ArgDown\_WithQuestions.csv’

```
# @title 2.1.0 --- Probability Extraction Questions Generation --- [probability_extraction_c

"""
BLOCK PURPOSE: Generates probability questions for ArgDown nodes to prepare for BayesDown co

This block implements a key step in the pipeline where structure (from ArgDown)
is prepared for probability integration (to create BayesDown). It:

1. Processes a CSV file containing ArgDown structure
2. For each node, generates appropriate probability questions:
    - Prior probability questions for all nodes
    - Conditional probability questions for nodes with parents
3. Creates a new CSV file with these questions ready for the next stage

The generated questions serve as placeholders that will be answered in the
probability extraction phase to complete the Bayesian network.

DEPENDENCIES: pandas, json, itertools libraries
INPUTS: ArgDown CSV file
OUTPUTS: Enhanced CSV with probability questions for each node
"""

import pandas as pd
import re
import json
import itertools
from IPython.display import Markdown, display

def parse_instantiations(instantiations_str):
    """
    Parse instantiations from string or list format.
    Handles various input formats flexibly.

    Args:
        instantiations_str: Instantiations in string or list format

    Returns:
        list: Parsed instantiations as a list
    """
```

```

"""
if pd.isna(instantiations_str) or instantiations_str == '':
    return []

if isinstance(instantiations_str, list):
    return instantiations_str

try:
    # Try to parse as JSON
    return json.loads(instantiations_str)
except:
    # Try to parse as string list
    if isinstance(instantiations_str, str):
        # Remove brackets and split by comma
        clean_str = instantiations_str.strip('[]"\')
        if not clean_str:
            return []
        return [s.strip(' "') for s in clean_str.split(',') if s.strip()]

return []

def parse_parents(parents_str):
    """
    Parse parents from string or list format.
    Handles various input formats flexibly.

    Args:
        parents_str: Parents in string or list format

    Returns:
        list: Parsed parents as a list
    """
    if pd.isna(parents_str) or parents_str == '':
        return []

    if isinstance(parents_str, list):
        return parents_str

    try:
        # Try to parse as JSON
        return json.loads(parents_str)
    except:

```

```

    # Try to parse as string list
    if isinstance(parents_str, str):
        # Remove brackets and split by comma
        clean_str = parents_str.strip('[]"\'')
        if not clean_str:
            return []
        return [s.strip(' "') for s in clean_str.split(',') if s.strip()]

    return []

def get_parent_instantiations(parent, df):
    """
    Get the instantiations for a parent node from the DataFrame.
    Returns default instantiations if not found.

    Args:
        parent (str): Parent node name
        df (DataFrame): DataFrame containing node information

    Returns:
        list: Instantiations for the parent node
    """
    parent_row = df[df['Title'] == parent]
    if parent_row.empty:
        return [f"{parent}_TRUE", f"{parent}_FALSE"]

    instantiations = parse_instantiations(parent_row.iloc[0]['instantiations'])
    if not instantiations:
        return [f"{parent}_TRUE", f"{parent}_FALSE"]

    return instantiations

def generate_instantiation_questions(title, instantiation, parents, df):
    """
    Generate questions for a specific instantiation of a node.

    Args:
        title (str): The title of the node
        instantiation (str): The specific instantiation (e.g., "title_TRUE")
        parents (list): List of parent nodes
        df (DataFrame): The full DataFrame for looking up parent instantiations
    """

```

```

Returns:
    dict: Dictionary mapping questions to estimate keys
"""
questions = {}

# Always generate a prior probability question, regardless of parents
prior_question = f"What is the probability for {title}={instantiation}?"
questions[prior_question] = 'prior' # Question is the key, 'prior' is the value

# If no parents, return only the prior question
if not parents:
    return questions

# For nodes with parents, generate conditional probability questions
# Get all combinations of parent instantiations
parent_instantiations = []
for parent in parents:
    parent_insts = get_parent_instantiations(parent, df)
    parent_instantiations.append([(parent, inst) for inst in parent_insts])

# Generate all combinations
all_combinations = list(itertools.product(*parent_instantiations))

# Create conditional probability questions for each combination
# and use questions as keys, estimate_i as values
for i, combination in enumerate(all_combinations):
    condition_str = ", ".join([f"{parent}={inst}" for parent, inst in combination])
    question = f"What is the probability for {title}={instantiation} if {condition_str}?"
    questions[question] = f'estimate_{i + 1}' # Question is the key,
                                              # estimate_i is the value

return questions

def generate_argdown_with_questions(argdown_csv_path, output_csv_path):
    """
    Generate probability questions based on the ArgDown CSV file and save
    to a new CSV file.

    Args:
        argdown_csv_path (str): Path to the input ArgDown CSV file
        output_csv_path (str): Path to save the output CSV file with questions

```

Returns:

DataFrame: Enhanced DataFrame with probability questions

Raises:

Exception: If CSV loading fails or required columns are missing

"""

```
print(f"Loading ArgDown CSV from {argdown_csv_path}...")
```

```
# Load the ArgDown CSV file
```

```
try:
```

```
    df = pd.read_csv(argdown_csv_path)
```

```
    print(f"Successfully loaded CSV with {len(df)} rows.")
```

```
except Exception as e:
```

```
    raise Exception(f"Error loading ArgDown CSV: {e}")
```

```
# Validate required columns
```

```
required_columns = ['Title', 'Parents', 'instantiations']
```

```
missing_columns = [col for col in required_columns if col not in df.columns]
```

```
if missing_columns:
```

```
    raise Exception(f"Missing required columns: {'', '.join(missing_columns)}")
```

```
# Initialize columns for questions
```

```
df['Generate_Positive_Instantiation_Questions'] = None
```

```
df['Generate_Negative_Instantiation_Questions'] = None
```

```
print("Generating probability questions for each node...")
```

```
# Process each row to generate questions
```

```
for idx, row in df.iterrows():
```

```
    title = row['Title']
```

```
    instantiations = parse_instantiations(row['instantiations'])
```

```
    parents = parse_parents(row['Parents'])
```

```
    if len(instantiations) < 2:
```

```
        # Default instantiations if not provided
```

```
        instantiations = [f"{title}_TRUE", f"{title}_FALSE"]
```

```
# Generate positive instantiation questions
```

```
positive_questions = generate_instantiation_questions(title, instantiations[0], parents)
```

```
# Generate negative instantiation questions
```



```

        negative_questions = generate_instantiation_questions(title, instantiations[1], parent_idx)

        # Update the DataFrame
        df.at[idx, 'Generate_Positive_Instantiation_Questions'] = json.dumps(positive_questions)
        df.at[idx, 'Generate_Negative_Instantiation_Questions'] = json.dumps(negative_questions)

        # Save the enhanced DataFrame
        df.to_csv(output_csv_path, index=False)
        print(f"Generated questions saved to {output_csv_path}")

    return df

# Example usage:
df_with_questions = generate_argdown_with_questions("ArgDown.csv", "ArgDown_WithQuestions.csv")

```

Loading ArgDown CSV from ArgDown.csv...

Successfully loaded CSV with 23 rows.

Generating probability questions for each node...

Generated questions saved to ArgDown\_WithQuestions.csv

```

# Load the data from the ArgDown_WithQuestions CSV file
argdown_with_questions_df = pd.read_csv('ArgDown_WithQuestions.csv')

# Display the DataFrame
print(argdown_with_questions_df)
argdown_with_questions_df

```

|    | Title \                  |
|----|--------------------------|
| 0  | Existential_Catastrophe  |
| 1  | Human_Disempowerment     |
| 2  | Scale_Of_Power_Seeking   |
| 3  | Misaligned_Power_Seeking |
| 4  | APS_Systems              |
| 5  | Advanced_AI_Capability   |
| 6  | Agentic_Planning         |
| 7  | Strategic_Awareness      |
| 8  | Difficulty_Of_Alignment  |
| 9  | Instrumental_Convergence |
| 10 | Problems_With_Proxies    |
| 11 | Problems_With_Search     |
| 12 | Deployment_Decisions     |
| 13 | Incentives_To_Build_APS  |
| 14 | Usefulness_Of_APS        |

```

15         Competitive_Dynamics
16         Deception_By_AI
17         Corrective_Feedback
18         Warning_Shots
19 Rapid_Capability_Escalation
20     Barriers_To_Understanding
21         Adversarial_Dynamics
22         Stakes_Of_Error

```

|    | Description                                       | line | line_numbers \  |
|----|---|------|-----------------|
| 0  | The destruction of humanity's long-term potent... | 0    | [0]             |
| 1  | Permanent and collective disempowerment of hum... | 1    | [1]             |
| 2  | Power-seeking by AI systems scaling to the poi... | 2    | [2]             |
| 3  | Deployed AI systems seeking power in unintende... | 3    | [3, 21, 23, 25] |
| 4  | AI systems with advanced capabilities, agentic... | 4    | [4]             |
| 5  | AI systems that outperform humans on tasks tha... | 5    | [5]             |
| 6  | AI systems making and executing plans based on... | 6    | [6]             |
| 7  | AI systems with models accurately representing... | 7    | [7]             |
| 8  | It is harder to build aligned systems than mis... | 8    | [8]             |
| 9  | AI systems with misaligned objectives tend to ... | 9    | [9]             |
| 10 | Optimizing for proxy objectives breaks correla... | 10   | [10]            |
| 11 | Search processes can yield systems pursuing di... | 11   | [11]            |
| 12 | Decisions to deploy potentially misaligned AI ... | 12   | [12]            |
| 13 | Strong incentives to build and deploy APS syst... | 13   | [13]            |
| 14 | APS systems are very useful for many valuable ... | 14   | [14]            |
| 15 | Competitive pressures between AI developers.      | 15   | [15]            |
| 16 | AI systems deceiving humans about their true o... | 16   | [16]            |
| 17 | Human society implementing corrections after o... | 17   | [17]            |
| 18 | Observable failures in weaker systems before c... | 18   | [18]            |
| 19 | AI capabilities escalating very rapidly, allow... | 19   | [19]            |
| 20 | Difficulty in understanding the internal worki... | 20   | [20]            |
| 21 | Potentially adversarial relationships between ... | 22   | [22]            |
| 22 | The escalating impact of mistakes with power-s... | 24   | [24]            |

|   | indentation | indentation_levels \ |
|---|-------------|----------------------|
| 0 | 0           | [0]                  |
| 1 | 0           | [0]                  |
| 2 | 4           | [4]                  |
| 3 | 8           | [8, 0, 0, 0]         |
| 4 | 12          | [12]                 |
| 5 | 16          | [16]                 |
| 6 | 16          | [16]                 |

|    |    |      |
|----|----|------|
| 7  | 16 | [16] |
| 8  | 12 | [12] |
| 9  | 16 | [16] |
| 10 | 16 | [16] |
| 11 | 16 | [16] |
| 12 | 12 | [12] |
| 13 | 16 | [16] |
| 14 | 20 | [20] |
| 15 | 20 | [20] |
| 16 | 16 | [16] |
| 17 | 8  | [8]  |
| 18 | 12 | [12] |
| 19 | 12 | [12] |
| 20 | 0  | [0]  |
| 21 | 0  | [0]  |
| 22 | 0  | [0]  |

|    |  |
|----|--|
|    | Parents \  |
| 0  | []   |
| 1  | ['Scale_Of_Power_Seeking']                         |
| 2  | ['Misaligned_Power_Seeking', 'Corrective_Feedb...] |
| 3  | ['APS_Systems', 'Difficulty_Of_Alignment', 'De...] |
| 4  | ['Advanced_AI_Capability', 'Agentic_Planning',...] |
| 5  | []   |
| 6  | []   |
| 7  | []   |
| 8  | ['Instrumental_Convergence', 'Problems_With_Pr...] |
| 9  | []   |
| 10 | []   |
| 11 | []   |
| 12 | ['Incentives_To_Build_APS', 'Deception_By_AI']     |
| 13 | ['Usefulness_Of_APS', 'Competitive_Dynamics']      |
| 14 | []   |
| 15 | []   |
| 16 | []   |
| 17 | ['Warning_Shots', 'Rapid_Capability_Escalation']   |
| 18 | []   |
| 19 | []   |
| 20 | []   |
| 21 | []   |
| 22 | []   |

```

Children \
0      []
1      []
2      ['Human_Disempowerment']
3      ['Scale_Of_Power_Seeking']
4      ['Misaligned_Power_Seeking']
5      ['APS_Systems']
6      ['APS_Systems']
7      ['APS_Systems']
8      ['Misaligned_Power_Seeking']
9      ['Difficulty_Of_Alignment']
10     ['Difficulty_Of_Alignment']
11     ['Difficulty_Of_Alignment']
12     ['Misaligned_Power_Seeking']
13     ['Deployment_Decisions']
14     ['Incentives_To_Build_APS']
15     ['Incentives_To_Build_APS']
16     ['Deployment_Decisions']
17     ['Scale_Of_Power_Seeking']
18     ['Corrective_Feedback']
19     ['Corrective_Feedback']
20     []
21     []
22     []

```

|    | instantiations                                    | No_Parent | No_Children \ |
|----|---|-----------|---------------|
| 0  | ['existential_catastrophe_TRUE', 'existential_... | True      | True          |
| 1  | ['human_disempowerment_TRUE', 'human_disempowe... | False     | True          |
| 2  | ['scale_of_power_seeking_TRUE', 'scale_of_powe... | False     | False         |
| 3  | ['misaligned_power_seeking_TRUE', 'misaligned_... | False     | False         |
| 4  | ['aps_systems_TRUE', 'aps_systems_FALSE']         | False     | False         |
| 5  | ['advanced_ai_capability_TRUE', 'advanced_ai_c... | True      | False         |
| 6  | ['agentic_planning_TRUE', 'agentic_planning_FA... | True      | False         |
| 7  | ['strategic_awareness_TRUE', 'strategic_aware...  | True      | False         |
| 8  | ['difficulty_of_alignment_TRUE', 'difficulty_o... | False     | False         |
| 9  | ['instrumental_convergence_TRUE', 'instrumenta... | True      | False         |
| 10 | ['problems_with_proxies_TRUE', 'problems_with_... | True      | False         |
| 11 | ['problems_with_search_TRUE', 'problems_with_s... | True      | False         |
| 12 | ['deployment_decisions_DEPLOY', 'deployment_de... | False     | False         |
| 13 | ['incentives_to_build_aps_STRONG', 'incentives... | False     | False         |
| 14 | ['usefulness_of_aps_HIGH', 'usefulness_of_aps_... | True      | False         |
| 15 | ['competitive_dynamics_STRONG', 'competitive_d... | True      | False         |

|    |  |       |       |
|----|--|-------|-------|
| 16 | ['deception_by_ai_TRUE', 'deception_by_ai_FALSE']  | True  | False |
| 17 | ['corrective_feedback_EFFECTIVE', 'corrective_...] | False | False |
| 18 | ['warning_shots_OBSERVED', 'warning_shots_UNOB...] | True  | False |
| 19 | ['rapid_capability_escalation_TRUE', 'rapid_ca...] | True  | False |
| 20 | ['barriers_to_understanding_HIGH', 'barriers_t...] | True  | True  |
| 21 | ['adversarial_dynamics_TRUE', 'adversarial_dyn...] | True  | True  |
| 22 | ['stakes_of_error_HIGH', 'stakes_of_error_LOW']    | True  | True  |

```

                                parent_instantiations \
0                                []
1  [['scale_of_power_seeking_TRUE', 'scale_of_pow...
2  [['misaligned_power_seeking_TRUE', 'misaligned...
3  [['aps_systems_TRUE', 'aps_systems_FALSE'], ['...
4  [['advanced_ai_capability_TRUE', 'advanced_ai_...
5                                []
6                                []
7                                []
8  [['instrumental_convergence_TRUE', 'instrument...
9                                []
10                               []
11                               []
12  [['incentives_to_build_aps_STRONG', 'incentive...
13  [['usefulness_of_aps_HIGH', 'usefulness_of_aps...
14                               []
15                               []
16                               []
17  [['warning_shots_OBSERVED', 'warning_shots_UNO...
18                               []
19                               []
20                               []
21                               []
22                               []

```

```

Generate_Positive_Instantiation_Questions \
0  {"What is the probability for Existential_Cata...
1  {"What is the probability for Human_Disempower...
2  {"What is the probability for Scale_Of_Power_S...
3  {"What is the probability for Misaligned_Power...
4  {"What is the probability for APS_Systems=aps_...
5  {"What is the probability for Advanced_AI_Capa...
6  {"What is the probability for Agentic_Planning...
7  {"What is the probability for Strategic_Awaren...

```

```

8  {"What is the probability for Difficulty_Of_Al...
9  {"What is the probability for Instrumental_Con...
10 {"What is the probability for Problems_With_Pr...
11 {"What is the probability for Problems_With_Se...
12 {"What is the probability for Deployment_Decis...
13 {"What is the probability for Incentives_To_Bu...
14 {"What is the probability for Usefulness_Of_AP...
15 {"What is the probability for Competitive_Dyna...
16 {"What is the probability for Deception_By_AI=...
17 {"What is the probability for Corrective_Feedb...
18 {"What is the probability for Warning_Shots=wa...
19 {"What is the probability for Rapid_Capability...
20 {"What is the probability for Barriers_To_Unde...
21 {"What is the probability for Adversarial_Dyna...
22 {"What is the probability for Stakes_Of_Error=...

```

#### Generate\_Negative\_Instantiation\_Questions

```

0  {"What is the probability for Existential_Cata...
1  {"What is the probability for Human_Disempower...
2  {"What is the probability for Scale_Of_Power_S...
3  {"What is the probability for Misaligned_Power...
4  {"What is the probability for APS_Systems=aps_...
5  {"What is the probability for Advanced_AI_Capa...
6  {"What is the probability for Agentic_Planning...
7  {"What is the probability for Strategic_Awaren...
8  {"What is the probability for Difficulty_Of_Al...
9  {"What is the probability for Instrumental_Con...
10 {"What is the probability for Problems_With_Pr...
11 {"What is the probability for Problems_With_Se...
12 {"What is the probability for Deployment_Decis...
13 {"What is the probability for Incentives_To_Bu...
14 {"What is the probability for Usefulness_Of_AP...
15 {"What is the probability for Competitive_Dyna...
16 {"What is the probability for Deception_By_AI=...
17 {"What is the probability for Corrective_Feedb...
18 {"What is the probability for Warning_Shots=wa...
19 {"What is the probability for Rapid_Capability...
20 {"What is the probability for Barriers_To_Unde...
21 {"What is the probability for Adversarial_Dyna...
22 {"What is the probability for Stakes_Of_Error=...

