

CONCEPTUAL DEPENDENCY

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Conceptual Dependency

Primary Disciplinary Field(s): Artificial Intelligence (AI), Natural Language Processing (NLP), Cognitive Science

Proponents: Roger Schank

1. Core Principles

Conceptual Dependency (CD) is a formal semantic system developed by computer scientist Roger Schank in the early 1970s, primarily aimed at modeling the deep, underlying meaning of natural language sentences in a manner suitable for computational processing. The fundamental assertion of CD is that meaning, regardless of the surface structure or specific human language employed (e.g., English, Chinese, Spanish), can be decomposed into a finite, small set of conceptual primitives. This system seeks to move past the superficial syntactic analysis of language, which often fails to capture the true intent or conceptual relationships, and instead represent sentences based on the actions, states, and relationships inherent in the meaning itself. This focus on semantic unions is critical for achieving robust **natural language comprehension** in computer software, as it allows AI systems to make necessary inferences and predictions that are integral to human understanding. By standardizing meaning into a fixed set of canonical forms, CD enables computers to represent sentences like "John hit Mary" and "Mary was hit by John" using the exact same internal structure, thus simplifying the process of memory storage and retrieval, and, most importantly, facilitating knowledge inference, which is often crucial for tasks like reading comprehension or dialogue generation. The entire framework rests upon the principle of semantic uniqueness, dictating that any two sentences that share the identical meaning must also share the identical conceptual dependency representation.

The motivation for creating CD stemmed from the realization that parsing syntactic structures alone was insufficient for building genuinely intelligent systems capable of story understanding or dialogue. Language is inherently ambiguous, and multiple surface forms can convey identical underlying actions, while seemingly similar actions can have vastly different conceptual implications. For example, the actions 'to give' and 'to sell' both involve a transfer, but 'to sell' implies an exchange of money or goods, whereas 'to give' often implies altruism or simple transfer of possession without reciprocal action. CD addresses this by stripping away linguistic variability to reveal the core conceptual actions at play. This reductionist approach not only simplifies the knowledge base required for a machine to understand language but also provides a theoretical model for how human cognition might store and process linguistic information based on primitive actions and states rather than voluminous linguistic permutations. Therefore, CD serves both as a practical knowledge representation system in Artificial Intelligence and as a theoretical contribution to cognitive psychology regarding semantic memory organization.

A key principle of CD is the use of conceptual case frames, which dictate how the primitives must interact. These frames specify the required participants (actor, object, recipient, instrument) for any given primitive action. For instance, the primitive action of physically moving something (PTRANS) necessarily requires an actor performing the movement, an object being moved, an initial starting location, and a final destination. If a sentence fails to explicitly state all these elements, the CD representation structure guides the system to infer the missing information, which is a hallmark of sophisticated NLP systems. This structured dependency notation ensures that the representation is unambiguous and complete, providing a detailed semantic foundation that can be used directly for generating logical inferences about unstated events or consequences. This ability to normalize different expressions into canonical, actionable representations is perhaps the most powerful aspect of the Conceptual Dependency theory for automated reasoning.

2. Historical Development and Context

Conceptual Dependency was pioneered by Roger Schank in the context of early AI research at Stanford University and Yale University during a period when the field was moving away from logic-based and purely statistical approaches toward cognitive modeling. Schank's work was deeply influenced by the need to create AI programs that could truly "understand" text, not just translate or parse it. In the 1960s and early 1970s, many linguistic models, such as Noam Chomsky's Transformational Grammar, focused heavily on the formal rules governing syntax, often overlooking the deeper semantic content necessary for knowledge processing. Schank posited that if machines were to mimic human comprehension, they needed a semantic representation system that was independent of surface grammar. CD was initially developed in conjunction with Schank's PhD dissertation, but rapidly evolved into the foundational knowledge representation system for several seminal AI programs.

The evolution of CD was intrinsically linked to the development of specific story-understanding programs. Early programs like MARGIE (Memory, Analysis, Response Generation, and Inference on English) relied entirely on CD structures to analyze input, perform inferences, and generate responses. Later, CD became the bedrock for more sophisticated models of memory organization, most famously the Script, Plan, and Theme (SPT) theory, developed by Schank and Robert Abelson. Scripts, for example, are standardized sequences of events (e.g., the 'restaurant script') represented internally using CD primitive actions. Without the standardized, language-neutral representation provided by CD, these higher-level memory structures would be impossible to formalize computationally. Therefore, CD represents a crucial historical step, bridging the gap between raw linguistic input and organized conceptual memory structures within AI models.

