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Common-Sense Reasoning and Abstraction

Saurabh Rai[1], Anusshka Teli[2], Pooja Shingade[3], Siddhi Uttekar[4]

PG Scholar[1], Lecturers[2, 3, 4]

Department of CSE

AISSMS College of Engineering

Email ID: *saurabh.rai45@rediffmail.com[1]*

ABSTRACT

Common-sense reasoning (CSR) and abstraction form critical pillars of human-like intelligence. CSR allows systems to make inferences in everyday contexts, while abstraction enables the simplification of complex concepts for higher-level cognitive processing. Integrating these two capabilities is essential for developing robust artificial intelligence (AI) systems that exhibit general intelligence. This paper reviews the current state of research in CSR and abstraction, emphasizing computational models, knowledge representation techniques, and applications in AI. The study identifies challenges in modeling human-like common-sense knowledge and proposes directions for integrating abstraction mechanisms to improve reasoning efficiency. Additionally, the paper highlights the potential of hybrid approaches combining symbolic, statistical, and neuro-symbolic methods.

KEYWORDS: *Common-sense reasoning, abstraction, knowledge representation, AI, cognitive modeling, neuro-symbolic AI*

INTRODUCTION

Common-sense reasoning (CSR) enables humans to interpret, infer, and act in real-world situations with incomplete or ambiguous information. While humans accomplish this effortlessly, artificial systems struggle to replicate similar capabilities. Abstraction, on the other hand, allows humans to reduce the complexity of their environment by representing objects, events, and relationships in simplified forms. Together, CSR and abstraction form a foundation for higher-order cognition, including problem-solving, planning, and decision-making.

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Artificial intelligence research increasingly focuses on equipping systems with CSR and abstraction capabilities to achieve more generalizable and context-aware intelligence. This paper reviews the conceptual frameworks, computational models, and recent advancements in these domains.

CONCEPTUAL OVERVIEW

Common-sense reasoning (CSR) and abstraction are two foundational cognitive capabilities that enable humans to navigate complex, dynamic, and uncertain environments. Understanding these concepts is crucial for designing AI systems that can reason effectively and generalize knowledge across diverse contexts.

1. Common-Sense Reasoning (CSR)

Common-sense reasoning refers to the human ability to interpret everyday situations and draw inferences based on prior knowledge. Unlike formal logic or strictly rule-based reasoning, CSR is flexible, context-sensitive, and often operates under uncertainty. The knowledge involved is largely implicit, accumulated through experience, observation, and social interaction, rather than explicitly taught.

Key Properties of CSR:

1. **Context Sensitivity:**

   CSR enables individuals or systems to interpret information relative to the surrounding environment. For instance, the statement *"It's cold outside"* can lead to different actions depending on context: wearing a jacket, closing a window, or turning on heating. For AI, context sensitivity allows dynamic adaptation of reasoning strategies according to input conditions.

2. **Default Reasoning:**

   Often, humans make reasonable assumptions when complete information is unavailable. For example, if you see someone carrying an umbrella, you might infer that it is raining, even without direct observation of rain. AI systems employing default reasoning can fill in gaps with probable assumptions, improving robustness in real-world applications.

3. **Causal Inference:**

   Understanding cause-and-effect relationships is central to CSR. Humans intuitively know that *"ice melts when heated"* or *"touching fire causes burns"*. Causal reasoning allows

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prediction, planning, and explanation. In AI, causal models enable systems to go beyond pattern recognition, allowing reasoning about interventions and hypothetical scenarios.

Example:

A person walking past a puddle automatically avoids stepping in it because of the inferred cause-effect relationship: water can wet shoes. For AI, replicating such inference requires integrating environmental perception with knowledge of outcomes.

CSR in AI Systems:

- **Rule-based systems:** Encode common-sense facts explicitly (e.g., *if ice melts → water forms*).
- **Probabilistic models:** Estimate likelihoods when certainty is low (Bayesian networks).
- **Neural models:** Capture statistical patterns of language and behavior to infer plausible actions or relations.

2. Abstraction

Abstraction is the cognitive process of identifying essential features while ignoring irrelevant details to form generalized representations. It enables humans to recognize patterns, categorize objects, and reason at higher conceptual levels. Abstraction is crucial in both human cognition and AI for managing complexity.

Levels of Abstraction:

- **Object-Level Abstraction:**

  Focuses on concrete entities and their attributes. Example: *apple*, *car*, or *tree*.

- **Conceptual-Level Abstraction:**

  Groups entities into broader categories based on shared characteristics.

  Example: *apple* and *orange* → *fruit*; *car* and *truck* → *vehicle*. This level facilitates knowledge transfer and efficient learning.