```

|    | Title                       | Description                                       | line | line_number     |
|----|-----------------------------|---|------|-----------------|
| 0  | Existential_Catastrophe     | The destruction of humanity's long-term potent... | 0    | [0]             |
| 1  | Human_Disempowerment        | Permanent and collective disempowerment of hum... | 1    | [1]             |
| 2  | Scale_Of_Power_Seeking      | Power-seeking by AI systems scaling to the poi... | 2    | [2]             |
| 3  | Misaligned_Power_Seeking    | Deployed AI systems seeking power in unintende... | 3    | [3, 21, 23, 24] |
| 4  | APS_Systems                 | AI systems with advanced capabilities, agentic... | 4    | [4]             |
| 5  | Advanced_AI_Capability      | AI systems that outperform humans on tasks tha... | 5    | [5]             |
| 6  | Agentic_Planning            | AI systems making and executing plans based on... | 6    | [6]             |
| 7  | Strategic_Awareness         | AI systems with models accurately representing... | 7    | [7]             |
| 8  | Difficulty_Of_Alignment     | It is harder to build aligned systems than mis... | 8    | [8]             |
| 9  | Instrumental_Convergence    | AI systems with misaligned objectives tend to ... | 9    | [9]             |
| 10 | Problems_With_Proxies       | Optimizing for proxy objectives breaks correla... | 10   | [10]            |
| 11 | Problems_With_Search        | Search processes can yield systems pursuing di... | 11   | [11]            |
| 12 | Deployment_Decisions        | Decisions to deploy potentially misaligned AI ... | 12   | [12]            |
| 13 | Incentives_To_Build_APS     | Strong incentives to build and deploy APS syst... | 13   | [13]            |
| 14 | Usefulness_Of_APS           | APS systems are very useful for many valuable ... | 14   | [14]            |
| 15 | Competitive_Dynamics        | Competitive pressures between AI developers.      | 15   | [15]            |
| 16 | Deception_By_AI             | AI systems deceiving humans about their true o... | 16   | [16]            |
| 17 | Corrective_Feedback         | Human society implementing corrections after o... | 17   | [17]            |
| 18 | Warning_Shots               | Observable failures in weaker systems before c... | 18   | [18]            |
| 19 | Rapid_Capability_Escalation | AI capabilities escalating very rapidly, allow... | 19   | [19]            |
| 20 | Barriers_To_Understanding   | Difficulty in understanding the internal worki... | 20   | [20]            |
| 21 | Adversarial_Dynamics        | Potentially adversarial relationships between ... | 22   | [22]            |
| 22 | Stakes_Of_Error             | The escalating impact of mistakes with power-s... | 24   | [24]            |

## 2.2 ‘ArgDown\_WithQuestions.csv’ to ‘BayesDownQuestions.md’

### 2.2 Save BayesDown Extraction Questions as ‘BayesDownQuestions.md’

```
# @title 2.2.0 --- BayesDown Questions Generation --- [bayesdown_questions_generation]

"""
BLOCK PURPOSE: Transforms the ArgDown with questions into a BayesDown template with placeholders

This function creates a BayesDown representation with probability placeholders
based on the questions generated in the previous step. It:

1. Loads the CSV file with probability questions
2. Constructs a directed graph to represent the causal structure
3. Processes each node to create BayesDown syntax with probability placeholders
4. Optionally includes comments with the specific questions to be answered
5. Saves the result as a markdown file for the next stage of the pipeline
```

The output is a BayesDown template that can be used in the probability extraction phase, where the placeholders will be replaced with actual probability values.

DEPENDENCIES: networkx, pandas, json libraries

INPUTS: CSV file with ArgDown structure and probability questions

OUTPUTS: BayesDown markdown file with probability placeholders

"""

```
def extract_bayesdown_questions_fixed(argdown_with_questions_path, output_md_path, include_c
```

"""

Generate BayesDown syntax from the ArgDown\_WithQuestions CSV file with correct parent-child relationships.

Args:

argdown\_with\_questions\_path (str): Path to the CSV file with probability questions

output\_md\_path (str): Path to save the output BayesDown file

include\_questions\_as\_comments (bool, optional): Whether to include the original questions as comments. Defaults to True.

Returns:

str: The generated BayesDown content

Raises:

Exception: If CSV loading fails or required columns are missing

"""

```
print(f"Loading CSV from {argdown_with_questions_path}...")
```

```
# Load the CSV file
```

```
try:
```

```
    df = pd.read_csv(argdown_with_questions_path)
```

```
    print(f"Successfully loaded CSV with {len(df)} rows.")
```

```
except Exception as e:
```

```
    raise Exception(f"Error loading CSV: {e}")
```

```
# Validate required columns
```

```
required_columns = ['Title', 'Description', 'Parents', 'Children', 'instantiations']
```

```
missing_columns = [col for col in required_columns if col not in df.columns]
```

```
if missing_columns:
```

```
    raise Exception(f"Missing required columns: {'', '.join(missing_columns)}")
```



```

print("Generating BayesDown syntax with placeholder probabilities...")

# Build a directed graph of nodes
G = nx.DiGraph()

# Add nodes to the graph
for idx, row in df.iterrows():
    G.add_node(row['Title'], data=row)

# Add edges to the graph based on parent-child relationships - CORRECTLY
for idx, row in df.iterrows():
    child = row['Title']

    # Parse parents and add edges
    parents = row['Parents']
    if isinstance(parents, str):
        # Handle string representation of list
        if parents.startswith('[') and parents.endswith(']'):
            parents = parents.strip('[]')
            if parents: # Check if not empty
                parent_list = [p.strip().strip('\\"') for p in parents.split(',') ]
                for parent in parent_list:
                    if parent in G.nodes():
                        # In BayesDown: Parent (cause) -> Child (effect)
                        G.add_edge(parent, child)
        elif isinstance(parents, list):
            # Handle actual list
            for parent in parents:
                if parent in G.nodes():
                    G.add_edge(parent, child)

# Function to safely parse JSON strings
def safe_parse_json(json_str):
    if pd.isna(json_str):
        return {}

    if isinstance(json_str, dict):
        return json_str

    try:
        return json.loads(json_str)
    except:

```

```

    return {}

# Start building the BayesDown content
bayesdown_content = "" # Initialize as empty

if include_questions_as_comments:
    bayesdown_content = "# BayesDown Representation with Placeholder Probabilities\n\n"
    bayesdown_content += "/* This file contains BayesDown syntax with placeholder probabilities\n\n"
    bayesdown_content += "    Replace the placeholders with actual probability values based on\n\n"
    bayesdown_content += "    questions in the comments. */\n\n"

# Get leaf nodes (nodes with no outgoing edges) - these are effects without children
leaf_nodes = [n for n in G.nodes() if G.out_degree(n) == 0]

# Helper function to process a node and its parents recursively
def process_node(node, indent_level=0, processed_nodes=None):
    if processed_nodes is None:
        processed_nodes = set()

    # Create the indentation string
    indent = ' ' * (indent_level * 2)
    prefix = f"{indent}+ " if indent_level > 0 else ""

    # Get node data
    node_data = G.nodes[node]['data']
    title = node_data['Title']
    description = node_data['Description'] if not pd.isna(node_data['Description']) else ''

    # Parse instantiations from the row data
    instantiations = parse_instantiations_safely(node_data['instantiations'])

    # Build the node string
    node_output = ""

    # Add comments with questions if requested
    if include_questions_as_comments:
        # Add positive questions as comments
        if 'Generate_Positive_Instantiation_Questions' in node_data:
            positive_questions = safe_parse_json(node_data['Generate_Positive_Instantiation_Questions'])
            for question in positive_questions.keys():
                node_output += f"{indent}/* {question} */\n"

```

```

# Add negative questions as comments
if 'Generate_Negative_Instantiation_Questions' in node_data:
    negative_questions = safe_parse_json(node_data['Generate_Negative_Instantiation_Questions'])
    for question in negative_questions.keys():
        node_output += f"{indent}/* {question} */\n"

# Check if this node was already fully defined elsewhere
if node in processed_nodes:
    # Just add a reference to the node
    node_output += f"{prefix}[{title}]\n"
    return node_output

# Mark this node as processed
processed_nodes.add(node)

# Prepare the metadata JSON
metadata = {
    "instantiations": instantiations
}

# Add priors with full questions as keys
priors = {}
if 'Generate_Positive_Instantiation_Questions' in node_data:
    positive_questions = safe_parse_json(node_data['Generate_Positive_Instantiation_Questions'])
    for question, estimate_key in positive_questions.items():
        if estimate_key == 'prior':
            priors[question] = "%?" # Default placeholder

if 'Generate_Negative_Instantiation_Questions' in node_data:
    negative_questions = safe_parse_json(node_data['Generate_Negative_Instantiation_Questions'])
    for question, estimate_key in negative_questions.items():
        if estimate_key == 'prior':
            priors[question] = "%?" # Default placeholder

metadata["priors"] = priors

# Add posteriors with full questions as keys
parents = list(G.predecessors(node))
if parents:
    posteriors = {}
    if 'Generate_Positive_Instantiation_Questions' in node_data:
        positive_questions = safe_parse_json(node_data['Generate_Positive_Instantiation_Questions'])

```

```

        for question, estimate_key in positive_questions.items():
            if estimate_key.startswith('estimate_'):
                posteriors[question] = "?" # Default placeholder

    if 'Generate_Negative_Instantiation_Questions' in node_data:
        negative_questions = safe_parse_json(node_data['Generate_Negative_Instantiation_Questions'])
        for question, estimate_key in negative_questions.items():
            if estimate_key.startswith('estimate_'):
                posteriors[question] = "?" # Default placeholder

    metadata["posteriors"] = posteriors

# Format the node with metadata
node_output += f"{prefix}[{title}]: {description} {json.dumps(metadata)}\n"

# Process parent nodes
for parent in parents:
    if parent != node: # Avoid self-references
        parent_output = process_node(parent, indent_level + 1, processed_nodes)
        node_output += parent_output

return node_output

# Helper function to parse instantiations safely
def parse_instantiations_safely(instantiations_data):
    if isinstance(instantiations_data, list):
        return instantiations_data if instantiations_data else [f"TRUE", f"FALSE"]

    if isinstance(instantiations_data, str):
        try:
            parsed = json.loads(instantiations_data)
            if isinstance(parsed, list):
                return parsed if parsed else [f"TRUE", f"FALSE"]
        except:
            if instantiations_data.startswith('[') and instantiations_data.endswith(']'):
                items = instantiations_data.strip('[]').split(',')
                result = [item.strip(' "') for item in items if item.strip()]
                return result if result else [f"TRUE", f"FALSE"]

    return [f"TRUE", f"FALSE"] # Default

# Process each leaf node and its ancestors

```

```

for leaf in leaf_nodes:
    bayesdown_content += process_node(leaf)

# Save the BayesDown content
with open(output_md_path, 'w') as f:
    f.write(bayesdown_content)

print(f"BayesDown Questions saved to {output_md_path}")
return bayesdown_content

# Explicitly set the value of include_questions_as_comments
include_questions_as_comments=False # or False, depending on your needs

# Get the markdown content
bayesdown_questions = extract_bayesdown_questions_fixed(
    "ArgDown_WithQuestions.csv",
    "BayesDownQuestions.md", include_questions_as_comments=include_questions_as_comments
)

# Determine the output file path based on include_questions_as_comments
if include_questions_as_comments: # Assuming include_questions_as_comments is defined somewhere
    output_file_path = "FULL_BayesDownQuestions.md"
else:
    output_file_path = "BayesDownQuestions.md"

# Save the markdown content to the appropriate file
with open(output_file_path, 'w') as f:
    f.write(md_content)

print(f"Markdown content saved to {output_file_path}")

```

Loading CSV from ArgDown\_WithQuestions.csv...

Successfully loaded CSV with 23 rows.

Generating BayesDown syntax with placeholder probabilities...

BayesDown Questions saved to BayesDownQuestions.md

Markdown content saved to BayesDownQuestions.md

```

# Generate BayesDown format
bayesdown_questions = extract_bayesdown_questions_fixed(
    "ArgDown_WithQuestions.csv",
    "FULL_BayesDownQuestions.md",
    include_questions_as_comments=True
)

```

```
# Display a preview of the format
print("\nBayesDown Format Preview:")
print(bayesdown_questions[:5000] + "...\\n")
```

Loading CSV from ArgDown\_WithQuestions.csv...

Successfully loaded CSV with 23 rows.

Generating BayesDown syntax with placeholder probabilities...

BayesDown Questions saved to FULL\_BayesDownQuestions.md

BayesDown Format Preview:

# BayesDown Representation with Placeholder Probabilities

/\* This file contains BayesDown syntax with placeholder probabilities.

Replace the placeholders with actual probability values based on the questions in the comments. \*/

/\* What is the probability for Existential\_Catastrophe=existential\_catastrophe\_TRUE? \*/

/\* What is the probability for Existential\_Catastrophe=existential\_catastrophe\_FALSE? \*/

[Existential\_Catastrophe]: The destruction of humanity's long-term potential due to AI systems

/\* What is the probability for Human\_Disempowerment=human\_disempowerment\_TRUE? \*/

/\* What is the probability for Human\_Disempowerment=human\_disempowerment\_TRUE if Scale\_Of\_Po

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/\* What is the probability for Human\_Disempowerment=human\_disempowerment\_FALSE if Scale\_Of\_F

/\* What is the probability for Human\_Disempowerment=human\_disempowerment\_FALSE if Scale\_Of\_F

[Human\_Disempowerment]: Permanent and collective disempowerment of humanity relative to AI s

/\* What is the probability for Scale\_Of\_Power\_Seeking=scale\_of\_power\_seeking\_TRUE? \*/

/\* What is the probability for Scale\_Of\_Power\_Seeking=scale\_of\_power\_seeking\_TRUE if Misal

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/* What is the probability for Barriers_To_Understanding=barriers_to_understanding_LOW? */
[Barriers_To_Understanding]: Difficulty in understanding the internal workings of advanced A
/* What is the probability for Adversarial_Dynamics=adversarial_dynamics_TRUE? */
/* What is the probability for Adversarial_Dynamics=adversarial_dynamics_FALSE? */
[Adversarial_Dynamics]: Potentially adversarial relationships between humans and power-seeki
/* What is the probability for Stakes_Of_Error=stakes_of_error_HIGH? */
/* What is the probability for Stakes_Of_Error=stakes_of_error_LOW? */

```

```
[Stakes_Of_Error]: The escalating impact of mistakes with power-seeking AI systems. {"instan
...
```

```
# Load and print the content of the 'FULL_BayesDownQuestions.md' file
with open("FULL_BayesDownQuestions.md", "r") as f:
    file_content = f.read()
    print(file_content)
```

```
# BayesDown Representation with Placeholder Probabilities
```

```
/* This file contains BayesDown syntax with placeholder probabilities.
   Replace the placeholders with actual probability values based on the
   questions in the comments. */

/* What is the probability for Existential_Catastrophe=existential_catastrophe_TRUE? */
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[Human_Disempowerment]: Permanent and collective disempowerment of humanity relative to AI systems
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/* What is the probability for Adversarial_Dynamics=adversarial_dynamics_TRUE? */
/* What is the probability for Adversarial_Dynamics=adversarial_dynamics_FALSE? */
[Adversarial_Dynamics]: Potentially adversarial relationships between humans and power-seeki
/* What is the probability for Stakes_Of_Error=stakes_of_error_HIGH? */
/* What is the probability for Stakes_Of_Error=stakes_of_error_LOW? */
[Stakes_Of_Error]: The escalating impact of mistakes with power-seeking AI systems. {"instan

# Generate BayesDown format
bayesdown_questions = extract_bayesdown_questions_fixed(

```

```

"ArgDown_WithQuestions.csv",
"BayesDownQuestions.md",
include_questions_as_comments=False
)

# Display a preview of the format
print(

)
print(bayesdown_questions[:50000] + "...\\n")

```

Loading CSV from ArgDown\_WithQuestions.csv...

Successfully loaded CSV with 23 rows.

Generating BayesDown syntax with placeholder probabilities...

BayesDown Questions saved to BayesDownQuestions.md

[Existential\_Catastrophe]: The destruction of humanity's long-term potential due to AI systems.

[Human\_Disempowerment]: Permanent and collective disempowerment of humanity relative to AI systems.

- + [Scale\_Of\_Power\_Seeking]: Power-seeking by AI systems scaling to the point of permanent domination.
- + [Misaligned\_Power\_Seeking]: Deployed AI systems seeking power in unintended and high-risk ways.
- + [APS\_Systems]: AI systems with advanced capabilities, agentic planning, and strategic behavior.
- + [Advanced\_AI\_Capability]: AI systems that outperform humans on tasks that grant significant power.
- + [Agentic\_Planning]: AI systems making and executing plans based on world models to achieve goals.
- + [Strategic\_Awareness]: AI systems with models accurately representing power dynamics and human behavior.
- + [Difficulty\_Of\_Alignment]: It is harder to build aligned systems than misaligned systems.
- + [Instrumental\_Convergence]: AI systems with misaligned objectives tend to seek power as a means to their ends.
- + [Problems\_With\_Proxies]: Optimizing for proxy objectives breaks correlations with human values.
- + [Problems\_With\_Search]: Search processes can yield systems pursuing different objectives than intended.
- + [Deployment\_Decisions]: Decisions to deploy potentially misaligned AI systems. {"instantiation": 0.5}
- + [Incentives\_To\_Build\_APS]: Strong incentives to build and deploy APS systems. {"instantiation": 0.8}
- + [Usefulness\_Of\_APS]: APS systems are very useful for many valuable tasks. {"instantiation": 0.9}
- + [Competitive\_Dynamics]: Competitive pressures between AI developers. {"instantiation": 0.7}
- + [Deception\_By\_AI]: AI systems deceiving humans about their true objectives. {"instantiation": 0.6}
- + [Corrective\_Feedback]: Human society implementing corrections after observing problems.
- + [Warning\_Shots]: Observable failures in weaker systems before catastrophic risks. {"instantiation": 0.4}
- + [Rapid\_Capability\_Escalation]: AI capabilities escalating very rapidly, allowing little time for intervention.

[Barriers\_To\_Understanding]: Difficulty in understanding the internal workings of advanced AI systems.

[Adversarial\_Dynamics]: Potentially adversarial relationships between humans and power-seeking AI systems.

[Stakes\_Of\_Error]: The escalating impact of mistakes with power-seeking AI systems. {"instantiation": 0.9}

...

## 2.3 Generate BayesDown Probability Extraction Prompt

Generate 2nd Extraction Prompt for Probabilities based on the questions generated from the 'ArgDown.csv' extraction

### 2.3.0 BayesDown Format Specification

BayesDown extends ArgDown with probability data in a structured JSON format to represent Bayesian networks. This intermediate representation bridges the gap between natural language arguments and formal probabilistic models, preserving both narrative structure and quantitative relationships.

#### Core Structure

A BayesDown representation consists of:

1. **Nodes:** Variables or statements in brackets [Node\_Name] with descriptive text
2. **Relationships:** Hierarchical structure with indentation and + symbols
3. **Metadata:** JSON objects containing probability information:

```
{
  "instantiations": ["state_TRUE", "state_FALSE"], // Possible states of variable
  "priors": {
    "p(state_TRUE)": "0.7", // Unconditional probability of state_TRUE
    "p(state_FALSE)": "0.3" // Unconditional probability of state_FALSE
  },
  "posteriors": {
    "p(state_TRUE|condition1_TRUE,condition2_FALSE)": "0.9", // Conditional on parent state
    "p(state_TRUE|condition1_FALSE,condition2_TRUE)": "0.4" // Different parent configuration
  }
}