CD provided a significant departure from previous approaches because it dictated that only a small, fixed set of actions and relationships were sufficient to encode the meaning of any sentence. This parsimony was radical at the time and offered a powerful alternative to systems that required

vast, unconstrained vocabularies or highly complex formal logic systems. The historical development of CD demonstrates a commitment to the cognitive reality of representation--the belief that the human mind itself operates using fundamental conceptual units, a view that placed Schank's work firmly within the emerging field of Cognitive Science, which sought to understand intelligence through computational modeling. This commitment to modeling human memory mechanisms became the driving force behind Schank's subsequent research efforts throughout the 1970s and 1980s.

3. Key Concepts and Components (The Primitives)

Conceptual Dependency is fundamentally comprised of four atomic categories, which combine to retain the semantic unions of sentences in innate linguistics, as noted in the source material. These categories function as the building blocks for all conceptual representations, providing a framework for analyzing any sentence based on who did what to whom, where, and how. The use of these primitives ensures that semantic distinctions are always preserved while linguistic variations are neutralized.

The four fundamental atomic parts of the theory, expanded upon from the source content, are detailed below.

Items (Picture Producers or PPs): These correspond generally to nouns or conceptual entities that can be acted upon or described. They represent the animate or inanimate objects involved in the action. Examples include people, physical objects, and abstract concepts that can take on states (e.g., 'book,' 'John,' 'mind').

Actions (Primitive Actions or ACTs): These are the core conceptual verbs. Schank argued that all human actions can be reduced to a specific, limited set of fundamental actions, typically numbering around 11 to 15. These primitives specify the type of conceptual transition or movement occurring.

Changers of Items (Picture Aiders or PAs): These correspond to attributes or states that modify the PPs. PAs are often represented linguistically as adjectives or as states of being. They describe the condition of an item (e.g., 'happy,' 'tall,' 'broken'). In CD diagrams, a state change is a crucial element, showing how the value of an attribute changes over time due to an action.

Changers of Actions (Action Aiders or AAs): These are modifications to the primitive actions, often corresponding to adverbs in natural language. They describe the manner in which an action is performed (e.g., 'quickly,' 'loudly,' 'carefully').

The most defining aspect of CD is the set of **Primitive Actions (ACTs)**, as they govern the entire structure of the conceptual representation. Schank detailed these actions to be exhaustive across all possible human physical and mental activities. Examples of these primitives include: **PTRANS** (Physical TRANSfer of location, e.g., 'John went home'); **ATRANS** (Abstract TRANSfer of

possession or control, e.g., 'Mary gave John a book'); **MTRANS** (Mental TRANSfer of information, e.g., 'John told Mary a secret'); **MBUILD** (Mental BUILDing of new information, e.g., 'Mary decided'); **INGEST** (Taking something into an organism, e.g., 'John ate the soup'); **EXPEL** (Forcing something out of an organism, e.g., 'Mary cried'); and **MOVE** (Moving a body part, e.g., 'John waved'). By restricting all verbs in the language to these few fundamental actions, the system forces semantic clarity and consistency, which is vital for automated inference generation.

4. Structure of Conceptual Dependency Diagrams

The CD framework uses a specific graphical notation to represent the relationships between the conceptual primitives, ensuring that the roles played by each element in the sentence are clearly defined. This notation is crucial for the computational aspect of the theory, transforming the linear structure of language into a directed graph structure that highlights causality and dependency. The basic structure involves conceptual links (arrows and double arrows) connecting the Actor (PP), the Action (ACT), and the various Conceptual Cases (Object, Recipient, Instrument).

The core relationship is the Actor-Action link, typically represented by a double arrow ($\Leftrightarrow$), signifying a two-way dependency between an actor and the primitive action they performed. For example, if 'John' (PP) performs 'PTRANS' (ACT), the diagram shows John $\Leftrightarrow$ PTRANS. Other links specify the object of the action (an arrow pointing from the ACT to the PP that is the object), the direction of transfer, or the instrument used. A key feature is the relationship between an action and the resulting state change. For instance, the action 'INGEST' (eating) causes a state change in the actor (e.g., the hunger rating decreases), and this causality is explicitly mapped in the diagram using special causal links.