- **Procedural-Level Abstraction:**

  Involves rules, processes, or strategies that govern behavior. Example: *driving a vehicle* or *baking a cake*. Procedural abstraction allows reasoning about sequences of actions without considering every fine-grained detail.

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Importance in AI:

- **Hierarchical Planning:** Abstraction allows AI to plan actions at multiple levels, e.g., a robot can reason about "clean the room" rather than tracking individual movements of every hand and foot.
- **Knowledge Transfer:** Abstract representations enable AI systems to generalize learned concepts to new contexts. For example, recognizing a “drone” as a type of “flying vehicle” allows navigation algorithms to apply knowledge learned from other vehicles.
- **Efficiency:** Reduces cognitive or computational load by ignoring unnecessary details, making reasoning faster and more scalable.

Example:

Humans recognize a *vehicle* as an abstraction encompassing cars, trucks, motorcycles, and buses. This allows predictions and reasoning about vehicles without memorizing details of each individual type.

Integration of CSR and Abstraction:

- CSR often relies on abstraction to simplify reasoning tasks. For instance, inferring that *“vehicles should stop at a red light”* applies across cars, trucks, and motorcycles without separately learning rules for each type.
- Abstraction, in turn, benefits from common-sense knowledge to determine which features are relevant (e.g., “size matters for parking” but “color does not”).

RELATIONSHIP BETWEEN CSR AND ABSTRACTION

Common-sense reasoning (CSR) and abstraction are deeply intertwined cognitive processes that complement each other in both human intelligence and artificial intelligence systems. While CSR provides the knowledge and inference mechanisms to understand the world, abstraction allows for generalization and simplification of that knowledge. Understanding their relationship is crucial for designing AI systems capable of human-like reasoning.

1. Abstraction Simplifies Reasoning

Abstraction reduces the complexity of reasoning tasks by focusing only on the essential features of a situation while ignoring irrelevant details. This simplification enables AI systems to generalize knowledge across different scenarios and apply learned rules to novel situations.

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Key Points:

- **Reduction of Cognitive Load:**
  By working with abstract representations, an AI system does not need to consider every detail of a scenario. For instance, instead of reasoning about each individual car, an AI can treat all cars as instances of the *vehicle* category.
- **Generalization Across Domains:**
  Abstraction allows systems to apply a single rule to multiple instances. For example, a rule like *"vehicles stop at a red traffic signal"* can apply to cars, trucks, motorcycles, and buses without writing separate rules for each.
- **Hierarchical Reasoning:**
  Abstraction supports multi-level reasoning, where higher-level concepts guide overall planning, and lower-level details are filled in as needed. For example, in a robotics task, an AI might plan "prepare tea" at the conceptual level and then follow step-by-step actions like "boil water" at the procedural level.

Example:

Consider an AI tasked with predicting weather-related road conditions. Instead of analyzing each puddle, snow patch, or fallen leaf individually, the system can abstract the environment into "wet surface," "icy patch," and "obstruction," applying general safety rules to all cases. This reduces computation and improves reasoning speed.

2. CSR Guides Abstraction

While abstraction simplifies reasoning, determining **which details to retain and which to ignore** is not trivial. This is where CSR plays a critical role. Common-sense knowledge informs an AI system about which features of a situation are relevant for effective abstraction.

Key Points:

- **Feature Relevance:**
  CSR helps identify which attributes of objects or events matter in a given context. For example, in understanding vehicles, CSR tells the system that *weight, size, and maneuverability* are relevant for parking, while *color* is mostly irrelevant.
- **Context-Aware Abstraction:**
  Abstraction alone may discard important nuances. CSR ensures that abstractions

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remain contextually valid. For example, when reasoning about food safety, an AI must retain features like temperature and expiration date while abstracting away packaging aesthetics.

- **Dynamic Abstraction Levels:**
  CSR allows AI systems to adjust the level of abstraction based on the situation. In high-level planning, coarse abstractions (e.g., "prepare for rain") suffice, while in detailed tasks (e.g., navigating a slippery road), finer-grained abstractions are needed.

Example:

A human knows that ice cream melts quickly under the sun. When teaching a robot to serve ice cream, CSR guides abstraction by emphasizing temperature and time rather than the flavor or packaging, ensuring practical, context-relevant reasoning.

3. Synergistic Interaction in AI Systems

In AI, CSR and abstraction often operate together in hybrid reasoning architectures:

- **Symbolic AI:** Uses abstract concepts and logical rules guided by CSR-like knowledge.
- **Neuro-symbolic AI:** Neural networks extract patterns from data (learning abstraction), while symbolic reasoning injects common-sense knowledge to select relevant features.
- **Decision-Making Systems:** CSR informs which variables to prioritize in abstract models, enabling faster and safer decisions.