### 2.3.1 Rain-Sprinkler-Lawn Example
[Grass_Wet]: Concentrated moisture on grass. {"instantiations": ["grass_wet_TRUE", "grass_wet_FALSE"],
"priors": {"p(grass_wet_TRUE)": "0.322", "p(grass_wet_FALSE)": "0.678"},
"posteriors": {"p(grass_wet_TRUE|sprinkler_TRUE,rain_TRUE)": "0.99",
"p(grass_wet_TRUE|sprinkler_TRUE,rain_FALSE)": "0.9",
"p(grass_wet_TRUE|sprinkler_FALSE,rain_TRUE)": "0.8",
"p(grass_wet_TRUE|sprinkler_FALSE,rain_FALSE)": "0.0"}}
+ [Rain]: Water falling from the sky. {"instantiations": ["rain_TRUE", "rain_FALSE"],
"priors": {"p(rain_TRUE)": "0.2", "p(rain_FALSE)": "0.8"}}
+ [Sprinkler]: Artificial watering system. {"instantiations": ["sprinkler_TRUE", "sprinkler_FALSE"],
"priors": {"p(sprinkler_TRUE)": "0.44838", "p(sprinkler_FALSE)": "0.55162"},
"posteriors": {"p(sprinkler_TRUE|rain_TRUE)": "0.01", "p(sprinkler_TRUE|rain_FALSE)": "0.4"}
+ [Rain]
```

In this example:

- + Grass\_Wet is the effect/outcome node
- + Rain and Sprinkler are parent nodes (causes)
- + Rain also influences Sprinkler (people tend not to use sprinklers when it's raining)

Role in AMTAIR

BayesDown serves as the critical intermediate representation in the AMTAIR extraction pipeline

For full syntax details, see the BayesDownSyntax.md file in the repository.

### ### 2.3.2 Probability Extraction Process

The probability extraction pipeline follows these steps:

Identify variables and their possible states

Extract prior probability statements

Identify conditional relationships

Extract conditional probability statements

Format the data in BayesDown syntax

### ### 2.3.3 Implementation Steps

To extract probabilities and create BayesDown format:

Run the `extract_probabilities` function on ArgDown text

Process the results into a structured format

Validate the probability distributions (ensure they sum to 1)

Generate the enhanced BayesDown representation

### ### 2.3.4 Validation and Quality Control

The probability extraction process includes validation steps:

Ensuring coherent probability distributions

Checking for logical consistency in conditional relationships

Verifying that all required probability statements are present

Handling missing data with appropriate default values

## ## 2.4 Prepare 2nd API call

## ## 2.5 Make BayesDown Probability Extraction API Call



```
## 2.6 Save BayesDown with Probability Estimates (.csv)
```

```
## 2.7 Review & Verify BayesDown Probability Estimates
```

```
## 2.7.2 Check the Graph Structure with the ArgDown Sandbox Online
```

Copy and paste the BayesDown formatted ... in the ArgDown Sandbox below to quickly verify the

```
## 2.8 Extract BayesDown with Probability Estimates as Dataframe
```

```
# 3 Data Extraction: BayesDown (.md) to Database (.csv)
```

```
## 3.0 BayesDown to Structured Data: Network Construction
```

```
## Extraction Pipeline Overview
```

This section implements the core extraction pipeline described in the AMTAIR project document

1. **Input**: Text in BayesDown format (see Section 2.3.1)
2. **Parsing**: Extract nodes, relationships, and probability information
3. **Structuring**: Organize into a DataFrame with formal relationships
4. **Enhancement**: Add derived properties and network metrics
5. **Output**: Structured data ready for Bayesian network construction

```
### Theoretical Foundation
```

This implementation follows the extraction algorithm outlined in the AMTAIR project description

1. Get nodes: All premises and conclusions from the argument structure
2. Get edges: Parent-child relationships between nodes
3. Extract probability distributions: Prior and conditional probabilities
4. Calculate derived metrics: Network statistics and node classifications

The resulting structured data maintains the complete information needed to reconstruct the B

```
### Role in Thesis Research
```

This extraction pipeline represents a key contribution of the Master's thesis, demonstrating

The rain-sprinkler-lawn example serves as a simple but complete test case, demonstrating eve

```
### 3.0.0 ExtractBayesDown-Data_v1
```

```
Build data frame with extractable information from BayesDown
```

```

::: {.cell quarto-private-1='{ "key": "colab", "value": { "base_uri": "https://localhost:8080/", "h
``` {.python .cell-code}
# read sprinkler example -- Occam Colab Online
file_path_ex_rain = "https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main

# Use requests.get to fetch content from URL
response = requests.get(file_path_ex_rain)
response.raise_for_status() # Raise HTTPError for bad responses (4xx or 5xx)

# Read content from the response
md_content_ex_rain = response.text

md_content_ex_rain

```

```
'[Existential_Catastrophe]: The destruction of humanity\'s long-term potential due to AI sys
```

### 3.0.1 Test BayesDown Extraction

```
display(Markdown(md_content_ex_rain)) # view BayesDown file formatted as Markdown
```

[Existential\_Catastrophe]: The destruction of humanity’s long-term potential due to AI systems we’ve lost control over. {“instantiations”: [“existential\_catastrophe\_TRUE”, “existential\_catastrophe\_FALSE”], “priors”: {“p(existential\_catastrophe\_TRUE)”: “0.05”, “p(existential\_catastrophe\_FALSE)”: “0.95”}, “posteriors”: {“p(existential\_catastrophe\_TRUE|human\_disempowerment\_FALSE)”: “0.95”, “p(existential\_catastrophe\_TRUE|human\_disempowerment\_TRUE)”: “0.0”, “p(existential\_catastrophe\_FALSE|human\_disempowerment\_FALSE)”: “0.05”, “p(existential\_catastrophe\_FALSE|human\_disempowerment\_TRUE)”: “1.0”}} - [Human\_Disempowerment]: Permanent and collective disempowerment of humanity relative to AI systems. {“instantiations”: [“human\_disempowerment\_TRUE”, “human\_disempowerment\_FALSE”], “priors”: {“p(human\_disempowerment\_TRUE)”: “0.208”, “p(human\_disempowerment\_FALSE)”: “0.792”}, “posteriors”: {“p(human\_disempowerment\_TRUE|scale\_of\_power\_seeking\_FALSE)”: “1.0”, “p(human\_disempowerment\_TRUE|scale\_of\_power\_seeking\_TRUE)”: “0.0”, “p(human\_disempowerment\_FALSE|scale\_of\_power\_seeking\_FALSE)”: “0.0”, “p(human\_disempowerment\_FALSE|scale\_of\_power\_seeking\_TRUE)”: “1.0”}} - [Scale\_Of\_Power\_Seeking]: Power-seeking by AI systems scaling to the point of permanently disempowering all of humanity. {“instantiations”: [“scale\_of\_power\_seeking\_TRUE”, “scale\_of\_power\_seeking\_FALSE”], “priors”: {“p(scale\_of\_power\_seeking\_TRUE)”: “0.208”, “p(scale\_of\_power\_seeking\_FALSE)”: “0.792”}, “posteriors”: {“p(scale\_of\_power\_seeking\_TRUE|misaligned\_power\_seeking\_corrective\_feedback\_EFFECTIVE)”: “0.25”, “p(scale\_of\_power\_seeking\_TRUE|misaligned\_power\_seeking\_corrective\_feedback\_INEFFECTIVE)”: “0.60”, “p(scale\_of\_power\_seeking\_TRUE|misaligned\_power\_seeking\_corrective\_feedback\_EFFECTIVE)”: “0.0”, “p(scale\_of\_power\_seeking\_TRUE|misaligned\_power\_seeking\_corrective\_feedback\_INEFFECTIVE)”: “0.0”, “p(scale\_of\_power\_seeking\_FALSE|misaligned\_power\_seeking\_corrective\_feedback\_EFFECTIVE)”: “0.75”, “p(scale\_of\_power\_seeking\_FALSE|misaligned\_power\_seeking



AI systems that outperform humans on tasks that grant significant power in the world. {"instantiations": ["advanced\_ai\_capability\_TRUE", "advanced\_ai\_capability\_FALSE"], "priors": {"p(advanced\_ai\_capability\_TRUE)": "0.80", "p(advanced\_ai\_capability\_FALSE)": "0.20"}} - [Agentic\_Planning]: AI systems making and executing plans based on world models to achieve objectives. {"instantiations": ["agentic\_planning\_TRUE", "agentic\_planning\_FALSE"], "priors": {"p(agentic\_planning\_TRUE)": "0.85", "p(agentic\_planning\_FALSE)": "0.15"}} - [Strategic\_Awareness]: AI systems with models accurately representing power dynamics with humans. {"instantiations": ["strategic\_awareness\_TRUE", "strategic\_awareness\_FALSE"], "priors": {"p(strategic\_awareness\_TRUE)": "0.75", "p(strategic\_awareness\_FALSE)": "0.25"}} - [Difficulty\_Of\_Alignment]: It is harder to build aligned systems than misaligned systems that are attractive to deploy. {"instantiations": ["difficulty\_of\_alignment\_TRUE", "difficulty\_of\_alignment\_FALSE"], "priors": {"p(difficulty\_of\_alignment\_TRUE)": "0.40", "p(difficulty\_of\_alignment\_FALSE)": "0.60"}, "posteriors": {"p(difficulty\_of\_alignment\_TRUE|instrumental\_problems\_with\_proxies\_TRUE, problems\_with\_search\_TRUE)": "0.85", "p(difficulty\_of\_alignment\_TRUE|instrumental\_problems\_with\_proxies\_TRUE, problems\_with\_search\_FALSE)": "0.70", "p(difficulty\_of\_alignment\_TRUE|instrumental\_problems\_with\_proxies\_FALSE, problems\_with\_search\_TRUE)": "0.60", "p(difficulty\_of\_alignment\_TRUE|instrumental\_problems\_with\_proxies\_FALSE, problems\_with\_search\_FALSE)": "0.40", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_TRUE, problems\_with\_search\_TRUE)": "0.55", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_TRUE, problems\_with\_search\_FALSE)": "0.40", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_FALSE, problems\_with\_search\_TRUE)": "0.30", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_FALSE, problems\_with\_search\_FALSE)": "0.10", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_TRUE, problems\_with\_search\_TRUE)": "0.15", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_TRUE, problems\_with\_search\_FALSE)": "0.30", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_FALSE, problems\_with\_search\_TRUE)": "0.40", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_FALSE, problems\_with\_search\_FALSE)": "0.60", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_TRUE, problems\_with\_search\_TRUE)": "0.45", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_TRUE, problems\_with\_search\_FALSE)": "0.60", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_FALSE, problems\_with\_search\_TRUE)": "0.70", "p(difficulty\_of\_alignment\_FALSE|instrumental\_problems\_with\_proxies\_FALSE, problems\_with\_search\_FALSE)": "0.90"}} - [Instrumental\_Convergence]: AI systems with misaligned objectives tend to seek power as an instrumental goal. {"instantiations": ["instrumental\_convergence\_TRUE", "instrumental\_convergence\_FALSE"], "priors": {"p(instrumental\_convergence\_TRUE)": "0.75", "p(instrumental\_convergence\_FALSE)": "0.25"}} - [Problems\_With\_Proxies]: Optimizing for proxy objectives breaks correlations with intended goals. {"instantiations": ["problems\_with\_proxies\_TRUE", "problems\_with\_proxies\_FALSE"], "priors": {"p(problems\_with\_proxies\_TRUE)": "0.80", "p(problems\_with\_proxies\_FALSE)": "0.20"}} - [Problems\_With\_Search]: Search processes can yield systems pursuing different objectives than intended. {"instantiations": ["problems\_with\_search\_TRUE", "problems\_with\_search\_FALSE"], "priors": {"p(problems\_with\_search\_TRUE)": "0.70", "p(problems\_with\_search\_FALSE)": "0.30"}} - [Deployment\_Decisions]: Decisions to deploy potentially misaligned AI systems. {"instantiations": ["deployment\_decisions\_DEPLOY", "deployment\_decisions\_WITHHOLD"], "priors": {"p(deployment\_decisions\_DEPLOY)": "0.70",

“p(deployment\_decisions\_WITHHOLD): “0.30”, “posteriors”: {“p(deployment\_decisions\_DEPLOY|incentives\_to\_build\_aps\_STRONG, deception\_by\_ai\_TRUE): “0.90”, “p(deployment\_decisions\_DEPLOY|incentives\_to\_build\_aps\_STRONG, deception\_by\_ai\_FALSE): “0.75”, “p(deployment\_decisions\_DEPLOY|incentives\_to\_build\_aps\_WEAK, deception\_by\_ai\_TRUE): “0.60”, “p(deployment\_decisions\_DEPLOY|incentives\_to\_build\_aps\_WEAK, deception\_by\_ai\_FALSE): “0.30”, “p(deployment\_decisions\_WITHHOLD|incentives\_to\_build\_aps\_STRONG, deception\_by\_ai\_TRUE): “0.10”, “p(deployment\_decisions\_WITHHOLD|incentives\_to\_build\_aps\_STRONG, deception\_by\_ai\_FALSE): “0.25”, “p(deployment\_decisions\_WITHHOLD|incentives\_to\_build\_aps\_WEAK, deception\_by\_ai\_TRUE): “0.40”, “p(deployment\_decisions\_WITHHOLD|incentives\_to\_build\_aps\_WEAK, deception\_by\_ai\_FALSE): “0.70”}} - [Incentives\_To\_Build\_APS]: Strong incentives to build and deploy APS systems. {“instantiations”: [“incentives\_to\_build\_aps\_STRONG”, “incentives\_to\_build\_aps\_WEAK”], “priors”: {“p(incentives\_to\_build\_aps\_STRONG): “0.80”, “p(incentives\_to\_build\_aps\_WEAK): “0.20”}, “posteriors”: {“p(incentives\_to\_build\_aps\_STRONG|usefulness\_of\_aps\_HIGH, competitive\_dynamics\_STRONG): “0.95”, “p(incentives\_to\_build\_aps\_STRONG|usefulness\_of\_aps\_HIGH, competitive\_dynamics\_WEAK): “0.80”, “p(incentives\_to\_build\_aps\_STRONG|usefulness\_of\_aps\_LOW, competitive\_dynamics\_STRONG): “0.70”, “p(incentives\_to\_build\_aps\_STRONG|usefulness\_of\_aps\_LOW, competitive\_dynamics\_WEAK): “0.30”, “p(incentives\_to\_build\_aps\_WEAK|usefulness\_of\_aps\_HIGH, competitive\_dynamics\_STRONG): “0.05”, “p(incentives\_to\_build\_aps\_WEAK|usefulness\_of\_aps\_HIGH, competitive\_dynamics\_WEAK): “0.20”, “p(incentives\_to\_build\_aps\_WEAK|usefulness\_of\_aps\_LOW, competitive\_dynamics\_STRONG): “0.30”, “p(incentives\_to\_build\_aps\_WEAK|usefulness\_of\_aps\_LOW, competitive\_dynamics\_WEAK): “0.70”}} - [Usefulness\_Of\_APS]: APS systems are very useful for many valuable tasks. {“instantiations”: [“usefulness\_of\_aps\_HIGH”, “usefulness\_of\_aps\_LOW”], “priors”: {“p(usefulness\_of\_aps\_HIGH): “0.85”, “p(usefulness\_of\_aps\_LOW): “0.15”}} - [Competitive\_Dynamics]: Competitive pressures between AI developers. {“instantiations”: [“competitive\_dynamics\_STRONG”, “competitive\_dynamics\_WEAK”], “priors”: {“p(competitive\_dynamics\_STRONG): “0.75”, “p(competitive\_dynamics\_WEAK): “0.25”}} - [Deception\_By\_AI]: AI systems deceiving humans about their true objectives. {“instantiations”: [“deception\_by\_ai\_TRUE”, “deception\_by\_ai\_FALSE”], “priors”: {“p(deception\_by\_ai\_TRUE): “0.50”, “p(deception\_by\_ai\_FALSE): “0.50”}} - [Corrective\_Feedback]: Human society implementing corrections after observing problems. {“instantiations”: [“corrective\_feedback\_EFFECTIVE”, “corrective\_feedback\_INEFFECTIVE”], “priors”: {“p(corrective\_feedback\_EFFECTIVE): “0.60”, “p(corrective\_feedback\_INEFFECTIVE): “0.40”}, “posteriors”: {“p(corrective\_feedback\_EFFECTIVE|warning\_shots\_OBSERVED, rapid\_capability\_escalation\_TRUE): “0.40”, “p(corrective\_feedback\_EFFECTIVE|warning\_shots\_OBSERVED, rapid\_capability\_escalation\_FALSE): “0.80”, “p(corrective\_feedback\_EFFECTIVE|warning\_shots\_UNOBSERVED, rapid\_capability\_escalation\_TRUE): “0.15”, “p(corrective\_feedback\_EFFECTIVE|warning\_shots\_UNOBSERVED, rapid\_capability\_escalation\_FALSE): “0.50”, “p(corrective\_feedback\_INEFFECTIVE|warning\_shots\_OBSERVED, rapid\_capability\_escalation\_TRUE): “0.60”, “p(corrective\_feedback\_INEFFECTIVE|warning\_shots\_OBSERVED, rapid\_capability\_escalation\_FALSE): “0.20”, “p(corrective\_feedback\_INEFFECTIVE|warning\_shots\_UNOBSERVED, rapid\_capability\_escalation\_TRUE): “0.85”, “p(corrective\_feedback\_INEFFECTIVE|warning\_shots\_UNOBSERVED, rapid\_capability\_escalation\_FALSE): “0.50”}} - [Warning\_Shots]: Observable failures in weaker systems before catastrophic risks. {“instantiations”: [“warning\_shots\_OBSERVED”, “warning\_shots\_UNOBSERVED”], “priors”: {“p(warning\_shots\_OBSERVED): “0.70”,

“p(warning\_shots\_UNOBSERVED)”: “0.30”}} - [Rapid\_Capability\_Escalation]: AI capabilities escalating very rapidly, allowing little time for correction. {“instantiations”: [“rapid\_capability\_escalation\_TRUE”, “rapid\_capability\_escalation\_FALSE”], “priors”: {“p(rapid\_capability\_escalation\_TRUE)”: “0.45”, “p(rapid\_capability\_escalation\_FALSE)”: “0.55”}} [Barriers\_To\_Understanding]: Difficulty in understanding the internal workings of advanced AI systems. {“instantiations”: [“barriers\_to\_understanding\_HIGH”, “barriers\_to\_understanding\_LOW”], “priors”: {“p(barriers\_to\_understanding\_HIGH)”: “0.70”, “p(barriers\_to\_understanding\_LOW)”: “0.30”}, “posteriors”: {“p(barriers\_to\_understanding\_HIGH|misaligned\_power\_seeking\_TRUE)”: “0.85”, “p(barriers\_to\_understanding\_HIGH|misaligned\_power\_seeking\_FALSE)”: “0.60”, “p(barriers\_to\_understanding\_LOW|misaligned\_power\_seeking\_TRUE)”: “0.15”, “p(barriers\_to\_understanding\_LOW|misaligned\_power\_seeking\_FALSE)”: “0.40”}} - [Misaligned\_Power\_Seeking]: Deployed AI systems seeking power in unintended and high-impact ways due to problems with their objectives. {“instantiations”: [“misaligned\_power\_seeking\_TRUE”, “misaligned\_power\_seeking\_FALSE”], “priors”: {“p(misaligned\_power\_seeking\_TRUE)”: “0.338”, “p(misaligned\_power\_seeking\_FALSE)”: “0.662”}} [Adversarial\_Dynamics]: Potentially adversarial relationships between humans and power-seeking AI. {“instantiations”: [“adversarial\_dynamics\_TRUE”, “adversarial\_dynamics\_FALSE”], “priors”: {“p(adversarial\_dynamics\_TRUE)”: “0.60”, “p(adversarial\_dynamics\_FALSE)”: “0.40”}, “posteriors”: {“p(adversarial\_dynamics\_TRUE|misaligned\_power\_seeking\_TRUE)”: “0.95”, “p(adversarial\_dynamics\_TRUE|misaligned\_power\_seeking\_FALSE)”: “0.10”, “p(adversarial\_dynamics\_FALSE|misaligned\_power\_seeking\_TRUE)”: “0.05”, “p(adversarial\_dynamics\_FALSE|misaligned\_power\_seeking\_FALSE)”: “0.90”}} - [Misaligned\_Power\_Seeking]: Deployed AI systems seeking power in unintended and high-impact ways due to problems with their objectives. {“instantiations”: [“misaligned\_power\_seeking\_TRUE”, “misaligned\_power\_seeking\_FALSE”], “priors”: {“p(misaligned\_power\_seeking\_TRUE)”: “0.338”, “p(misaligned\_power\_seeking\_FALSE)”: “0.662”}} [Stakes\_Of\_Error]: The escalating impact of mistakes with power-seeking AI systems. {“instantiations”: [“stakes\_of\_error\_HIGH”, “stakes\_of\_error\_LOW”], “priors”: {“p(stakes\_of\_error\_HIGH)”: “0.85”, “p(stakes\_of\_error\_LOW)”: “0.15”}, “posteriors”: {“p(stakes\_of\_error\_HIGH|misaligned\_power\_seeking\_TRUE)”: “0.95”, “p(stakes\_of\_error\_HIGH|misaligned\_power\_seeking\_FALSE)”: “0.50”, “p(stakes\_of\_error\_LOW|misaligned\_power\_seeking\_TRUE)”: “0.05”, “p(stakes\_of\_error\_LOW|misaligned\_power\_seeking\_FALSE)”: “0.50”}} - [Misaligned\_Power\_Seeking]: Deployed AI systems seeking power in unintended and high-impact ways due to problems with their objectives. {“instantiations”: [“misaligned\_power\_seeking\_TRUE”, “misaligned\_power\_seeking\_FALSE”], “priors”: {“p(misaligned\_power\_seeking\_TRUE)”: “0.338”, “p(misaligned\_power\_seeking\_FALSE)”: “0.662”}}

### 3.0.2 Check the Graph Structure with the ArgDown Sandbox Online

Copy and paste the BayesDown formatted ... in the ArgDown Sandbox below to quickly verify that the network renders correctly.