This rigorous structural mapping has significant advantages for inference. Since the underlying conceptual representation is constant, regardless of linguistic expression, the machine can apply fixed inference rules to the CD structure. For instance, any diagram containing the primitive action ATRANS (transfer of possession) allows the system to automatically infer that the original possessor no longer has the item and the recipient now does. Furthermore, if a CD diagram contains an action, the system can search its memory for scripts or plans that contain that action, thereby predicting subsequent potential events. This systematicity makes CD a powerful tool for modeling complex narrative understanding where explicit statements are often sparse and vast amounts of information must be inferred.

5. Applications and Influence

Conceptual Dependency was highly influential in the 1970s and 1980s, providing the computational backbone for several pioneering AI systems in Natural Language Processing. Its primary application was in the development of sophisticated story-understanding and memory

systems, demonstrating that machines could move beyond simple keyword matching to genuinely process the meaning and implications of text.

MARGIE (Memory, Analysis, Response Generation, and Inference on English): MARGIE was one of the first systems to utilize CD heavily. It took English sentences, converted them into CD representations, used these representations to generate inferences (i.e., making educated guesses about unstated consequences or motivations), and then generated new English sentences based on the inferred CD structures. This system demonstrated the power of the canonical semantic representation for complex cognitive tasks.

SAM (Script Applier Mechanism): Developed by Schank's group, SAM used CD as the language for defining and applying 'Scripts'--pre-packaged, standardized sequences of events (e.g., going to a doctor, visiting a bank). When SAM encountered a story, it converted the sentences into CD, matched the CD structure to a known script, and used the script's expected sequence of events to fill in gaps and make predictions, vastly improving comprehension and summarization ability.

PAM (Plan Applier Mechanism): Building on SAM, PAM used CD to represent and understand goal-directed behavior based on 'Plans' and 'Themes,' moving beyond routine script applications to understand novel situations. PAM demonstrated how CD could encode complex human motivations and intentionality, such as understanding why a character performed a certain action based on their established goals.

Beyond specific applications, CD's most lasting influence is its contribution to the field of **Knowledge Representation**, emphasizing the necessity of semantic primitives and canonical forms for AI. The concepts developed within CD directly led to the development of higher-level organizational structures (Scripts, MOPs - Memory Organization Packets) that influenced research in cognitive modeling, memory structure, and the philosophy of language representation throughout the late 20th century. Although modern NLP systems often rely on statistical and deep learning models, the fundamental cognitive principle--that understanding requires reducing language to its core conceptual components--remains a powerful theoretical underpinning in cognitive science.

6. Criticisms and Limitations

Despite its theoretical elegance and practical success in early AI systems, Conceptual Dependency faced significant criticism, largely concerning its scalability, reductionism, and inherent complexity when dealing with highly abstract concepts.

One of the primary objections centers on the **reductionist nature** of the primitive actions. While primitives like PTRANS and INGEST work well for simple, physical actions, critics argue that reducing abstract concepts--such as 'believing,' 'loving,' 'hoping,' or 'justice'--to combinations of the 11 or so fundamental actions is either impossible or results in representations that are excessively

cumbersome and unintuitive. The effort required to encode a complex, nuanced concept often outweighs the benefit of using the primitive system, suggesting that the initial set of primitives may be incomplete or insufficient for encoding the full spectrum of human linguistic meaning. Furthermore, the selection of the primitives themselves was sometimes viewed as arbitrary or culturally biased, raising questions about the universal applicability of the system across all human languages and conceptual structures.

Another significant limitation involves the practical complexity of implementation. While CD simplifies the number of possible 'verbs,' the process of analyzing a raw English sentence and converting it into the appropriate, highly structured CD diagram is computationally demanding and requires extensive knowledge engineering. The conversion process is often highly complex, relying on intricate rules and inference mechanisms to map surface linguistic features to the appropriate underlying primitives, especially when dealing with idioms, metaphors, or complex syntactic constructions. This labor-intensive mapping process hindered the widespread adoption of CD in real-world, large-scale NLP applications, particularly as statistical and connectionist approaches began to offer simpler, less knowledge-intensive methods for achieving high performance in language tasks. The difficulty in scaling the CD knowledge base and inference rules to cover the totality of human language became a major practical barrier.

7. Further Reading

[Conceptual Dependency Theory \(Wikipedia\)](#)

[Schank, R. C. \(1972\). Conceptual dependency: A theory of natural language understanding. Cognitive Psychology, 3\(4\), 552-631.](#)

[Schank, R. C., & Abelson, R. P. \(1977\). Scripts, Plans, Goals, and Understanding: An Inquiry into Human Knowledge Structures. Erlbaum.](#)