Table 1: Interaction between CSR and Abstraction

Aspect	Common-Sense Reasoning	Abstraction
Role	Contextual inference, causal understanding	Simplifying complex scenarios
Output	Plausible assumptions, inferences	Generalized concepts, hierarchies
Dependency	Uses abstract concepts for generalization	Relies on CSR to select relevant features
Example	"If it rains, the ground will get wet"	Grouping "apple" and "orange" as "fruit"

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KNOWLEDGE REPRESENTATION TECHNIQUES

Effective common-sense reasoning (CSR) and abstraction rely heavily on **robust knowledge representation (KR) mechanisms**. KR provides the structure for storing, organizing, and retrieving knowledge so that AI systems can reason about the world and generalize across contexts. Different approaches—symbolic, probabilistic, and neural—offer unique strengths and trade-offs for representing common-sense knowledge and supporting abstraction.

1. Symbolic Approaches

Symbolic knowledge representation relies on **explicit, human-readable logical structures** to encode facts, concepts, and relationships. These methods are interpretable and allow rule-based reasoning.

Key Techniques:

1. **Ontologies:**

   Ontologies define hierarchical relationships among concepts. They encode the taxonomy of objects, categories, and attributes.

   - *Example:* WordNet organizes English words into synsets (groups of synonyms) and shows semantic relationships such as “is-a” or “part-of.”
   - *Use in CSR & Abstraction:* Enables generalization, e.g., understanding that a “sparrow” and “eagle” are both “birds” and can fly.

2. **Frames:**

   Frames represent objects as structured collections of attributes (slots) and associated values.

   - *Example:* A “Car” frame might include attributes like color, number of wheels, fuel type, and maximum speed.
   - *Use in CSR:* Supports reasoning about specific instances while maintaining abstract categories.

3. **Rules:**

   Rule-based systems use if-then logic to infer knowledge.

   - *Example:* IF “ice temperature < 0°C” THEN “state = solid.”
   - *Use in CSR:* Captures causal relationships and common-sense facts.

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Advantages:

- Highly interpretable and explainable
- Enables deductive reasoning and logical inference
- Supports clear hierarchical abstraction

Limitations:

- Rigid: Difficult to handle incomplete or uncertain knowledge
- Struggles with ambiguity or conflicting information
- Knowledge engineering is labor-intensive

2. Probabilistic Approaches

Probabilistic knowledge representation addresses **uncertainty and incomplete information** in reasoning. It allows AI systems to make plausible inferences when data are ambiguous or missing.

Key Techniques:

1. **Bayesian Networks (BNs):**
   Graphical models representing variables as nodes and probabilistic dependencies as edges.
   - *Example:* Predicting whether it will rain based on cloud cover, humidity, and temperature.
   - *Use in CSR:* Models causal relationships and default reasoning under uncertainty.

2. **Markov Logic Networks (MLNs):**
   Combines first-order logic with probabilistic reasoning, enabling flexible representation of common-sense rules with uncertainty.
   - *Example:* "Birds typically fly" encoded as a probabilistic rule. The system allows exceptions, e.g., penguins.

Advantages:

- Handles uncertainty naturally
- Learns patterns from data
- Supports probabilistic inference and prediction

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Limitations:

- Computationally expensive for large knowledge bases
- Requires substantial amounts of data for accurate learning
- May struggle with highly abstract reasoning without additional symbolic support

3. Neural and Neuro-Symbolic Approaches

Neural and neuro-symbolic methods combine **pattern learning** and **structured reasoning** to represent complex, context-sensitive knowledge. These approaches are particularly suited to modern AI systems requiring flexible common-sense reasoning and abstraction.

a) Neural Networks (NNs):

Deep learning models learn latent representations from large datasets, capturing statistical patterns for inference.

- *Example:* Transformer-based language models (like GPT) can predict likely outcomes and answer questions using implicit common-sense knowledge.
- *Use in CSR & Abstraction:* Captures generalizations without explicit rules, e.g., understanding that "if you drop a glass, it may break" from context in text data.

b) Neuro-Symbolic AI:

Integrates symbolic reasoning with neural networks. Neural models learn embeddings and patterns, while symbolic components provide structure, logic, and explainability.

- *Example:* A system that uses neural networks to identify objects in images and symbolic reasoning to infer relationships: "If a knife is near a hand, caution is needed."
- *Use in CSR & Abstraction:* Combines the generalization power of neural networks with the interpretability and causal reasoning of symbolic methods.