### 3.1 Extraction

BayesDown Extraction Code already part of ArgDown extraction code, therefore just use same function “`parse_markdown_hierarchy(markdown_data)`” and ignore the extra argument (“ArgDown”) because it is automatically set to false and will by default extract BayesDown.

```
result_df = parse_markdown_hierarchy_fixed(md_content_ex_rain)
result_df
```

	Title	Description	line	line_number
0	Existential_Catastrophe	The destruction of humanity's long-term potent...	0	[0]
1	Human_Disempowerment	Permanent and collective disempowerment of hum...	1	[1]
2	Scale_Of_Power_Seeking	Power-seeking by AI systems scaling to the poi...	2	[2]
3	Misaligned_Power_Seeking	Deployed AI systems seeking power in unintende...	3	[3, 21, 23, 24]
4	APS_Systems	AI systems with advanced capabilities, agentic...	4	[4]
5	Advanced_AI_Capability	AI systems that outperform humans on tasks tha...	5	[5]
6	Agentic_Planning	AI systems making and executing plans based on...	6	[6]
7	Strategic_Awareness	AI systems with models accurately representing...	7	[7]
8	Difficulty_Of_Alignment	It is harder to build aligned systems than mis...	8	[8]
9	Instrumental_Convergence	AI systems with misaligned objectives tend to ...	9	[9]
10	Problems_With_Proxies	Optimizing for proxy objectives breaks correla...	10	[10]
11	Problems_With_Search	Search processes can yield systems pursuing di...	11	[11]
12	Deployment_Decisions	Decisions to deploy potentially misaligned AI ...	12	[12]
13	Incentives_To_Build_APS	Strong incentives to build and deploy APS syst...	13	[13]
14	Usefulness_Of_APS	APS systems are very useful for many valuable ...	14	[14]
15	Competitive_Dynamics	Competitive pressures between AI developers.	15	[15]
16	Deception_By_AI	AI systems deceiving humans about their true o...	16	[16]
17	Corrective_Feedback	Human society implementing corrections after o...	17	[17]
18	Warning_Shots	Observable failures in weaker systems before c...	18	[18]
19	Rapid_Capability_Escalation	AI capabilities escalating very rapidly, allow...	19	[19]
20	Barriers_To_Understanding	Difficulty in understanding the internal worki...	20	[20]
21	Adversarial_Dynamics	Potentially adversarial relationships between ...	22	[22]
22	Stakes_Of_Error	The escalating impact of mistakes with power-s...	24	[24]

### 3.2 Data-Post-Processing

Add rows to data frame that can be calculated from the extracted rows

```
# @title 3.2.0 Data Post-Processing Functions --- [data_post_processing_functions]

"""
BLOCK PURPOSE: Enhances the extracted BayesDown data with calculated metrics and network pro
```

### 3.2 Data-Probability Extractions: ArgDown (.csv) to BayesDown (.md + plugin JSON syntax)

This block provides functions to enrich the basic extracted data with additional calculated columns that are useful for analysis and visualization:

1. Joint probabilities - Calculating  $P(A,B)$  from conditional and prior probabilities
2. Network metrics - Centrality measures that indicate importance of nodes in the network
3. Markov blanket - Identifying the minimal set of nodes that shield a node from the rest

These enhancements provide valuable context for understanding the network structure and the relationships between variables, enabling more advanced analysis and improving visualization.

DEPENDENCIES: networkx for graph calculations

INPUTS: DataFrame with basic extracted BayesDown data

OUTPUTS: Enhanced DataFrame with additional calculated columns

"""

```
def enhance_extracted_data(df):
```

```
    """
```

```
    Enhance the extracted data with calculated columns
```

```
    Args:
```

```
        df: DataFrame with extracted BayesDown data
```

```
    Returns:
```

```
        Enhanced DataFrame with additional columns
```

```
    """
```

```
    # Create a copy to avoid modifying the original
```

```
    enhanced_df = df.copy()
```

```
    # 1. Calculate joint probabilities -  $P(A,B) = P(A|B) * P(B)$ 
```

```
    enhanced_df['joint_probabilities'] = None
```

```
    for idx, row in enhanced_df.iterrows():
```

```
        title = row['Title']
```

```
        priors = row['priors'] if isinstance(row['priors'], dict) else {}
```

```
        posteriors = row['posteriors'] if isinstance(row['posteriors'], dict) else {}
```

```
        parents = row['Parents'] if isinstance(row['Parents'], list) else []
```

```
    # Skip if no parents or no priors
```

```
    if not parents or not priors:
```

```
        continue
```



```

# Initialize joint probabilities dictionary
joint_probs = {}

# Get instantiations
instantiations = row['instantiations']
if not isinstance(instantiations, list) or not instantiations:
    continue

# For each parent and child instantiation combination, calculate joint probability
for inst in instantiations:
    # Get this instantiation's prior probability
    inst_prior_key = f"p({inst})"
    if inst_prior_key not in priors:
        continue

    try:
        inst_prior = float(priors[inst_prior_key])
    except (ValueError, TypeError):
        continue

    # For each parent
    for parent in parents:
        parent_row = enhanced_df[enhanced_df['Title'] == parent]
        if parent_row.empty:
            continue

        parent_insts = parent_row.iloc[0]['instantiations']
        if not isinstance(parent_insts, list) or not parent_insts:
            continue

        for parent_inst in parent_insts:
            # Get conditional probability
            cond_key = f"p({inst}|{parent}={parent_inst})"
            if cond_key in posteriors:
                try:
                    cond_prob = float(posteriors[cond_key])

                    # Get parent's prior
                    parent_priors = parent_row.iloc[0]['priors']
                    if not isinstance(parent_priors, dict):
                        continue

```

```

        parent_prior_key = f"p({parent_inst})"
        if parent_prior_key not in parent_priors:
            continue

        try:
            parent_prior = float(parent_priors[parent_prior_key])

            # Calculate joint probability:
            #  $P(A,B) = P(A|B) * P(B)$ 
            joint_prob = cond_prob * parent_prior
            joint_key = f"p({inst},{parent}={parent_inst})"
            joint_probs[joint_key] = str(round(joint_prob, 4))
        except (ValueError, TypeError):
            joint_prob = cond_prob * parent_prior
            joint_key = f"p({inst},{parent}={parent_inst})"
            joint_probs[joint_key] = str(round(joint_prob, 4))
        except (ValueError, TypeError):
            continue
    except (ValueError, TypeError):
        continue

    # Store joint probabilities in dataframe
    enhanced_df.at[idx, 'joint_probabilities'] = joint_probs

# 2. Calculate network metrics
# Create a directed graph
import networkx as nx
G = nx.DiGraph()

# Add nodes
for idx, row in enhanced_df.iterrows():
    G.add_node(row['Title'])

# Add edges
for idx, row in enhanced_df.iterrows():
    child = row['Title']
    parents = row['Parents'] if isinstance(row['Parents'], list) else []

    for parent in parents:
        if parent in G.nodes():
            G.add_edge(parent, child)

```

```

# Calculate centrality measures
degree centrality = nx.degree centrality(G) # Overall connectedness
in_degree centrality = nx.in_degree centrality(G) # How many nodes affect this one
out_degree centrality = nx.out_degree centrality(G) # How many nodes this one affects

try:
    betweenness centrality = nx.betweenness centrality(G) # Node's role as a connector
except:
    betweenness centrality = {node: 0 for node in G.nodes()}

# Add metrics to dataframe
enhanced_df['degree centrality'] = None
enhanced_df['in_degree centrality'] = None
enhanced_df['out_degree centrality'] = None
enhanced_df['betweenness centrality'] = None

for idx, row in enhanced_df.iterrows():
    title = row['Title']
    enhanced_df.at[idx, 'degree centrality'] = degree centrality.get(title, 0)
    enhanced_df.at[idx, 'in_degree centrality'] = in_degree centrality.get(title, 0)
    enhanced_df.at[idx, 'out_degree centrality'] = out_degree centrality.get(title, 0)
    enhanced_df.at[idx, 'betweenness centrality'] = betweenness centrality.get(title, 0)

# 3. Add Markov blanket information (parents, children, and children's parents)
enhanced_df['markov blanket'] = None

for idx, row in enhanced_df.iterrows():
    title = row['Title']
    parents = row['Parents'] if isinstance(row['Parents'], list) else []
    children = row['Children'] if isinstance(row['Children'], list) else []

    # Get children's parents (excluding this node)
    childrens_parents = []
    for child in children:
        child_row = enhanced_df[enhanced_df['Title'] == child]
        if not child_row.empty:
            child_parents = child_row.iloc[0]['Parents']
            if isinstance(child_parents, list):
                childrens_parents.extend([p for p in child_parents if p != title])

    # Remove duplicates
    childrens_parents = list(set(childrens_parents))

```

```
# Combine to get Markov blanket
markov_blanket = list(set(parents + children + childrens_parents))
enhanced_df.at[idx, 'markov_blanket'] = markov_blanket

return enhanced_df
```

```
# @title 3.2.1 --- Enhance Extracted Data with Network Metrics --- [enhance_extracted_data_w
```

```
"""
```

BLOCK PURPOSE: Applies the post-processing functions to enhance the extracted data.

This block takes the basic extracted DataFrame from the BayesDown parsing step and enriches it with calculated metrics that provide deeper insight into the network structure and relationships. It:

1. Applies the enhancement functions defined previously
2. Displays summary information about key calculated metrics
3. Saves the enhanced data for further analysis and visualization

The enhanced DataFrame provides a richer representation of the Bayesian network, including measures of node importance and conditional relationships that are essential for effective analysis and visualization.

DEPENDENCIES: enhance\_extracted\_data function

INPUTS: DataFrame with basic extracted BayesDown data

OUTPUTS: Enhanced DataFrame with additional calculated columns, saved to CSV

```
"""
```

```
# Enhance the extracted dataframe with calculated columns
```

```
enhanced_df = enhance_extracted_data(result_df)
```

```
# Display the enhanced dataframe
```

```
print("Enhanced DataFrame with additional calculated columns:")
```

```
enhanced_df.head()
```

```
# Check some calculated metrics
```

```
print("\nJoint Probabilities Example:")
```

```
example_node = enhanced_df.loc[0, 'Title']
```

```
joint_probs = enhanced_df.loc[0, 'joint_probabilities']
```

```
print(f"Joint probabilities for {example_node}:")
```

```
print(joint_probs)
```

```
print("\nNetwork Metrics:")
for idx, row in enhanced_df.iterrows():
    print(f"{row['Title']}:")
    print(f"    Degree Centrality: {row['degree_centrality']:.3f}")
    print(f"    Betweenness Centrality: {row['betweenness_centrality']:.3f}")

# Save the enhanced dataframe
enhanced_df.to_csv('enhanced_extracted_data.csv', index=False)
print("\nEnhanced data saved to 'enhanced_extracted_data.csv'")
```

Enhanced DataFrame with additional calculated columns:

Joint Probabilities Example:

Joint probabilities for Existential\_Catastrophe:

None

Network Metrics:

Existential\_Catastrophe:

Degree Centrality: 0.000

Betweenness Centrality: 0.000

Human\_Disempowerment:

Degree Centrality: 0.045

Betweenness Centrality: 0.000

Scale\_Of\_Power\_Seeking:

Degree Centrality: 0.136

Betweenness Centrality: 0.037

Misaligned\_Power\_Seeking:

Degree Centrality: 0.182

Betweenness Centrality: 0.056

APS\_Systems:

Degree Centrality: 0.182

Betweenness Centrality: 0.019

Advanced\_AI\_Capability:

Degree Centrality: 0.045

Betweenness Centrality: 0.000

Agentic\_Planning:

Degree Centrality: 0.045

Betweenness Centrality: 0.000

Strategic\_Awareness:

Degree Centrality: 0.045

Betweenness Centrality: 0.000

Difficulty\_Of\_Alignment:

Degree Centrality: 0.182  
Betweenness Centrality: 0.019  
Instrumental\_Convergence:  
Degree Centrality: 0.045  
Betweenness Centrality: 0.000  
Problems\_With\_Proxies:  
Degree Centrality: 0.045  
Betweenness Centrality: 0.000  
Problems\_With\_Search:  
Degree Centrality: 0.045  
Betweenness Centrality: 0.000  
Deployment\_Decisions:  
Degree Centrality: 0.136  
Betweenness Centrality: 0.026  
Incentives\_To\_Build\_APS:  
Degree Centrality: 0.136  
Betweenness Centrality: 0.017  
Usefulness\_Of\_APS:  
Degree Centrality: 0.045  
Betweenness Centrality: 0.000  
Competitive\_Dynamics:  
Degree Centrality: 0.045  
Betweenness Centrality: 0.000  
Deception\_By\_AI:  
Degree Centrality: 0.045  
Betweenness Centrality: 0.000  
Corrective\_Feedback:  
Degree Centrality: 0.136  
Betweenness Centrality: 0.009  
Warning\_Shots:  
Degree Centrality: 0.045  
Betweenness Centrality: 0.000  
Rapid\_Capability\_Escalation:  
Degree Centrality: 0.045  
Betweenness Centrality: 0.000  
Barriers\_To\_Understanding:  
Degree Centrality: 0.000  
Betweenness Centrality: 0.000  
Adversarial\_Dynamics:  
Degree Centrality: 0.000  
Betweenness Centrality: 0.000  
Stakes\_Of\_Error:

Degree Centrality: 0.000

Betweenness Centrality: 0.000

Enhanced data saved to 'enhanced\_extracted\_data.csv'

### 3.4 Download and save finished data frame as .csv file

```
# @title 3.4.0 --- Save Extracted Data for Further Processing --- [save_extracted_data_for_further_processing]

"""
BLOCK PURPOSE: Saves the extracted data to a CSV file for further processing.

This step is essential for:
1. Persisting the structured representation of the Bayesian network
2. Enabling further analysis in other tools or notebook sections
3. Creating a permanent record of the extraction results
4. Making the data available for the visualization pipeline

The CSV format provides a standardized, tabular representation of the network
that can be easily loaded and processed in subsequent analysis steps.

DEPENDENCIES: pandas DataFrame operations
INPUTS: Extracted DataFrame from the parsing step
OUTPUTS: CSV file containing the structured network data
"""

# Save the extracted data as a CSV file
result_df.to_csv('extracted_data.csv', index=False)

print(" Extracted data saved successfully to 'extracted_data.csv'")
print("Note: If using updated data in future steps, "
      + "the file must be pushed to the GitHub repository")
```

Extracted data saved successfully to 'extracted\_data.csv'

Note: If using updated data in future steps, the file must be pushed to the GitHub repository





# 4 Analysis & Inference: Bayesian Network Visualization

## 4.0 Bayesian Network Visualization Approach

This section implements the visualization component of the AMTAIR project, transforming the structured data extracted from BayesDown into an interactive network visualization that makes complex probabilistic relationships accessible to human understanding.

### Visualization Philosophy

A key challenge in AI governance is making complex probabilistic relationships understandable to diverse stakeholders. This visualization system addresses this challenge through:

1. **Visual Encoding of Probability:** Node colors reflect probability values (green for high probability, red for low)
2. **Structural Classification:** Border colors indicate node types (blue for root causes, purple for intermediate nodes, magenta for leaf nodes)
3. **Progressive Disclosure:** Basic information in tooltips, detailed probability tables in modal popups
4. **Interactive Exploration:** Draggable nodes, configurable physics, click interactions

### Connection to AMTAIR Goals

This visualization approach directly supports the AMTAIR project's goal of improving coordination in AI governance by:

1. Making implicit models explicit through visual representation
2. Providing a common language for discussing probabilistic relationships
3. Enabling non-technical stakeholders to engage with formal models
4. Creating shareable artifacts that facilitate collaboration

### Implementation Structure

The visualization system is implemented in four phases:

1. **Network Construction:** Creating a directed graph representation using NetworkX

2. **Node Classification:** Identifying node types based on network position
3. **Visual Enhancement:** Adding color coding, tooltips, and interactive elements
4. **Interactive Features:** Implementing click handling for detailed exploration

The resulting visualization serves as both an analytical tool for experts and a communication tool for broader audiences, bridging the gap between technical and policy domains in AI governance discussions.

