Chapter 20
From Existential Graphs to Conceptual Graphs

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ABSTRACT

Existential graphs (EGs) are a simple, readable, and expressive graphic notation for logic. Conceptual graphs (CGs) combine a logical foundation based on EGs with features of the semantic networks used in artificial intelligence and computational linguistics. CG design principles address logical, linguistic, and cognitive requirements: a formal semantics defined by the ISO standard for Common Logic; the flexibility to support the expressiveness, context dependencies, and metalevel commentary of natural language; and cognitively realistic operations for reasoning by induction, deduction, abduction, and analogy. To accommodate the vagueness and ambiguities of natural language, informal heuristics can supplement the formal semantics. With sufficient background knowledge and a clarifying dialog, informal graphs can be refined to any degree of precision. Peirce claimed that the rules for reasoning with EGs generate "a moving picture of the action of the mind in thought." Some philosophers and psychologists agree: Peirce's diagrams and rules are a good candidate for a natural logic that reflects the neural processes that support thought and language. They are psychologically realistic and computationally efficient.

1. LANGUAGES AND DIAGRAMS FOR LOGIC

Existential graphs and the conceptual graphs based on them are formally defined, but they follow the long tradition of deriving logical patterns from language patterns. For the first formal logic, Aristotle developed a stylized or controlled version of natural language (NL). To clarify the references and reduce ambiguity, he replaced pronouns with letters. For his *Elements of Geometry*, Euclid followed Aristotle's conventions as far as he could. When he needed more expressive power, Euclid added diagrams and a broader range of language patterns. Controlled Greek was the first CNL, but logicians and mathematicians translated it to controlled Latin, Arabic, and other languages. Over the centuries, they abbreviated words and phrases with various symbols and organized them in diagrams. The plus sign +, for example, is a simplified ampersand &, which abbreviated a hand-written *et* in Latin. The oldest surviving type hierarchy is the Tree of Porphyry from the third century AD.

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In the 19th century, George Boole (1854) presented his *laws of thought* as an algebra for propositional logic: 1 for truth; 0 for falsehood; + for *or*; × for *and*; and − for *not*. Thirty years later, Gottlob Frege and Charles Sanders Peirce independently developed notations for first-order logic (FOL). Frege (1879) invented tree diagrams for representing FOL, but nobody else adopted his notation. Peirce added *n*-adic relations to Boolean algebra in 1870, introduced quantifiers in 1880, and extended the algebraic notation to both first-order and higher-order logic in 1885. Giuseppe Peano (1889) adopted Peirce's algebra and changed some of the symbols to create the modern notation for predicate calculus. But in 1896, Peirce invented *existential graphs* (EGs) as a more *diagrammatic* notation for "the atoms and molecules of logic."

As an example, the English sentence *A cat is on a mat* and a controlled English version would be identical. Since Boolean algebra cannot represent the details of relations and quantifiers, it can only represent the full proposition by a single unanalyzed letter *p*. For his relational algebra of 1870, Peirce invented a notation for the details at the word and phrase level: Cat_i for a cat *i*, Mat_j for a mat *j*, and $\text{On}_{i,j}$ for something *i* on something *j*. The conjunction ($\text{Cat}_i \bullet \text{On}_{i,j} \bullet \text{Mat}_j$) can be read as an abbreviation for *A cat i is on a mat j*, but Peirce did not have a systematic way of handling quantifiers. In 1880, while he was revising his father's book on linear algebra, Peirce noticed that the Greek letters Σ for repeated addition and Π for repeated multiplication could be adapted to logic: the existential quantifier corresponds to repeated *or*, and the universal quantifier corresponds to repeated *and*. With existential quantifiers in front, the following formula represents the sentence *There exists something i, there exists something j, i is a cat, i is on j, and j is a mat*:

$$\Sigma_i\, \Sigma_j\, \text{Cat}_i \bullet \text{On}_{i,j} \bullet \text{Mat}_j$$

Since Peano wanted to mix mathematical and logical symbols in the same formulas, he invented new symbols by turning letters upside down or backwards. He replaced Boole's + for *or* with ∨ for the Latin *vel*, and he turned ∨ upside down for *and*. For the existential quantifier, he turned E backwards for ∃. With these symbols, Peano's version of Peirce's formula becomes:

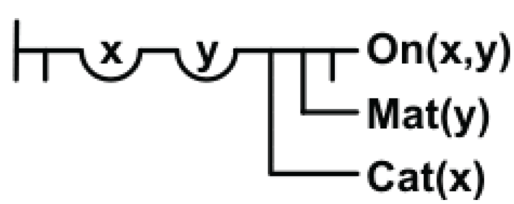
$$\exists i\, \exists j\, \text{Cat}(i) \wedge \text{On}(i,j) \wedge \text{Mat}(j)$$

The developments from Boole to Peirce to Peano continued the Aristotelian tradition of relating language to logic. But Frege (1879) had a low opinion of natural language. His goal was "to break the domination of the word over the human spirit by laying bare the misconceptions that through the use of language often almost unavoidably arise concerning the relations between concepts." For his *Begriffsschrift* (concept writing), Frege used only the operators that occur in his rules of inference: assertion (vertical line), negation (short vertical line), universal quantifier (cup that contains a variable), and implication (hook). Figure 1 represents *A cat is on a mat* with Frege's operators.

At the left of Figure 1, the vertical line asserts the entire diagram. The short vertical lines represent *not*, the cups represent *for every*, and the hooks represent *if-then*. With these operators, the diagram may be read *It is false that for every x, for every y, if x is a cat, then if y is a mat, then x is not on y*.

By contrast, Peirce's existential graph in Figure 2 expresses the sentence with a minimum of

Figure 1. Begriffsschrift for: A cat is on a mat



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