Advantages:

- Flexible and scalable
- Can capture implicit knowledge from large datasets
- Supports abstraction and generalization across domains

Limitations:

- Neural networks alone are often opaque ("black box")

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- Integrating symbolic logic with neural networks is complex
- Requires significant computational resources

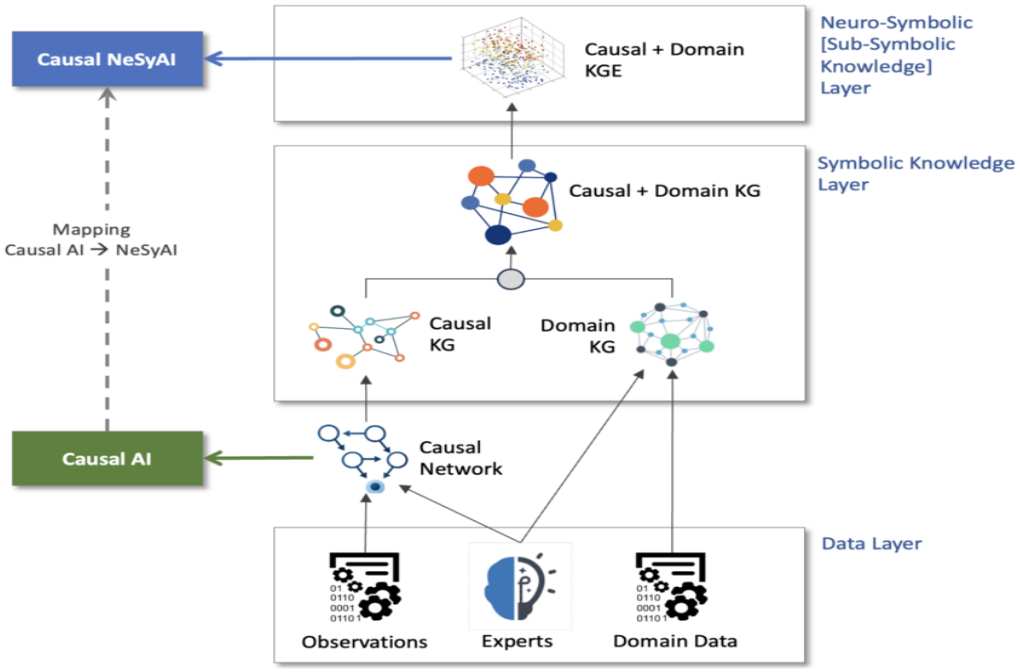


Figure 1: Hybrid Neuro-Symbolic Model for CSR and Abstraction

COMPUTATIONAL MODELS OF CSR AND ABSTRACTION

Several models attempt to simulate CSR and abstraction:

1. Cognitive Architectures

- **SOAR:** Unified architecture with memory and decision-making modules
- **ACT-R:** Combines declarative and procedural memory for reasoning

2. Knowledge Graphs

- Graph-based structures representing entities and relations
- Examples: ConceptNet, ATOMIC

3. Large Language Models (LLMs)

- Pre-trained transformers capture statistical patterns of language
- Can perform CSR-like tasks by leveraging implicit knowledge
- Limitation: Lack true understanding of causality

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APPLICATIONS

1. Artificial General Intelligence (AGI)

- CSR and abstraction are crucial for building AGI systems capable of reasoning across domains.

2. Robotics

- Robots utilize CSR and abstraction to navigate and manipulate objects in dynamic environments.

3. Natural Language Understanding

- Enables chatbots and virtual assistants to interpret ambiguous commands and respond contextually.

4. Decision Support Systems

- CSR-infused models assist in medical diagnosis, financial forecasting, and risk assessment.

CHALLENGES

- **Knowledge acquisition:** Common-sense knowledge is vast and difficult to encode
- **Ambiguity resolution:** Differentiating plausible from implausible inferences
- **Abstraction granularity:** Determining the correct level of generalization
- **Integration:** Combining symbolic, probabilistic, and neural approaches seamlessly

FUTURE DIRECTIONS

- **Hybrid Models:** Combining symbolic logic, probabilistic reasoning, and neural representations
- **Interactive Learning:** Systems that acquire common-sense knowledge through interaction
- **Meta-Reasoning:** Abstraction-aware reasoning for faster, more efficient inference
- **Explainable AI:** Transparent CSR and abstraction mechanisms for trust and verification

CONCLUSION

Common-sense reasoning and abstraction are essential for advancing artificial intelligence toward human-like cognition. While significant progress has been made using symbolic,

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probabilistic, and neural approaches, challenges remain in knowledge acquisition, ambiguity resolution, and hybrid integration. Future research must focus on creating adaptable, explainable, and abstraction-aware AI systems capable of robust reasoning in real-world scenarios. Combining these cognitive capabilities can bridge the gap between narrow AI and general intelligence.

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