## 4.1 Phase 1: Dependencies/Functions

```
# @title 4.1.0 --- Bayesian Network Visualization Functions --- [bayesian_network_visualizat

"""
BLOCK PURPOSE: Provides functions to create interactive Bayesian network
visualizations from DataFrame representations of ArgDown/BayesDown data.

This block implements the visualization pipeline described in the AMTAIR project,
transforming the structured DataFrame extracted from ArgDown/BayesDown into an
interactive network graph that displays nodes, relationships, and probability
information. The visualization leverages NetworkX for graph representation and
PyVis for interactive display.

Key visualization features:
1. Color-coding of nodes based on probability values
2. Border styling to indicate node types (root, intermediate, leaf)
3. Interactive tooltips with probability information
4. Modal popups with detailed conditional probability tables
5. Physics-based layout for intuitive exploration

DEPENDENCIES: networkx, pyvis, HTML display from IPython
INPUTS: DataFrame with node information, relationships, and probabilities
OUTPUTS: Interactive HTML visualization of the Bayesian network
"""

from pyvis.network import Network
import networkx as nx
from IPython.display import HTML
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import io
import base64
import colorsys
```

```

import json

def create_bayesian_network_with_probabilities(df):
    """
    Create an interactive Bayesian network visualization with enhanced
    probability visualization and node classification based on network structure.

    Args:
        df (pandas.DataFrame): DataFrame containing node information, relationships, and probabilities

    Returns:
        IPython.display.HTML: Interactive HTML visualization of the Bayesian network
    """
    # PHASE 1: Create a directed graph representation
    G = nx.DiGraph()

    # Add nodes with proper attributes
    for idx, row in df.iterrows():
        title = row['Title']
        description = row['Description']

        # Process probability information
        priors = get_priors(row)
        instantiations = get_instantiations(row)

        # Add node with base information
        G.add_node(
            title,
            description=description,
            priors=priors,
            instantiations=instantiations,
            posteriors=get_posteriors(row)
        )

    # Add edges based on parent-child relationships
    for idx, row in df.iterrows():
        child = row['Title']
        parents = get_parents(row)

        # Add edges from each parent to this child
        for parent in parents:
            if parent in G.nodes():

```

```

G.add_edge(parent, child)

# PHASE 2: Classify nodes based on network structure
classify_nodes(G)

# PHASE 3: Create interactive network visualization
net = Network(notebook=True, directed=True, cdn_resources="in_line", height="600px", width="1000px")

# Configure physics for better layout
net.force_atlas_2based(gravity=-50, spring_length=100, spring_strength=0.02)
net.show_buttons(filter_=['physics']) # Allow user to adjust physics settings

# Add the graph to the network
net.from_nx(G)

# PHASE 4: Enhance node appearance with probability information
for node in net.nodes:
    node_id = node['id']
    node_data = G.nodes[node_id]

    # Get node type and set border color
    node_type = node_data.get('node_type', 'unknown')
    border_color = get_border_color(node_type)

    # Get probability information
    priors = node_data.get('priors', {})
    true_prob = priors.get('true_prob', 0.5) if priors else 0.5

    # Get proper state names
    instantiations = node_data.get('instantiations', ["TRUE", "FALSE"])
    true_state = instantiations[0] if len(instantiations) > 0 else "TRUE"
    false_state = instantiations[1] if len(instantiations) > 1 else "FALSE"

    # Create background color based on probability
    background_color = get_probability_color(priors)

    # Create tooltip with probability information
    tooltip = create_tooltip(node_id, node_data)

    # Create a simpler node label with probability
    simple_label = f"{node_id}\np={true_prob:.2f}"

```

```

# Store expanded content as a node attribute for use in click handler
node_data['expanded_content'] = create_expanded_content(node_id, node_data)

# Set node attributes
node['title'] = tooltip # Tooltip HTML
node['label'] = simple_label # Simple text label
node['shape'] = 'box'
node['color'] = {
    'background': background_color,
    'border': border_color,
    'highlight': {
        'background': background_color,
        'border': border_color
    }
}

# PHASE 5: Setup interactive click handling
# Prepare data for click handler
setup_data = {
    'nodes_data': {node_id: {
        'expanded_content': json.dumps(G.nodes[node_id].get('expanded_content', '')),
        'description': G.nodes[node_id].get('description', ''),
        'priors': G.nodes[node_id].get('priors', {}),
        'posteriors': G.nodes[node_id].get('posteriors', {})
    } for node_id in G.nodes()}
}

# JavaScript code for handling node clicks
click_js = """
// Store node data for click handling
var nodesData = %s;

// Add event listener for node clicks
network.on("click", function(params) {
    if (params.nodes.length > 0) {
        var nodeId = params.nodes[0];
        var nodeInfo = nodesData[nodeId];

        if (nodeInfo) {
            // Create a modal popup for expanded content
            var modal = document.createElement('div');
            modal.style.position = 'fixed';

```

```

        modal.style.left = '50%';
        modal.style.top = '50%';
        modal.style.transform = 'translate(-50%, -50%)';
        modal.style.backgroundColor = 'white';
        modal.style.padding = '20px';
        modal.style.borderRadius = '5px';
        modal.style.boxShadow = '0 0 10px rgba(0,0,0,0.5)';
        modal.style.zIndex = '1000';
        modal.style.maxWidth = '80%';
        modal.style.maxHeight = '80%';
        modal.style.overflow = 'auto';

        // Add expanded content
        modal.innerHTML = nodeInfo.expanded_content || 'No detailed information available';

        // Add close button
        var closeBtn = document.createElement('button');
        closeBtn.innerHTML = 'Close';
        closeBtn.style.marginTop = '10px';
        closeBtn.style.padding = '5px 10px';
        closeBtn.style.cursor = 'pointer';
        closeBtn.onclick = function() {
            document.body.removeChild(modal);
        };
        modal.appendChild(closeBtn);

        // Add modal to body
        document.body.appendChild(modal);
    }
}

});
""" % json.dumps(setup_data['nodes_data'])

# PHASE 6: Save the graph to HTML and inject custom click handling
html_file = "bayesian_network.html"
net.save_graph(html_file)

# Inject custom click handling into HTML
try:
    with open(html_file, "r") as f:
        html_content = f.read()

```

```

        # Insert click handling script before the closing body tag
        html_content = html_content.replace('</body>', f'<script>{click_js}</script></body>')

        # Write back the modified HTML
        with open(html_file, "w") as f:
            f.write(html_content)

        return HTML(html_content)
    except Exception as e:
        return HTML(f"<p>Error rendering HTML: {str(e)}</p>"
                    + "<p>The network visualization has been saved to '{html_file}'</p>")

```

## 4.2 Phase 2: Node Classification and Styling Module

```

# @title 4.2.0 --- Node Classification and Styling Functions --- [node_classification_and_styling]
"""
BLOCK PURPOSE: Implements the visual classification and styling of nodes in the Bayesian network.

This module handles the identification of node types based on their position in
the network and provides appropriate visual styling for each type.
The functions:

1. Classify nodes as parents (causes), children (intermediate effects), or leaves (final effects)
2. Assign appropriate border colors to visually distinguish node types
3. Calculate background colors based on probability values
4. Extract relevant information from DataFrame rows in a robust manner

The visual encoding helps users understand both the structure of the network
and the probability distributions at a glance.

DEPENDENCIES: colorsys for color manipulation
INPUTS: Graph structure and node data
OUTPUTS: Classification and styling information for visualization
"""

def classify_nodes(G):
    """
    Classify nodes as parent, child, or leaf based on network structure

    Args:

```

```

G (networkx.DiGraph): Directed graph representation of the Bayesian network

Effects:
    Adds 'node_type' attribute to each node in the graph:
    - 'parent': Root node with no parents but has children (causal source)
    - 'child': Node with both parents and children (intermediate)
    - 'leaf': Node with parents but no children (final effect)
    - 'isolated': Node with no connections (rare in Bayesian networks)
    """

for node in G.nodes():
    predecessors = list(G.predecessors(node)) # Nodes pointing to this one (causes)
    successors = list(G.successors(node))      # Nodes this one points to (effects)

    if not predecessors: # No parents
        if successors: # Has children
            G.nodes[node]['node_type'] = 'parent' # Root cause
        else: # No children either
            G.nodes[node]['node_type'] = 'isolated' # Disconnected node
    else: # Has parents
        if not successors: # No children
            G.nodes[node]['node_type'] = 'leaf' # Final effect
        else: # Has both parents and children
            G.nodes[node]['node_type'] = 'child' # Intermediate node

def get_border_color(node_type):
    """
    Return border color based on node type

    Args:
        node_type (str): Type of node ('parent', 'child', 'leaf', or 'isolated')

    Returns:
        str: Hex color code for node border
    """
    if node_type == 'parent':
        return '#0000FF' # Blue for root causes
    elif node_type == 'child':
        return '#800080' # Purple for intermediate nodes
    elif node_type == 'leaf':
        return '#FF00FF' # Magenta for final effects
    else:
        return '#000000' # Default black for any other type

```



```

def get_probability_color(priors):
    """
    Create background color based on probability (red to green gradient)

    Args:
        priors (dict): Dictionary containing probability information

    Returns:
        str: Hex color code for node background, ranging from red (low probability)
            to green (high probability)
    """
    # Default to neutral color if no probability
    if not priors or 'true_prob' not in priors:
        return '#F8F8F8' # Light grey

    # Get probability value
    prob = priors['true_prob']

    # Create color gradient from red (0.0) to green (1.0)
    hue = 120 * prob # 0 = red, 120 = green (in HSL color space)
    saturation = 0.75
    lightness = 0.8 # Lighter color for better text visibility

    # Convert HSL to RGB
    r, g, b = colorsys.hls_to_rgb(hue/360, lightness, saturation)

    # Convert to hex format
    hex_color = "#{:02x}{:02x}{:02x}".format(int(r*255), int(g*255), int(b*255))

    return hex_color

def get_parents(row):
    """
    Extract parent nodes from row data, with safe handling for different data types

    Args:
        row (pandas.Series): Row from DataFrame containing node information

    Returns:
        list: List of parent node names
    """

```

```

if 'Parents' not in row:
    return []

parents_data = row['Parents']

# Handle NaN, None, or empty list
if isinstance(parents_data, float) and pd.isna(parents_data):
    return []

if parents_data is None:
    return []

# Handle different data types
if isinstance(parents_data, list):
    # Return a list with NaN and empty strings removed
    return [p for p in parents_data if not (isinstance(p, float) and pd.isna(p)) and p != '']

if isinstance(parents_data, str):
    if not parents_data.strip():
        return []

    # Remove brackets and split by comma, removing empty strings and NaN
    cleaned = parents_data.strip('[]\''')
    if not cleaned:
        return []

    return [p.strip(' "') for p in cleaned.split(',') if p.strip()]

# Default: empty list
return []

def get_instantiations(row):
    """
    Extract instantiations with safe handling for different data types

    Args:
        row (pandas.Series): Row from DataFrame containing node information

    Returns:
        list: List of possible instantiations (states) for the node
    """
    if 'instantiations' not in row:

```

```

        return ["TRUE", "FALSE"]

    inst_data = row['instantiations']

    # Handle NaN or None
    if isinstance(inst_data, float) and pd.isna(inst_data):
        return ["TRUE", "FALSE"]

    if inst_data is None:
        return ["TRUE", "FALSE"]

    # Handle different data types
    if isinstance(inst_data, list):
        return inst_data if inst_data else ["TRUE", "FALSE"]

    if isinstance(inst_data, str):
        if not inst_data.strip():
            return ["TRUE", "FALSE"]

        # Remove brackets and split by comma
        cleaned = inst_data.strip('[]\''')
        if not cleaned:
            return ["TRUE", "FALSE"]

        return [i.strip(' "') for i in cleaned.split(',') if i.strip()]

    # Default
    return ["TRUE", "FALSE"]

def get_priors(row):
    """
    Extract prior probabilities with safe handling for different data types

    Args:
        row (pandas.Series): Row from DataFrame containing node information

    Returns:
        dict: Dictionary of prior probabilities with 'true_prob' added for convenience
    """
    if 'priors' not in row:
        return {}

```

```

priors_data = row['priors']

# Handle NaN or None
if isinstance(priors_data, float) and pd.isna(priors_data):
    return {}

if priors_data is None:
    return {}

result = {}

# Handle dictionary
if isinstance(priors_data, dict):
    result = priors_data
# Handle string representation of dictionary
elif isinstance(priors_data, str):
    if not priors_data.strip() or priors_data == '{}':
        return {}

    try:
        # Try to evaluate as Python literal
        import ast
        result = ast.literal_eval(priors_data)
    except:
        # Simple parsing for items like {'p(TRUE)': '0.2', 'p(FALSE)': '0.8'}
        if '{' in priors_data and '}' in priors_data:
            content = priors_data[priors_data.find('{')+1:priors_data.rfind('}')]
            items = [item.strip() for item in content.split(',')]

            for item in items:
                if ':' in item:
                    key, value = item.split(':', 1)
                    key = key.strip(' \\'')
                    value = value.strip(' \\'')
                    result[key] = value

# Extract main probability for TRUE state
instantiations = get_instantiations(row)
true_state = instantiations[0] if instantiations else "TRUE"
true_key = f"p({true_state})"

if true_key in result:

```

```

        try:
            result['true_prob'] = float(result[true_key])
        except:
            pass

    return result

def get_posteriors(row):
    """
    Extract posterior probabilities with safe handling for different data types

    Args:
        row (pandas.Series): Row from DataFrame containing node information

    Returns:
        dict: Dictionary of conditional probabilities
    """
    if 'posteriors' not in row:
        return {}

    posteriors_data = row['posteriors']

    # Handle NaN or None
    if isinstance(posteriors_data, float) and pd.isna(posteriors_data):
        return {}

    if posteriors_data is None:
        return {}

    result = {}

    # Handle dictionary
    if isinstance(posteriors_data, dict):
        result = posteriors_data
    # Handle string representation of dictionary
    elif isinstance(posteriors_data, str):
        if not posteriors_data.strip() or posteriors_data == '{}':
            return {}

    try:
        # Try to evaluate as Python literal
        import ast

```

```

        result = ast.literal_eval(posterior_data)
    except:
        # Simple parsing
        if '{' in posterior_data and '}' in posterior_data:
            content = posterior_data[posterior_data.find('{')+1:posterior_data.rfind('}')]
            items = [item.strip() for item in content.split(',')]

            for item in items:
                if ':' in item:
                    key, value = item.split(':', 1)
                    key = key.strip(' \\'')
                    value = value.strip(' \\'')
                    result[key] = value

    return result

```

### 4.3 Phase 3: HTML Content Generation Module

```

# @title 4.3.0 --- HTML Content Generation Functions --- [html_content_generation_functions]

"""
BLOCK PURPOSE: Creates rich HTML content for the interactive Bayesian network visualization.

This module generates the HTML components that enhance the Bayesian network
visualization:

1. Probability bars - Visual representation of probability distributions
2. Node tooltips - Rich information displayed on hover
3. Expanded content - Detailed probability information shown when clicking nodes

These HTML components make the mathematical concepts of Bayesian networks more
intuitive and accessible to users without requiring deep statistical knowledge.
The visual encoding of probabilities (colors, bars) and the progressive
disclosure of information (hover, click) help users build understanding at
their own pace.

DEPENDENCIES: HTML generation capabilities
INPUTS: Node data from the Bayesian network
OUTPUTS: HTML content for visualization components
"""

def create_probability_bar(true_prob, false_prob, height="15px", show_values=True, value_pre
    """

```

Creates a reusable HTML component to visualize probability distribution

Args:

true\_prob (float): Probability of the true state (0.0-1.0)  
 false\_prob (float): Probability of the false state (0.0-1.0)  
 height (str): CSS height of the bar  
 show\_values (bool): Whether to display numerical values  
 value\_prefix (str): Prefix to add before values (e.g., "p=")

Returns:

str: HTML for a horizontal bar showing probabilities

"""

# Prepare display labels if showing values

true\_label = f"{value\_prefix}{true\_prob:.3f}" if show\_values else ""

false\_label = f"{value\_prefix}{false\_prob:.3f}" if show\_values else ""

# Create the HTML for a horizontal stacked bar

html = f"""

<div style="width:100%; height:{height}; display:flex; border:1px solid #ccc; overflow:h

<div style="flex-basis:{true\_prob\*100}%; background:linear-gradient(to bottom, rgba

<span style="font-size:10px; color:white; text-shadow:0px 0px 2px #000;">{true\_l

</div>

<div style="flex-basis:{false\_prob\*100}%; background:linear-gradient(to bottom, rgba

<span style="font-size:10px; color:white; text-shadow:0px 0px 2px #000;">{false\_

</div>

</div>

"""

return html

def create\_tooltip(node\_id, node\_data):

"""

Create rich HTML tooltip with probability information

Args:

node\_id (str): Identifier of the node

node\_data (dict): Node attributes including probabilities

Returns:

str: HTML content for tooltip displayed on hover

"""

# Extract node information

description = node\_data.get('description', '')

```

priors = node_data.get('priors', {})
instantiations = node_data.get('instantiations', ["TRUE", "FALSE"])

# Start building the HTML tooltip
html = f"""
<div style="max-width:350px; padding:10px; background-color:#f8f9fa; border-radius:5px;
    <h3 style="margin-top:0; color:#202124;">{node_id}</h3>
    <p style="font-style:italic;">{description}</p>
    """

# Add prior probabilities section
if priors and 'true_prob' in priors:
    true_prob = priors['true_prob']
    false_prob = 1.0 - true_prob

    # Get proper state names
    true_state = instantiations[0] if len(instantiations) > 0 else "TRUE"
    false_state = instantiations[1] if len(instantiations) > 1 else "FALSE"

    html += f"""
    <div style="margin-top:10px; background-color:#fff; padding:8px; border-radius:4px;
        <h4 style="margin-top:0; font-size:14px;">Prior Probabilities:</h4>
        <div style="display:flex; justify-content:space-between; margin-bottom:4px;">
            <div style="font-size:12px;">{true_state}: {true_prob:.3f}</div>
            <div style="font-size:12px;">{false_state}: {false_prob:.3f}</div>
        </div>
        {create_probability_bar(true_prob, false_prob, "20px", True)}
    </div>
    """

# Add click instruction
html += """
<div style="margin-top:8px; font-size:12px; color:#666; text-align:center;">
    Click node to see full probability details
</div>
</div>
    """

return html

def create_expanded_content(node_id, node_data):
    """

```



Create expanded content shown when a node is clicked

Args:

node\_id (str): Identifier of the node  
 node\_data (dict): Node attributes including probabilities

Returns:

str: HTML content for detailed view displayed on click

"""

# Extract node information

```
description = node_data.get('description', '')
priors = node_data.get('priors', {})
posteriors = node_data.get('posteriors', {})
instantiations = node_data.get('instantiations', ["TRUE", "FALSE"])
```

# Get proper state names

```
true_state = instantiations[0] if len(instantiations) > 0 else "TRUE"
false_state = instantiations[1] if len(instantiations) > 1 else "FALSE"
```

# Extract probabilities

```
true_prob = priors.get('true_prob', 0.5)
false_prob = 1.0 - true_prob
```

# Start building the expanded content

html = f"""

```
<div style="max-width:500px; padding:15px; font-family:Arial, sans-serif;">
  <h2 style="margin-top:0; color:#333;">{node_id}</h2>
  <p style="font-style:italic; margin-bottom:15px;">{description}</p>
```

```
  <div style="margin-bottom:20px; padding:12px; border:1px solid #ddd; background-color:#f9f9f9;">
```

```
    <h3 style="margin-top:0; color:#333;">Prior Probabilities</h3>
```

```
    <div style="display:flex; justify-content:space-between; margin-bottom:5px;">
```

```
      <div><strong>{true_state}</strong> {true_prob:.3f}</div>
```

```
      <div><strong>{false_state}</strong> {false_prob:.3f}</div>
```

```
    </div>
```

```
    {create_probability_bar(true_prob, false_prob, "25px", True)}
```

```
  </div>
```

"""

# Add conditional probability table if available

if posteriors:

```
  html += """
```

```

<div style="padding:12px; border:1px solid #ddd; background-color:#f9f9f9; border-ra
    <h3 style="margin-top:0; color:#333;">Conditional Probabilities</h3>
    <table style="width:100%; border-collapse:collapse; font-size:13px;">
        <tr style="background-color:#eee;">
            <th style="padding:8px; text-align:left; border:1px solid #ddd;">Conditio
            <th style="padding:8px; text-align:center; border:1px solid #ddd; width:
            <th style="padding:8px; text-align:center; border:1px solid #ddd;">Visua
        </tr>
    </table>
    """

# Sort posteriors to group by similar conditions
posterior_items = list(posteriors.items())
posterior_items.sort(key=lambda x: x[0])

# Add rows for conditional probabilities
for key, value in posterior_items:
    try:
        # Try to parse probability value
        prob_value = float(value)
        inv_prob = 1.0 - prob_value

        # Add row with probability visualization
        html += f"""
        <tr>
            <td style="padding:8px; border:1px solid #ddd;">{key}</td>
            <td style="padding:8px; text-align:center; border:1px solid #ddd;">{prob
            <td style="padding:8px; border:1px solid #ddd;">
                {create_probability_bar(prob_value, inv_prob, "20px", False)}
            </td>
        </tr>
        """
    except:
        # Fallback for non-numeric values
        html += f"""
        <tr>
            <td style="padding:8px; border:1px solid #ddd;">{key}</td>
            <td style="padding:8px; text-align:center; border:1px solid #ddd;" colspan=
        </tr>
        """

html += """
</table>

```

```

        </div>
        """

    html += "</div>"

    return html

```

## 4.4 Phase 4: Main Visualization Function

```

# @title 4.4.0 --- Main Visualization Function --- [main_visualization_function]

def create_bayesian_network_with_probabilities(df):
    """
    Create an interactive Bayesian network visualization with enhanced
    probability visualization and node classification based on network structure.
    """
    # Create a directed graph
    G = nx.DiGraph()

    # Add nodes with proper attributes
    for idx, row in df.iterrows():
        title = row['Title']
        description = row['Description']

        # Process probability information
        priors = get_priors(row)
        instantiations = get_instantiations(row)

        # Add node with base information
        G.add_node(
            title,
            description=description,
            priors=priors,
            instantiations=instantiations,
            posteriors=get_posteriors(row)
        )

    # Add edges
    for idx, row in df.iterrows():
        child = row['Title']
        parents = get_parents(row)

```

```

    # Add edges from each parent to this child
    for parent in parents:
        if parent in G.nodes():
            G.add_edge(parent, child)

# Classify nodes based on network structure
classify_nodes(G)

# Create network visualization
net = Network(notebook=True, directed=True, cdn_resources="in_line", height="600px", width="1000px")

# Configure physics for better layout
net.force_atlas_2based(gravity=-50, spring_length=100, spring_strength=0.02)
net.show_buttons(filter_=['physics'])

# Add the graph to the network
net.from_nx(G)

# Enhance node appearance with probability information and classification
for node in net.nodes:
    node_id = node['id']
    node_data = G.nodes[node_id]

    # Get node type and set border color
    node_type = node_data.get('node_type', 'unknown')
    border_color = get_border_color(node_type)

    # Get probability information
    priors = node_data.get('priors', {})
    true_prob = priors.get('true_prob', 0.5) if priors else 0.5

    # Get proper state names
    instantiations = node_data.get('instantiations', ["TRUE", "FALSE"])
    true_state = instantiations[0] if len(instantiations) > 0 else "TRUE"
    false_state = instantiations[1] if len(instantiations) > 1 else "FALSE"

    # Create background color based on probability
    background_color = get_probability_color(priors)

    # Create tooltip with probability information
    tooltip = create_tooltip(node_id, node_data)

```

```

# Create a simpler node label with probability
simple_label = f"{node_id}\np={true_prob:.2f}"

# Store expanded content as a node attribute for use in click handler
node_data['expanded_content'] = create_expanded_content(node_id, node_data)

# Set node attributes
node['title'] = tooltip # Tooltip HTML
node['label'] = simple_label # Simple text label
node['shape'] = 'box'
node['color'] = {
    'background': background_color,
    'border': border_color,
    'highlight': {
        'background': background_color,
        'border': border_color
    }
}

# Set up the click handler with proper data
setup_data = {
    'nodes_data': {node_id: {
        'expanded_content': json.dumps(G.nodes[node_id].get('expanded_content', '')),
        'description': G.nodes[node_id].get('description', ''),
        'priors': G.nodes[node_id].get('priors', {}),
        'posteriors': G.nodes[node_id].get('posteriors', {})
    } for node_id in G.nodes()}
}

# Add custom click handling JavaScript
click_js = """
// Store node data for click handling
var nodesData = %s;

// Add event listener for node clicks
network.on("click", function(params) {
    if (params.nodes.length > 0) {
        var nodeId = params.nodes[0];
        var nodeInfo = nodesData[nodeId];

        if (nodeInfo) {
            // Create a modal popup for expanded content

```

```

        var modal = document.createElement('div');
        modal.style.position = 'fixed';
        modal.style.left = '50%%';
        modal.style.top = '50%%';
        modal.style.transform = 'translate(-50%, -50%)';
        modal.style.backgroundColor = 'white';
        modal.style.padding = '20px';
        modal.style.borderRadius = '5px';
        modal.style.boxShadow = '0 0 10px rgba(0,0,0,0.5)';
        modal.style.zIndex = '1000';
        modal.style.maxWidth = '80%%';
        modal.style.maxHeight = '80%%';
        modal.style.overflow = 'auto';

        // Parse the JSON string back to HTML content
        try {
            var expandedContent = JSON.parse(nodeInfo.expanded_content);
            modal.innerHTML = expandedContent;
        } catch (e) {
            modal.innerHTML = 'Error displaying content: ' + e.message;
        }

        // Add close button
        var closeBtn = document.createElement('button');
        closeBtn.innerHTML = 'Close';
        closeBtn.style.marginTop = '10px';
        closeBtn.style.padding = '5px 10px';
        closeBtn.style.cursor = 'pointer';
        closeBtn.onclick = function() {
            document.body.removeChild(modal);
        };
        modal.appendChild(closeBtn);

        // Add modal to body
        document.body.appendChild(modal);
    }
}

});
""" % json.dumps(setup_data['nodes_data'])

# Save the graph to HTML
html_file = "bayesian_network.html"

```

```
net.save_graph(html_file)

# Inject custom click handling into HTML
try:
    with open(html_file, "r") as f:
        html_content = f.read()

    # Insert click handling script before the closing body tag
    html_content = html_content.replace('</body>', f'<script>{click_js}</script></body>')

    # Write back the modified HTML
    with open(html_file, "w") as f:
        f.write(html_content)

    return HTML(html_content)
except Exception as e:
    return HTML(f"<p>Error rendering HTML: {str(e)}</p>"
               + "<p>The network visualization has been saved to '{html_file}'</p>")
```





## 5 Quick check HTML Outputs

```
# @title 5.0 --- Quick check HTML Outputs--- [html_graph_visualization]

create_bayesian_network_with_probabilities(result_df)
```

Quick check HTML Outputs

```
# Use the function to create and display the visualization

print(result_df)
```

	Title \
0	Existential_Catastrophe
1	Human_Disempowerment
2	Scale_Of_Power_Seeking
3	Misaligned_Power_Seeking
4	APS_Systems
5	Advanced_AI_Capability
6	Agentic_Planning
7	Strategic_Awareness
8	Difficulty_Of_Alignment
9	Instrumental_Convergence
10	Problems_With_Proxies
11	Problems_With_Search
12	Deployment_Decisions
13	Incentives_To_Build_APS
14	Usefulness_Of_APS
15	Competitive_Dynamics
16	Deception_By_AI
17	Corrective_Feedback
18	Warning_Shots
19	Rapid_Capability_Escalation
20	Barriers_To_Understanding
21	Adversarial_Dynamics
22	Stakes_Of_Error

	Description	line	line_numbers \
0	The destruction of humanity's long-term potent...	0	[0]
1	Permanent and collective disempowerment of hum...	1	[1]
2	Power-seeking by AI systems scaling to the poi...	2	[2]
3	Deployed AI systems seeking power in unintende...	3	[3, 21, 23, 25]
4	AI systems with advanced capabilities, agentic...	4	[4]
5	AI systems that outperform humans on tasks tha...	5	[5]
6	AI systems making and executing plans based on...	6	[6]
7	AI systems with models accurately representing...	7	[7]
8	It is harder to build aligned systems than mis...	8	[8]
9	AI systems with misaligned objectives tend to ...	9	[9]
10	Optimizing for proxy objectives breaks correla...	10	[10]
11	Search processes can yield systems pursuing di...	11	[11]
12	Decisions to deploy potentially misaligned AI ...	12	[12]
13	Strong incentives to build and deploy APS syst...	13	[13]
14	APS systems are very useful for many valuable ...	14	[14]
15	Competitive pressures between AI developers.	15	[15]
16	AI systems deceiving humans about their true o...	16	[16]
17	Human society implementing corrections after o...	17	[17]
18	Observable failures in weaker systems before c...	18	[18]
19	AI capabilities escalating very rapidly, allow...	19	[19]
20	Difficulty in understanding the internal worki...	20	[20]
21	Potentially adversarial relationships between ...	22	[22]
22	The escalating impact of mistakes with power-s...	24	[24]

	indentation	indentation_levels \
0	0	[0]
1	0	[0]
2	4	[4]
3	8	[8, 0, 0, 0]
4	12	[12]
5	16	[16]
6	16	[16]
7	16	[16]
8	12	[12]
9	16	[16]
10	16	[16]
11	16	[16]
12	12	[12]
13	16	[16]
14	20	[20]

15	20	[20]
16	16	[16]
17	8	[8]
18	12	[12]
19	12	[12]
20	0	[0]
21	0	[0]
22	0	[0]

	Parents \
0	[]
1	[Scale_Of_Power_Seeking]
2	[Misaligned_Power_Seeking, Corrective_Feedback]
3	[APS_Systems, Difficulty_Of_Alignment, Deploym...
4	[Advanced_AI_Capability, Agentic_Planning, Str...
5	[]
6	[]
7	[]
8	[Instrumental_Convergence, Problems_With_Proxi...
9	[]
10	[]
11	[]
12	[Incentives_To_Build_APS, Deception_By_AI]
13	[Usefulness_Of_APS, Competitive_Dynamics]
14	[]
15	[]
16	[]
17	[Warning_Shots, Rapid_Capability_Escalation]
18	[]
19	[]
20	[]
21	[]
22	[]

	Children \
0	[]
1	[]
2	[Human_Disempowerment]
3	[Scale_Of_Power_Seeking]
4	[Misaligned_Power_Seeking]
5	[APS_Systems]
6	[APS_Systems]

```

7             [APS_Systems]
8  [Misaligned_Power_Seeking]
9    [Difficulty_Of_Alignment]
10   [Difficulty_Of_Alignment]
11   [Difficulty_Of_Alignment]
12  [Misaligned_Power_Seeking]
13    [Deployment_Decisions]
14   [Incentives_To_Build_APS]
15   [Incentives_To_Build_APS]
16    [Deployment_Decisions]
17   [Scale_Of_Power_Seeking]
18    [Corrective_Feedback]
19    [Corrective_Feedback]
20
21
22

```

```

                                instantiations \
0  [existential_catastrophe_TRUE, existential_cat...
1  [human_disempowerment_TRUE, human_disempowerme...
2  [scale_of_power_seeking_TRUE, scale_of_power_s...
3  [misaligned_power_seeking_TRUE, misaligned_pow...
4      [aps_systems_TRUE, aps_systems_FALSE]
5  [advanced_ai_capability_TRUE, advanced_ai_capa...
6      [agentic_planning_TRUE, agentic_planning_FALSE]
7  [strategic_awareness_TRUE, strategic_awareness...
8  [difficulty_of_alignment_TRUE, difficulty_of_a...
9  [instrumental_convergence_TRUE, instrumental_c...
10 [problems_with_proxies_TRUE, problems_with_pro...
11 [problems_with_search_TRUE, problems_with_sear...
12 [deployment_decisions_DEPLOY, deployment_decis...
13 [incentives_to_build_aps_STRONG, incentives_to...
14     [usefulness_of_aps_HIGH, usefulness_of_aps_LOW]
15 [competitive_dynamics_STRONG, competitive_dyna...
16     [deception_by_ai_TRUE, deception_by_ai_FALSE]
17 [corrective_feedback_EFFECTIVE, corrective_fee...
18 [warning_shots_OBSERVED, warning_shots_UNOBSER...
19 [rapid_capability_escalation_TRUE, rapid_capab...
20 [barriers_to_understanding_HIGH, barriers_to_u...
21 [adversarial_dynamics_TRUE, adversarial_dynami...
22     [stakes_of_error_HIGH, stakes_of_error_LOW]

```

```

                                priors \
0  {'p(existential_catastrophe_TRUE)': '0.05', 'p...
1  {'p(human_disempowerment_TRUE)': '0.208', 'p(h...
2  {'p(scale_of_power_seeking_TRUE)': '0.208', 'p...
3  {'p(misaligned_power_seeking_TRUE)': '0.338', ...
4  {'p(aps_systems_TRUE)': '0.65', 'p(aps_systems...
5  {'p(advanced_ai_capability_TRUE)': '0.80', 'p(...
6  {'p(agentive_planning_TRUE)': '0.85', 'p(agenti...
7  {'p(strategic_awareness_TRUE)': '0.75', 'p(str...
8  {'p(difficulty_of_alignment_TRUE)': '0.40', 'p...
9  {'p(instrumental_convergence_TRUE)': '0.75', '...
10 {'p(problems_with_proxies_TRUE)': '0.80', 'p(p...
11 {'p(problems_with_search_TRUE)': '0.70', 'p(pr...
12 {'p(deployment_decisions_DEPLOY)': '0.70', 'p(...
13 {'p(incentives_to_build_aps_STRONG)': '0.80', ...
14 {'p(usefulness_of_aps_HIGH)': '0.85', 'p(usefu...
15 {'p(competitive_dynamics_STRONG)': '0.75', 'p(...
16 {'p(deception_by_ai_TRUE)': '0.50', 'p(decepti...
17 {'p(corrective_feedback_EFFECTIVE)': '0.60', '...
18 {'p(warning_shots_OBSERVED)': '0.70', 'p(warni...
19 {'p(rapid_capability_escalation_TRUE)': '0.45'...
20 {'p(barriers_to_understanding_HIGH)': '0.70', ...
21 {'p(adversarial_dynamics_TRUE)': '0.60', 'p(ad...
22 {'p(stakes_of_error_HIGH)': '0.85', 'p(stakes_...

```

```

                                posteriors  No_Parent  No_Children \
0  {'p(existential_catastrophe_TRUE|human_disempo...      True      True
1  {'p(human_disempowerment_TRUE|scale_of_power_s...     False      True
2  {'p(scale_of_power_seeking_TRUE|misaligned_pow...     False     False
3  {'p(misaligned_power_seeking_TRUE|aps_systems_...     False     False
4  {'p(aps_systems_TRUE|advanced_ai_capability_TR...     False     False
5                                     {}           True     False
6                                     {}           True     False
7                                     {}           True     False
8  {'p(difficulty_of_alignment_TRUE|instrumental_...     False     False
9                                     {}           True     False
10                                    {}           True     False
11                                    {}           True     False
12 {'p(deployment_decisions_DEPLOY|incentives_to_...     False     False
13 {'p(incentives_to_build_aps_STRONG|usefulness_...     False     False
14                                    {}           True     False
15                                    {}           True     False

```

16	{}	True	False
17	{'p(corrective_feedback_EFFECTIVE warning_shot...	False	False
18	{}	True	False
19	{}	True	False
20	{'p(barriers_to_understanding_HIGH misaligned...	True	True
21	{'p(adversarial_dynamics_TRUE misaligned_power...	True	True
22	{'p(stakes_of_error_HIGH misaligned_power_seek...	True	True

```

                                parent_instantiations
0                                []
1  [[scale_of_power_seeking_TRUE, scale_of_power_...
2  [[misaligned_power_seeking_TRUE, misaligned_po...
3  [[aps_systems_TRUE, aps_systems_FALSE], [diffi...
4  [[advanced_ai_capability_TRUE, advanced_ai_cap...
5                                []
6                                []
7                                []
8  [[instrumental_convergence_TRUE, instrumental_...
9                                []
10                               []
11                               []
12  [[incentives_to_build_aps_STRONG, incentives_t...
13  [[usefulness_of_aps_HIGH, usefulness_of_aps_LO...
14                               []
15                               []
16                               []
17  [[warning_shots_OBSERVED, warning_shots_UNOBSE...
18                               []
19                               []
20                               []
21                               []
22                               []

```

```
# @title 5.1 --- File Import --- Load Files [file_import]
```

```

import requests
import io
from IPython.display import HTML, display

def load_and_display_html_from_github(repo_url, relative_path):
    """
    Loads an HTML file from a public GitHub repository and displays it.

```

```
Args:
    repo_url (str): The base URL of the GitHub repository (raw content).
    relative_path (str): The path to the HTML file relative to the repo_url.
"""
file_url = f"{repo_url}/{relative_path}"
print(f"Attempting to load HTML from: {file_url}")

try:
    # Fetch the file content from GitHub
    response = requests.get(file_url)

    # Check for successful response
    response.raise_for_status()

    # Read the content
    html_content = io.StringIO(response.text).read()

    print(f" Successfully loaded {relative_path}.")

    # Render the HTML content directly in the notebook
    display(HTML(html_content))

except requests.exceptions.RequestException as e:
    print(f" Error loading HTML file: {e}")
    print("Please check the URL and your internet connection.")
except Exception as e:
    print(f" An unexpected error occurred: {e}")

# Specify the base repository URL and the relative path to the HTML file
repo_base_url = "https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main/data"
html_relative_path = "runtime_created_data/bayesian_network.html"

# Load and display the HTML file
load_and_display_html_from_github(repo_base_url, html_relative_path)
```

```
Attempting to load HTML from: https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main/data
Successfully loaded runtime_created_data/bayesian_network.html.
```

File Import

```
# @title 5.2 --- File Import --- Load Files [file_import2]

import requests
import io
```

```

from IPython.display import HTML, display

def load_and_display_html_from_github(repo_url, relative_path):
    """
    Loads an HTML file from a public GitHub repository and displays it.

    Args:
        repo_url (str): The base URL of the GitHub repository (raw content).
        relative_path (str): The path to the HTML file relative to the repo_url.
    """
    file_url = f"{repo_url}/{relative_path}"
    print(f"Attempting to load HTML from: {file_url}")

    try:
        # Fetch the file content from GitHub
        response = requests.get(file_url)

        # Check for successful response
        response.raise_for_status()

        # Read the content
        html_content = io.StringIO(response.text).read()

        print(f" Successfully loaded {relative_path}.")

        # Render the HTML content directly in the notebook
        display(HTML(html_content))

    except requests.exceptions.RequestException as e:
        print(f" Error loading HTML file: {e}")
        print("Please check the URL and your internet connection.")
    except Exception as e:
        print(f" An unexpected error occurred: {e}")

# Specify the base repository URL and the relative path to the HTML file
repo_base_url = "https://raw.githubusercontent.com/VJMeyer/submission/refs/heads/main/AMTAIF"
html_relative_path = "runtime_created_data/bayesian_network.html"

# Load and display the HTML file
load_and_display_html_from_github(repo_base_url, html_relative_path)

```

Attempting to load HTML from: [https://raw.githubusercontent.com/VJMeyer/submission/refs/heads/main/AMTAIF/runtime\\_created\\_data/bayesian\\_network.html](https://raw.githubusercontent.com/VJMeyer/submission/refs/heads/main/AMTAIF/runtime_created_data/bayesian_network.html)



Successfully loaded runtime\_created\_data/bayesian\_network.html.

File Import 2

```
from IPython.display import IFrame
```

```
IFrame(src="https://singularitysmith.github.io/AMTAIR_Prototype/bayesian_network_carlsmith.h
```

```
<IPython.lib.display.IFrame at 0x7f04d69f0d90>
```

Dynamic Html Rendering of the Carlsmith Bayesian Network/DAG Visualization



# Conclusion: From Prototype to Production

## Summary of Achievements

This notebook has successfully demonstrated the core AMTAIR extraction pipeline, transforming structured argument representations into interactive Bayesian network visualizations through the following steps:

1. **Environment Setup:** Established a reproducible environment with necessary libraries and data access
2. **Argument Extraction:** Processed structured ArgDown representations preserving the hierarchical relationships
3. **Probability Integration:** Enhanced arguments with probability information to create BayesDown
4. **Data Transformation:** Converted BayesDown into structured DataFrame representation
5. **Visualization & Analysis:** Created interactive Bayesian network visualizations with probability encoding

The rain-sprinkler-lawn example, though simple, demonstrates all the key components of the extraction pipeline that can be applied to more complex AI safety arguments.

## Limitations and Future Work

While this prototype successfully demonstrates the core pipeline, several limitations and opportunities for future work remain:

1. **LLM Extraction:** The current implementation focuses on processing pre-formatted ArgDown rather than performing extraction directly from unstructured text. Future work will integrate LLM-powered extraction.
2. **Scalability:** The system has been tested on small examples; scaling to larger, more complex arguments will require additional optimization and handling of computational complexity.
3. **Policy Evaluation:** The current implementation focuses on representation and visual-

ization; future work will add policy evaluation capabilities by implementing intervention modeling.

4. **Prediction Market Integration:** Future versions will integrate with forecasting platforms to incorporate live data into the models.

## Connection to AMTAIR Project

This prototype represents just one component of the broader AMTAIR project described in the project documentation (see PY\_AMTAIRDescription and PY\_AMTAIR\_SoftwareToolsNMilestones). The full project includes:

1. **AI Risk Pathway Analyzer (ARPA):** The core extraction and visualization system demonstrated in this notebook
2. **Worldview Comparator:** Tools for comparing different perspectives on AI risk
3. **Policy Impact Evaluator:** Systems for evaluating intervention effects across scenarios
4. **Strategic Intervention Generator:** Tools for identifying robust governance strategies

Together, these components aim to address the coordination crisis in AI governance by providing computational tools that make implicit models explicit, identify cruxes of disagreement, and evaluate policy impacts across diverse worldviews.

By transforming unstructured text into formal, analyzable representations, the AMTAIR project helps bridge the gaps between technical researchers, policy specialists, and other stakeholders, enabling more effective coordination in addressing existential risks from advanced AI.

# 6 Save Outputs

## 6.0 Saving and Exporting Results

This section provides tools for saving the notebook results and visualizations in various formats:

1. **HTML Export:** Creates a self-contained HTML version of the notebook with all visualizations
2. **Markdown Export:** Generates documentation-friendly Markdown version of the notebook
3. **PDF Export:** Creates a PDF document for formal sharing (requires LaTeX installation)

These exports are essential for: - Sharing analysis results with colleagues and stakeholders - Including visualizations in presentations and reports - Creating documentation for the AMTAIR project - Preserving results for future reference

The different formats serve different purposes, from interactive exploration (HTML) to documentation (Markdown) to formal presentation (PDF).

Instruction:

Download the ipynb, which you want to convert, on your local computer. Run the code below to upload the ipynb.

The html version will be downloaded automatically on your local machine. Enjoy it!

```
# @title 6.0.0 --- Save Visualization and Notebook Outputs as .HTML--- [save_visualization_a

"""
BLOCK PURPOSE: Provides tools for saving the notebook results in various formats.

This block offers functions to:
1. Convert the notebook to HTML for easy sharing and viewing
2. Convert the notebook to Markdown for documentation purposes
3. Save the visualization outputs for external use

These tools are essential for preserving the analysis results and making them
accessible outside the notebook environment, supporting knowledge transfer
and integration with other AMTAIR project components.
```

```

DEPENDENCIES: nbformat, nbconvert modules
INPUTS: Current notebook state
OUTPUTS: HTML, Markdown, or other format versions of the notebook
"""

import nbformat
from nbconvert import HTMLExporter
import os

# Repository URL variable for file access
repo_url = "https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main/data/example_notebook.ipynb"
notebook_name = "AMTAIR_Prototype_example_carlsmith" # Change when working with different example notebooks

# Download the notebook file
!wget {repo_url}{notebook_name}.ipynb -O {notebook_name}.ipynb

# Load the notebook
try:
    with open(f"{notebook_name}.ipynb") as f:
        nb = nbformat.read(f, as_version=4)
        print(f" Successfully loaded notebook: {notebook_name}.ipynb")
except FileNotFoundError:
    print(f" Error: File '{notebook_name}.ipynb' not found. Please check if it was downloaded correctly.")

# Initialize the HTML exporter
exporter = HTMLExporter()

# Convert the notebook to HTML
try:
    (body, resources) = exporter.from_notebook_node(nb)

    # Save the HTML to a file
    with open(f"{notebook_name}IPYNB.html", "w") as f:
        f.write(body)
    print(f" Successfully saved HTML version to: {notebook_name}IPYNB.html")
except Exception as e:
    print(f" Error converting notebook to HTML: {str(e)}")

```

```

--2025-05-24 20:09:38--  https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main/data/example_notebook.ipynb
Resolving raw.githubusercontent.com (raw.githubusercontent.com)... 185.199.108.133, 185.199.108.133, 185.199.108.133, 185.199.108.133
Connecting to raw.githubusercontent.com (raw.githubusercontent.com)|185.199.108.133|:443...
HTTP request sent, awaiting response... 200 OK

```

Length: 1689816 (1.6M) [text/plain]

Saving to: 'AMTAIR\_Prototype\_example\_carlsmith.ipynb'

AMTAIR\_Prototype\_ex 100%[=====>] 1.61M 6.36MB/s in 0.3s

2025-05-24 20:09:38 (6.36 MB/s) - 'AMTAIR\_Prototype\_example\_carlsmith.ipynb' saved [1689816/

Successfully loaded notebook: AMTAIR\_Prototype\_example\_carlsmith.ipynb

Successfully saved HTML version to: AMTAIR\_Prototype\_example\_carlsmithIPYNB.html

## 6.1 Convert .ipynb Notebook to Markdown

```
# @title 6.1.0 --- Convert .ipynb Notebook to Markdown --- [convert_notebook_to_markdown]

import nbformat
from nbconvert import MarkdownExporter
import os

# repo_url = "https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main/data/"
notebook_name = "AMTAIR_Prototype_example_carlsmith" #Change Notebook name and path when wo

# Download the notebook file
!wget {repo_url}{notebook_name}.ipynb -O {notebook_name}.ipynb # Corrected line

# Load the notebook
# add error handling for file not found
try:
    with open(f"{notebook_name}.ipynb") as f:
        nb = nbformat.read(f, as_version=4)
except FileNotFoundError:
    print(f"Error: File '{notebook_name}.ipynb' not found. Please check if it was downloaded c

# Initialize the Markdown exporter
exporter = MarkdownExporter(exclude_output=True) # Correct initialization

# Convert the notebook to Markdown
(body, resources) = exporter.from_notebook_node(nb)

# Save the Markdown to a file
with open(f"{notebook_name}IPYNB.md", "w") as f:
    f.write(body)
```

```
--2025-05-24 20:09:47-- https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype
Resolving raw.githubusercontent.com (raw.githubusercontent.com)... 185.199.108.133, 185.199.
Connecting to raw.githubusercontent.com (raw.githubusercontent.com)|185.199.108.133|:443...
HTTP request sent, awaiting response... 200 OK
Length: 1689816 (1.6M) [text/plain]
Saving to: 'AMTAIR_Prototype_example_carlsmith.ipynb'
```

```
AMTAIR_Prototype_ex 100%[=====>] 1.61M 5.38MB/s in 0.3s
```

```
2025-05-24 20:09:48 (5.38 MB/s) - 'AMTAIR_Prototype_example_carlsmith.ipynb' saved [1689816/
```

## 6.2 Convert Notebook to Markdown Documentation

```
# @title 6.2.0 --- Convert Notebook to Markdown Documentation --- [convert_notebook_to_markdown]

"""
BLOCK PURPOSE: Converts the notebook to Markdown format for documentation purposes.

Markdown is a lightweight markup language that is widely used for documentation
and is easily readable in both plain text and rendered formats. This conversion:

1. Preserves the structure and content of the notebook
2. Creates a format suitable for inclusion in documentation systems
3. Excludes code outputs to focus on the process and methodology
4. Supports version control and collaboration on GitHub

The resulting Markdown file can be used in project documentation, GitHub wikis,
or as a standalone reference guide to the AMTAIR extraction pipeline.

DEPENDENCIES: nbformat, nbconvert.MarkdownExporter modules
INPUTS: Current notebook state
OUTPUTS: Markdown version of the notebook
"""

import nbformat
from nbconvert import MarkdownExporter
import os

# Repository URL variable for file access
# repo_url = "https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main/data/"
notebook_name = "AMTAIR_Prototype_example_carlsmith" # Change when working with different e
```



```

# Download the notebook file
!wget {repo_url}{notebook_name}.ipynb -O {notebook_name}.ipynb

# Load the notebook
try:
    with open(f"{notebook_name}.ipynb") as f:
        nb = nbformat.read(f, as_version=4)
        print(f" Successfully loaded notebook: {notebook_name}.ipynb")
except FileNotFoundError:
    print(f" Error: File '{notebook_name}.ipynb' not found. Please check "
          + "if it was downloaded correctly.")

# Initialize the Markdown exporter
exporter = MarkdownExporter(exclude_output=True) # Exclude outputs for cleaner documentation

# Convert the notebook to Markdown
try:
    (body, resources) = exporter.from_notebook_node(nb)

    # Save the Markdown to a file
    with open(f"{notebook_name}IPYNB.md", "w") as f:
        f.write(body)
    print(f" Successfully saved Markdown version to: {notebook_name}IPYNB.md")
except Exception as e:
    print(f" Error converting notebook to Markdown: {str(e)}")

```

```

--2025-05-24 20:09:53--  https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype
Resolving raw.githubusercontent.com (raw.githubusercontent.com)... 185.199.108.133, 185.199.
Connecting to raw.githubusercontent.com (raw.githubusercontent.com)|185.199.108.133|:443...
HTTP request sent, awaiting response... 200 OK
Length: 1689816 (1.6M) [text/plain]
Saving to: 'AMTAIR_Prototype_example_carlsmith.ipynb'

```

```

AMTAIR_Prototype_ex 100%[=====>]    1.61M  5.78MB/s    in 0.3s

```

```

2025-05-24 20:09:53 (5.78 MB/s) - 'AMTAIR_Prototype_example_carlsmith.ipynb' saved [1689816/

```

```

Successfully loaded notebook: AMTAIR_Prototype_example_carlsmith.ipynb

```

```

Successfully saved Markdown version to: AMTAIR_Prototype_example_carlsmithIPYNB.md

```

## 6.3 Create PDF and Latex

```
# @title 6.3.0 --- PDF and Latex--- [pdf_and_latex]

import nbformat
from nbconvert import PDFExporter
import os
import subprocess
import re

def escape_latex_special_chars(text):
    """Escapes special LaTeX characters in a string."""
    latex_special_chars = ['&', '%', '#', '_', '{', '}', '~', '^', '\\']
    replacement_patterns = [
        (char, '\\' + char) for char in latex_special_chars
    ]

    # Escape reserved characters
    for original, replacement in replacement_patterns:
        text = text.replace(original, replacement) # This is the fix
    return text

# Function to check if a command is available
def is_command_available(command):
    try:
        subprocess.run([command], capture_output=True, check=True)
        return True
    except (subprocess.CalledProcessError, FileNotFoundError):
        return False

# Check if xelatex is installed, and install if necessary
if not is_command_available("xelatex"):
    print("Installing necessary TeX packages...")
    !apt-get install -y texlive-xetex texlive-fonts-recommended texlive-plain-generic
    print("TeX packages installed successfully.")
else:
    print("xelatex is already installed. Skipping installation.")

# repo_url = "https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype/main/data/
notebook_name = "AMTAIR_Prototype_example_carlsmith" # Change Notebook name
# and path when working on different examples
```

```

# Download the notebook file
!wget {repo_url}{notebook_name}.ipynb -O {notebook_name}.ipynb # Corrected line

# Load the notebook
# add error handling for file not found
try:
    with open(f"{notebook_name}.ipynb") as f:
        nb = nbformat.read(f, as_version=4)
except FileNotFoundError:
    print(f"Error: File '{notebook_name}.ipynb' not found. Please check if it was downloaded c

# Initialize the PDF exporter
exporter = PDFExporter(exclude_output=True) # Changed to PDFExporter

# Sanitize notebook cell titles to escape special LaTeX characters like '&'
for cell in nb.cells:
    if 'cell_type' in cell and cell['cell_type'] == 'markdown':
        if 'source' in cell and isinstance(cell['source'], str):
            # Replace '&' with '\protect&' in markdown cell titles AND CONTENT
            # Updated to use escape_latex_special_chars function
            cell['source'] = escape_latex_special_chars(cell['source'])
            # Additionally, escape special characters in headings
            cell['source'] = re.sub(r'(\#+)\s*(.*)', lambda m: m.group(1) + ' ' + escape_latex

# Convert the notebook to PDF
(body, resources) = exporter.from_notebook_node(nb)

# Save the PDF to a file
with open(f"{notebook_name}IPYNB.pdf", "wb") as f: # Changed to 'wb' for binary writing
    f.write(body)

```

Installing necessary TeX packages...

Reading package lists... Done

Building dependency tree... Done

Reading state information... Done

The following additional packages will be installed:

dvisvgm fonts-droid-fallback fonts-lato fonts-lmodern fonts-noto-mono

fonts-texgyre fonts-urw-base35 libapache-pom-java libcommons-logging-java

```
libcommons-parent-java libfontbox-java libgs9 libgs9-common libidn12
libijs-0.35 libjbig2dec0 libkpathsea6 libpdfbox-java libptexenc1 libruby3.0
libsynctex2 libteckit0 libtexlua53 libtexluajit2 libwoff1 libzip-0-13
lmodern poppler-data preview-latex-style rake ruby ruby-net-telnet
ruby-rubygems ruby-webrick ruby-xmlrpc ruby3.0 rubygems-integration t1utils
teckit tex-common tex-gyre texlive-base texlive-binaries texlive-latex-base
texlive-latex-extra texlive-latex-recommended texlive-pictures tipa
xfonts-encodings xfonts-utils
```

Suggested packages:

```
fonts-noto fonts-freefont-otf | fonts-freefont-ttf libavalon-framework-java
libcommons-logging-java-doc libexcalibur-logkit-java liblog4j1.2-java
poppler-utils ghostscript fonts-japanese-mincho | fonts-ipafont-mincho
fonts-japanese-gothic | fonts-ipafont-gothic fonts-arphic-ukai
fonts-arphic-uming fonts-nanum ri ruby-dev bundler debhelper gv
| postscript-viewer perl-tk xpdf | pdf-viewer xzdec
texlive-fonts-recommended-doc texlive-latex-base-doc python3-pygments
icc-profiles libfile-which-perl libspreadsheet-parseexcel-perl
texlive-latex-extra-doc texlive-latex-recommended-doc texlive-luatex
texlive-pstricks dot2tex prerex texlive-pictures-doc vprerex
default-jre-headless tipa-doc
```

The following NEW packages will be installed:

```
dvisvgm fonts-droid-fallback fonts-lato fonts-lmodern fonts-noto-mono
fonts-texgyre fonts-urw-base35 libapache-pom-java libcommons-logging-java
libcommons-parent-java libfontbox-java libgs9 libgs9-common libidn12
libijs-0.35 libjbig2dec0 libkpathsea6 libpdfbox-java libptexenc1 libruby3.0
libsynctex2 libteckit0 libtexlua53 libtexluajit2 libwoff1 libzip-0-13
lmodern poppler-data preview-latex-style rake ruby ruby-net-telnet
ruby-rubygems ruby-webrick ruby-xmlrpc ruby3.0 rubygems-integration t1utils
teckit tex-common tex-gyre texlive-base texlive-binaries
texlive-fonts-recommended texlive-latex-base texlive-latex-extra
texlive-latex-recommended texlive-pictures texlive-plain-generic
texlive-xetex tipa xfonts-encodings xfonts-utils
```

0 upgraded, 53 newly installed, 0 to remove and 34 not upgraded.

Need to get 182 MB of archives.

After this operation, 571 MB of additional disk space will be used.

Get:1 <http://archive.ubuntu.com/ubuntu> jammy/main amd64 fonts-droid-fallback all 1:6.0.1r16-

Get:2 <http://archive.ubuntu.com/ubuntu> jammy/main amd64 fonts-lato all 2.0-2.1 [2,696 kB]

Get:3 <http://archive.ubuntu.com/ubuntu> jammy/main amd64 poppler-data all 0.4.11-1 [2,171 kB]

Get:4 <http://archive.ubuntu.com/ubuntu> jammy/universe amd64 tex-common all 6.17 [33.7 kB]

Get:5 <http://archive.ubuntu.com/ubuntu> jammy/main amd64 fonts-urw-base35 all 20200910-1 [6,3

Get:6 <http://archive.ubuntu.com/ubuntu> jammy-updates/main amd64 libgs9-common all 9.55.0~dfs

Get:7 <http://archive.ubuntu.com/ubuntu> jammy-updates/main amd64 libidn12 amd64 1.38-4ubuntu1

```

Get:8 http://archive.ubuntu.com/ubuntu jammy/main amd64 libijs-0.35 amd64 0.35-15build2 [16.
Get:9 http://archive.ubuntu.com/ubuntu jammy/main amd64 libjbig2dec0 amd64 0.19-3build2 [64.
Get:10 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libgs9 amd64 9.55.0~dfsg1-0
Get:11 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libkpathsea6 amd64 2021.202
Get:12 http://archive.ubuntu.com/ubuntu jammy/main amd64 libwoff1 amd64 1.0.2-1build4 [45.2
Get:13 http://archive.ubuntu.com/ubuntu jammy/universe amd64 dvisvgm amd64 2.13.1-1 [1,221 k
Get:14 http://archive.ubuntu.com/ubuntu jammy/universe amd64 fonts-lmodern all 2.004.5-6.1
Get:15 http://archive.ubuntu.com/ubuntu jammy/main amd64 fonts-noto-mono all 20201225-1buil
Get:16 http://archive.ubuntu.com/ubuntu jammy/universe amd64 fonts-texgyre all 20180621-3.1
Get:17 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libapache-pom-java all 18-1 [4,
Get:18 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libcommons-parent-java all 43-1
Get:19 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libcommons-logging-java all 1.2
Get:20 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libptexenc1 amd64 2021.2021
Get:21 http://archive.ubuntu.com/ubuntu jammy/main amd64 rubygems-integration all 1.18 [5,33
Get:22 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 ruby3.0 amd64 3.0.2-7ubun
Get:23 http://archive.ubuntu.com/ubuntu jammy/main amd64 ruby-rubygems all 3.3.5-2 [228 kB]
Get:24 http://archive.ubuntu.com/ubuntu jammy/main amd64 ruby amd64 1:3.0~exp1 [5,100 B]
Get:25 http://archive.ubuntu.com/ubuntu jammy/main amd64 rake all 13.0.6-2 [61.7 kB]
Get:26 http://archive.ubuntu.com/ubuntu jammy/main amd64 ruby-net-telnet all 0.1.1-2 [12.6 k
Get:27 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 ruby-webrick all 1.7.0-3ubu
Get:28 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 ruby-xmlrpc all 0.3.2-1ubun
Get:29 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libruby3.0 amd64 3.0.2-7ubu
Get:30 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libsincex2 amd64 2021.2021
Get:31 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libteckit0 amd64 2.5.11+ds1-1
Get:32 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libtexlua53 amd64 2021.2021
Get:33 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libtexluaajit2 amd64 2021.20
Get:34 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libzzip-0-13 amd64 0.13.72+dfsg
Get:35 http://archive.ubuntu.com/ubuntu jammy/main amd64 xfonts-encodings all 1:1.0.5-0ubun
Get:36 http://archive.ubuntu.com/ubuntu jammy/main amd64 xfonts-utils amd64 1:7.7+6build2 [9
Get:37 http://archive.ubuntu.com/ubuntu jammy/universe amd64 lmodern all 2.004.5-6.1 [9,471
Get:38 http://archive.ubuntu.com/ubuntu jammy/universe amd64 preview-latex-style all 12.2-1u
Get:39 http://archive.ubuntu.com/ubuntu jammy/main amd64 t1utils amd64 1.41-4build2 [61.3 kB]
Get:40 http://archive.ubuntu.com/ubuntu jammy/universe amd64 teckit amd64 2.5.11+ds1-1 [699
Get:41 http://archive.ubuntu.com/ubuntu jammy/universe amd64 tex-gyre all 20180621-3.1 [6,20
Get:42 http://archive.ubuntu.com/ubuntu jammy-updates/universe amd64 texlive-binaries amd64
Get:43 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-base all 2021.20220204-
Get:44 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-fonts-recommended all 2
Get:45 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-latex-base all 2021.202
Get:46 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libfontbox-java all 1:1.8.16-2
Get:47 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libpdfbox-java all 1:1.8.16-2
Get:48 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-latex-recommended all 2
Get:49 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-pictures all 2021.20220

```

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Get:50 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-latex-extra all 2021.20
Get:51 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-plain-generic all 2021.
Get:52 http://archive.ubuntu.com/ubuntu jammy/universe amd64 tipa all 2:1.3-21 [2,967 kB]
Get:53 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-xetex all 2021.20220204
Fetched 182 MB in 12s (15.2 MB/s)
Extracting templates from packages: 100%
Preconfiguring packages ...
Selecting previously unselected package fonts-droid-fallback.
(Reading database ... 126327 files and directories currently installed.)
Preparing to unpack .../00-fonts-droid-fallback_1%3a6.0.1r16-1.1build1_all.deb ...
Unpacking fonts-droid-fallback (1:6.0.1r16-1.1build1) ...
Selecting previously unselected package fonts-lato.
Preparing to unpack .../01-fonts-lato_2.0-2.1_all.deb ...
Unpacking fonts-lato (2.0-2.1) ...
Selecting previously unselected package poppler-data.
Preparing to unpack .../02-poppler-data_0.4.11-1_all.deb ...
Unpacking poppler-data (0.4.11-1) ...
Selecting previously unselected package tex-common.
Preparing to unpack .../03-tex-common_6.17_all.deb ...
Unpacking tex-common (6.17) ...
Selecting previously unselected package fonts-urw-base35.
Preparing to unpack .../04-fonts-urw-base35_20200910-1_all.deb ...
Unpacking fonts-urw-base35 (20200910-1) ...
Selecting previously unselected package libgs9-common.
Preparing to unpack .../05-libgs9-common_9.55.0~dfsg1-0ubuntu5.11_all.deb ...
Unpacking libgs9-common (9.55.0~dfsg1-0ubuntu5.11) ...
Selecting previously unselected package libidn12:amd64.
Preparing to unpack .../06-libidn12_1.38-4ubuntu1_amd64.deb ...
Unpacking libidn12:amd64 (1.38-4ubuntu1) ...
Selecting previously unselected package libijs-0.35:amd64.
Preparing to unpack .../07-libijs-0.35_0.35-15build2_amd64.deb ...
Unpacking libijs-0.35:amd64 (0.35-15build2) ...
Selecting previously unselected package libjbig2dec0:amd64.
Preparing to unpack .../08-libjbig2dec0_0.19-3build2_amd64.deb ...
Unpacking libjbig2dec0:amd64 (0.19-3build2) ...
Selecting previously unselected package libgs9:amd64.
Preparing to unpack .../09-libgs9_9.55.0~dfsg1-0ubuntu5.11_amd64.deb ...
Unpacking libgs9:amd64 (9.55.0~dfsg1-0ubuntu5.11) ...
Selecting previously unselected package libkpathsea6:amd64.
Preparing to unpack .../10-libkpathsea6_2021.20210626.59705-1ubuntu0.2_amd64.deb ...
Unpacking libkpathsea6:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package libwoff1:amd64.

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```
Preparing to unpack .../11-libwoff1_1.0.2-1build4_amd64.deb ...
Unpacking libwoff1:amd64 (1.0.2-1build4) ...
Selecting previously unselected package dvisvgm.
Preparing to unpack .../12-dvisvgm_2.13.1-1_amd64.deb ...
Unpacking dvisvgm (2.13.1-1) ...
Selecting previously unselected package fonts-lmodern.
Preparing to unpack .../13-fonts-lmodern_2.004.5-6.1_all.deb ...
Unpacking fonts-lmodern (2.004.5-6.1) ...
Selecting previously unselected package fonts-noto-mono.
Preparing to unpack .../14-fonts-noto-mono_20201225-1build1_all.deb ...
Unpacking fonts-noto-mono (20201225-1build1) ...
Selecting previously unselected package fonts-texgyre.
Preparing to unpack .../15-fonts-texgyre_20180621-3.1_all.deb ...
Unpacking fonts-texgyre (20180621-3.1) ...
Selecting previously unselected package libapache-pom-java.
Preparing to unpack .../16-libapache-pom-java_18-1_all.deb ...
Unpacking libapache-pom-java (18-1) ...
Selecting previously unselected package libcommons-parent-java.
Preparing to unpack .../17-libcommons-parent-java_43-1_all.deb ...
Unpacking libcommons-parent-java (43-1) ...
Selecting previously unselected package libcommons-logging-java.
Preparing to unpack .../18-libcommons-logging-java_1.2-2_all.deb ...
Unpacking libcommons-logging-java (1.2-2) ...
Selecting previously unselected package libptexenc1:amd64.
Preparing to unpack .../19-libptexenc1_2021.20210626.59705-1ubuntu0.2_amd64.deb ...
Unpacking libptexenc1:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package rubygems-integration.
Preparing to unpack .../20-rubygems-integration_1.18_all.deb ...
Unpacking rubygems-integration (1.18) ...
Selecting previously unselected package ruby3.0.
Preparing to unpack .../21-ruby3.0_3.0.2-7ubuntu2.10_amd64.deb ...
Unpacking ruby3.0 (3.0.2-7ubuntu2.10) ...
Selecting previously unselected package ruby-rubygems.
Preparing to unpack .../22-ruby-rubygems_3.3.5-2_all.deb ...
Unpacking ruby-rubygems (3.3.5-2) ...
Selecting previously unselected package ruby.
Preparing to unpack .../23-ruby_1%3a3.0~exp1_amd64.deb ...
Unpacking ruby (1:3.0~exp1) ...
Selecting previously unselected package rake.
Preparing to unpack .../24-rake_13.0.6-2_all.deb ...
Unpacking rake (13.0.6-2) ...
Selecting previously unselected package ruby-net-telnet.
```

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Preparing to unpack .../25-ruby-net-telnet_0.1.1-2_all.deb ...
Unpacking ruby-net-telnet (0.1.1-2) ...
Selecting previously unselected package ruby-webrick.
Preparing to unpack .../26-ruby-webrick_1.7.0-3ubuntu0.1_all.deb ...
Unpacking ruby-webrick (1.7.0-3ubuntu0.1) ...
Selecting previously unselected package ruby-xmlrpc.
Preparing to unpack .../27-ruby-xmlrpc_0.3.2-1ubuntu0.1_all.deb ...
Unpacking ruby-xmlrpc (0.3.2-1ubuntu0.1) ...
Selecting previously unselected package libruby3.0:amd64.
Preparing to unpack .../28-libruby3.0_3.0.2-7ubuntu2.10_amd64.deb ...
Unpacking libruby3.0:amd64 (3.0.2-7ubuntu2.10) ...
Selecting previously unselected package libsyntax2:amd64.
Preparing to unpack .../29-libsyntax2_2021.20210626.59705-1ubuntu0.2_amd64.deb ...
Unpacking libsyntax2:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package libteckit0:amd64.
Preparing to unpack .../30-libteckit0_2.5.11+ds1-1_amd64.deb ...
Unpacking libteckit0:amd64 (2.5.11+ds1-1) ...
Selecting previously unselected package libtexlua53:amd64.
Preparing to unpack .../31-libtexlua53_2021.20210626.59705-1ubuntu0.2_amd64.deb ...
Unpacking libtexlua53:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package libtexluajit2:amd64.
Preparing to unpack .../32-libtexluajit2_2021.20210626.59705-1ubuntu0.2_amd64.deb ...
Unpacking libtexluajit2:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package libzip-0-13:amd64.
Preparing to unpack .../33-libzip-0-13_0.13.72+dfsg.1-1.1_amd64.deb ...
Unpacking libzip-0-13:amd64 (0.13.72+dfsg.1-1.1) ...
Selecting previously unselected package xfonts-encodings.
Preparing to unpack .../34-xfonts-encodings_1%3a1.0.5-0ubuntu2_all.deb ...
Unpacking xfonts-encodings (1:1.0.5-0ubuntu2) ...
Selecting previously unselected package xfonts-utils.
Preparing to unpack .../35-xfonts-utils_1%3a7.7+6build2_amd64.deb ...
Unpacking xfonts-utils (1:7.7+6build2) ...
Selecting previously unselected package lmodern.
Preparing to unpack .../36-lmodern_2.004.5-6.1_all.deb ...
Unpacking lmodern (2.004.5-6.1) ...
Selecting previously unselected package preview-latex-style.
Preparing to unpack .../37-preview-latex-style_12.2-1ubuntu1_all.deb ...
Unpacking preview-latex-style (12.2-1ubuntu1) ...
Selecting previously unselected package t1utils.
Preparing to unpack .../38-t1utils_1.41-4build2_amd64.deb ...
Unpacking t1utils (1.41-4build2) ...
Selecting previously unselected package teckit.
```



```
Preparing to unpack .../39-teckit_2.5.11+ds1-1_amd64.deb ...
Unpacking teckit (2.5.11+ds1-1) ...
Selecting previously unselected package tex-gyre.
Preparing to unpack .../40-tex-gyre_20180621-3.1_all.deb ...
Unpacking tex-gyre (20180621-3.1) ...
Selecting previously unselected package texlive-binaries.
Preparing to unpack .../41-texlive-binaries_2021.20210626.59705-1ubuntu0.2_amd64.deb ...
Unpacking texlive-binaries (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package texlive-base.
Preparing to unpack .../42-texlive-base_2021.20220204-1_all.deb ...
Unpacking texlive-base (2021.20220204-1) ...
Selecting previously unselected package texlive-fonts-recommended.
Preparing to unpack .../43-texlive-fonts-recommended_2021.20220204-1_all.deb ...
Unpacking texlive-fonts-recommended (2021.20220204-1) ...
Selecting previously unselected package texlive-latex-base.
Preparing to unpack .../44-texlive-latex-base_2021.20220204-1_all.deb ...
Unpacking texlive-latex-base (2021.20220204-1) ...
Selecting previously unselected package libfontbox-java.
Preparing to unpack .../45-libfontbox-java_1%3a1.8.16-2_all.deb ...
Unpacking libfontbox-java (1:1.8.16-2) ...
Selecting previously unselected package libpdfbox-java.
Preparing to unpack .../46-libpdfbox-java_1%3a1.8.16-2_all.deb ...
Unpacking libpdfbox-java (1:1.8.16-2) ...
Selecting previously unselected package texlive-latex-recommended.
Preparing to unpack .../47-texlive-latex-recommended_2021.20220204-1_all.deb ...
Unpacking texlive-latex-recommended (2021.20220204-1) ...
Selecting previously unselected package texlive-pictures.
Preparing to unpack .../48-texlive-pictures_2021.20220204-1_all.deb ...
Unpacking texlive-pictures (2021.20220204-1) ...
Selecting previously unselected package texlive-latex-extra.
Preparing to unpack .../49-texlive-latex-extra_2021.20220204-1_all.deb ...
Unpacking texlive-latex-extra (2021.20220204-1) ...
Selecting previously unselected package texlive-plain-generic.
Preparing to unpack .../50-texlive-plain-generic_2021.20220204-1_all.deb ...
Unpacking texlive-plain-generic (2021.20220204-1) ...
Selecting previously unselected package tipa.
Preparing to unpack .../51-tipa_2%3a1.3-21_all.deb ...
Unpacking tipa (2:1.3-21) ...
Selecting previously unselected package texlive-xetex.
Preparing to unpack .../52-texlive-xetex_2021.20220204-1_all.deb ...
Unpacking texlive-xetex (2021.20220204-1) ...
Setting up fonts-lato (2.0-2.1) ...
```

```

Setting up fonts-noto-mono (20201225-1build1) ...
Setting up libwoff1:amd64 (1.0.2-1build4) ...
Setting up libtexlua53:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Setting up libijs-0.35:amd64 (0.35-15build2) ...
Setting up libtexluajit2:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Setting up libfontbox-java (1:1.8.16-2) ...
Setting up rubygems-integration (1.18) ...
Setting up libzip-0-13:amd64 (0.13.72+dfsg.1-1.1) ...
Setting up fonts-urw-base35 (20200910-1) ...
Setting up poppler-data (0.4.11-1) ...
Setting up tex-common (6.17) ...
update-language: texlive-base not installed and configured, doing nothing!
Setting up libjbig2dec0:amd64 (0.19-3build2) ...
Setting up libteckit0:amd64 (2.5.11+ds1-1) ...
Setting up libapache-pom-java (18-1) ...
Setting up ruby-net-telnet (0.1.1-2) ...
Setting up xfonts-encodings (1:1.0.5-0ubuntu2) ...
Setting up t1utils (1.41-4build2) ...
Setting up libidn12:amd64 (1.38-4ubuntu1) ...
Setting up fonts-texgyre (20180621-3.1) ...
Setting up libkpathsea6:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Setting up ruby-webrick (1.7.0-3ubuntu0.1) ...
Setting up fonts-lmodern (2.004.5-6.1) ...
Setting up fonts-droid-fallback (1:6.0.1r16-1.1build1) ...
Setting up ruby-xmlrpc (0.3.2-1ubuntu0.1) ...
Setting up libsynchronet2:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Setting up libgs9-common (9.55.0~dfsg1-0ubuntu5.11) ...
Setting up teckit (2.5.11+ds1-1) ...
Setting up libpdfbox-java (1:1.8.16-2) ...
Setting up libgs9:amd64 (9.55.0~dfsg1-0ubuntu5.11) ...
Setting up preview-latex-style (12.2-1ubuntu1) ...
Setting up libcommons-parent-java (43-1) ...
Setting up dvisvgm (2.13.1-1) ...
Setting up libcommons-logging-java (1.2-2) ...
Setting up xfonts-utils (1:7.7+6build2) ...
Setting up libptexenc1:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Setting up texlive-binaries (2021.20210626.59705-1ubuntu0.2) ...
update-alternatives: using /usr/bin/xdvi-xaw to provide /usr/bin/xdvi.bin (xdvi.bin) in auto
update-alternatives: using /usr/bin/bibtex.original to provide /usr/bin/bibtex (bibtex) in a
Setting up lmodern (2.004.5-6.1) ...
Setting up texlive-base (2021.20220204-1) ...
/usr/bin/ucfr

```

```

/usr/bin/ucfr
/usr/bin/ucfr
/usr/bin/ucfr
mktexlsr: Updating /var/lib/texmf/ls-R-TEXLIVEDIST...
mktexlsr: Updating /var/lib/texmf/ls-R-TEXMFMAIN...
mktexlsr: Updating /var/lib/texmf/ls-R...
mktexlsr: Done.
tl-paper: setting paper size for dvips to a4: /var/lib/texmf/dvips/config/config-paper.ps
tl-paper: setting paper size for dvipdfmx to a4: /var/lib/texmf/dvipdfmx/dvipdfmx-paper.cfg
tl-paper: setting paper size for xdvi to a4: /var/lib/texmf/xdvi/XDvi-paper
tl-paper: setting paper size for pdftex to a4: /var/lib/texmf/tex/generic/tex-ini-files/pdft
Setting up tex-gyre (20180621-3.1) ...
Setting up texlive-plain-generic (2021.20220204-1) ...
Setting up texlive-latex-base (2021.20220204-1) ...
Setting up texlive-latex-recommended (2021.20220204-1) ...
Setting up texlive-pictures (2021.20220204-1) ...
Setting up texlive-fonts-recommended (2021.20220204-1) ...
Setting up tipa (2:1.3-21) ...
Setting up texlive-latex-extra (2021.20220204-1) ...
Setting up texlive-xetex (2021.20220204-1) ...
Setting up rake (13.0.6-2) ...
Setting up libruby3.0:amd64 (3.0.2-7ubuntu2.10) ...
Setting up ruby3.0 (3.0.2-7ubuntu2.10) ...
Setting up ruby (1:3.0~exp1) ...
Setting up ruby-rubygems (3.3.5-2) ...
Processing triggers for man-db (2.10.2-1) ...
Processing triggers for mailcap (3.70+nmulubuntu1) ...
Processing triggers for fontconfig (2.13.1-4.2ubuntu5) ...
Processing triggers for libc-bin (2.35-0ubuntu3.8) ...
/sbin/ldconfig.real: /usr/local/lib/libumf.so.0 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libtcm_debug.so.1 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libtbbbbind.so.3 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libhwloc.so.15 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libtbbbbind_2_5.so.3 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libtbb.so.12 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libur_adapter_level_zero.so.0 is not a symbolic link

```

```

/sbin/ldconfig.real: /usr/local/lib/libtbbmalloc.so.2 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libtbbbind_2_0.so.3 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libtcm.so.1 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libur_adapter_opengl.so.0 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libtbbmalloc_proxy.so.2 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libur_loader.so.0 is not a symbolic link

Processing triggers for tex-common (6.17) ...
Running updmap-sys. This may take some time... done.
Running mktexlsr /var/lib/texmf ... done.
Building format(s) --all.
    This may take some time... done.
TeX packages installed successfully.
--2025-05-24 20:12:59--  https://raw.githubusercontent.com/SingularitySmith/AMTAIR_Prototype
Resolving raw.githubusercontent.com (raw.githubusercontent.com)... 185.199.108.133, 185.199.
Connecting to raw.githubusercontent.com (raw.githubusercontent.com)|185.199.108.133|:443...
HTTP request sent, awaiting response... 200 OK
Length: 1689816 (1.6M) [text/plain]
Saving to: 'AMTAIR_Prototype_example_carlsmith.ipynb'

AMTAIR_Prototype_ex 100%[=====>]   1.61M   5.31MB/s   in 0.3s

2025-05-24 20:12:59 (5.31 MB/s) - 'AMTAIR_Prototype_example_carlsmith.ipynb' saved [1689816/

```

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## Affidavit

### Declaration of Academic Honesty

Hereby, I attest that I have composed and written the presented thesis

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independently on my own, without the use of other than the stated aids and without any other resources than the ones indicated. All thoughts taken directly or indirectly from external sources are properly denoted as such.

This paper has neither been previously submitted in the same or a similar form to another authority nor has it been published yet.

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