An Introduction to Inheritance Theory

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Talk Overview

- What's human reasoning?
- What's so special about commonsense reasoning?
- Inheritance Theory, an alternative model for representing common sense.
- Conclusion.

Defining Human Reasoning

- **A common definition involves two categories, deduction and induction.**

$$\frac{\textit{Gaby is crying.}}{\textit{Someone is crying.}} \tag{1}$$

$$\frac{\textit{Gaby is crying.}}{\textit{Everyone is crying.}} \tag{2}$$

$$\frac{\textit{Gaby is crying.}}{\textit{The sun is shining.}} \tag{3}$$

Defining Human Reasoning (continued)

- An alternative definition is the *strict* and *loose* views of reasoning.
- What do the previous definitions have in common?
- Are there other definitions?

Defining Human Reasoning (continued)

- **Consider the following framework of reasoning:**

$$y = F(x) \tag{4}$$

Defining Human Reasoning (continued)

- **Now consider the expanded framework below:**

$$y = F(x, k) \tag{5}$$

Defining Human Reasoning (continued)

- **Reasoning can also be defined as *Weak*, based on $y = F(x)$, and *Strong*, based on $y = F(x, k)$, methods.**

- **Where does *analogical reasoning* (structural alignment) fit in?**

Commonsense Reasoning

- **What is it?**

  Grapes are fruit.
  Bananas are fruit.
  Onions are neither grapes nor bananas.

Commonsense Reasoning

- **But what if we later learned more information?**

    Grapes are fruit.
    Bananas are fruit.
    Onions are neither grapes nor bananas.
    Onions are herbs.

Commonsense Reasoning (continued)

- **The ability to reason with incomplete information and to change our minds (non-monotonic reasoning).**

- **How can we formalize it?**

Commonsense Reasoning (continued)

- **Mathematical logic was devised to formalize precise facts and correct reasoning.**

Grapes are fruit.
Bananas are fruit.
Onions are neither grapes nor bananas.

$$\forall x.(grapes(x) \Rightarrow fruit(x)) \tag{6}$$

$$\forall x.(bananas(x) \Rightarrow fruit(x)) \tag{7}$$

$$\forall x.(onions(x) \Rightarrow \neg(grapes(x) \vee bananas(x))) \tag{8}$$

Commonsense Reasoning (continued)

- **Mathematical logic is monotonic in nature.**

$$\textit{if } \Phi \vdash \alpha \textit{ and } \Phi \subseteq \psi, \textit{ then } \psi \vdash \alpha. \tag{9}$$

Commonsense Reasoning (continued)

- **Why give a computer commonsense?**
- **How are computers endowed *with commonsense?***
- ***Default Logic,* Circumscription, *Closed World Assumption*, and *Inheritance Theory* provide a means for representing commonsense reasoning.**

Commonsense Reasoning (continued)

- **An example of reasoning with *default reasoning*.**

knowledge base: $has(menu, enchiladas)$ (10)

$has(menu, mole)$

defaults rules:

$$\frac{has(menu, enchiladas) : M(order(enchiladas))}{order(enchiladas)} \quad (11)$$

$$\frac{has(menu, mole) : M(order(mole))}{order(mole)} \quad (12)$$

Commonsense Reasoning (continued)

- **Reasoners are generally divided into two categories: *skeptical* and *credulous*.**

Inheritance Theory

- **An *Inheritance Network* or *Inheritance Hierarchy* is a directed acyclic graph.**

- **Reasoning is done using a *Path-Based* approach.**

Inheritance Theory (continued)

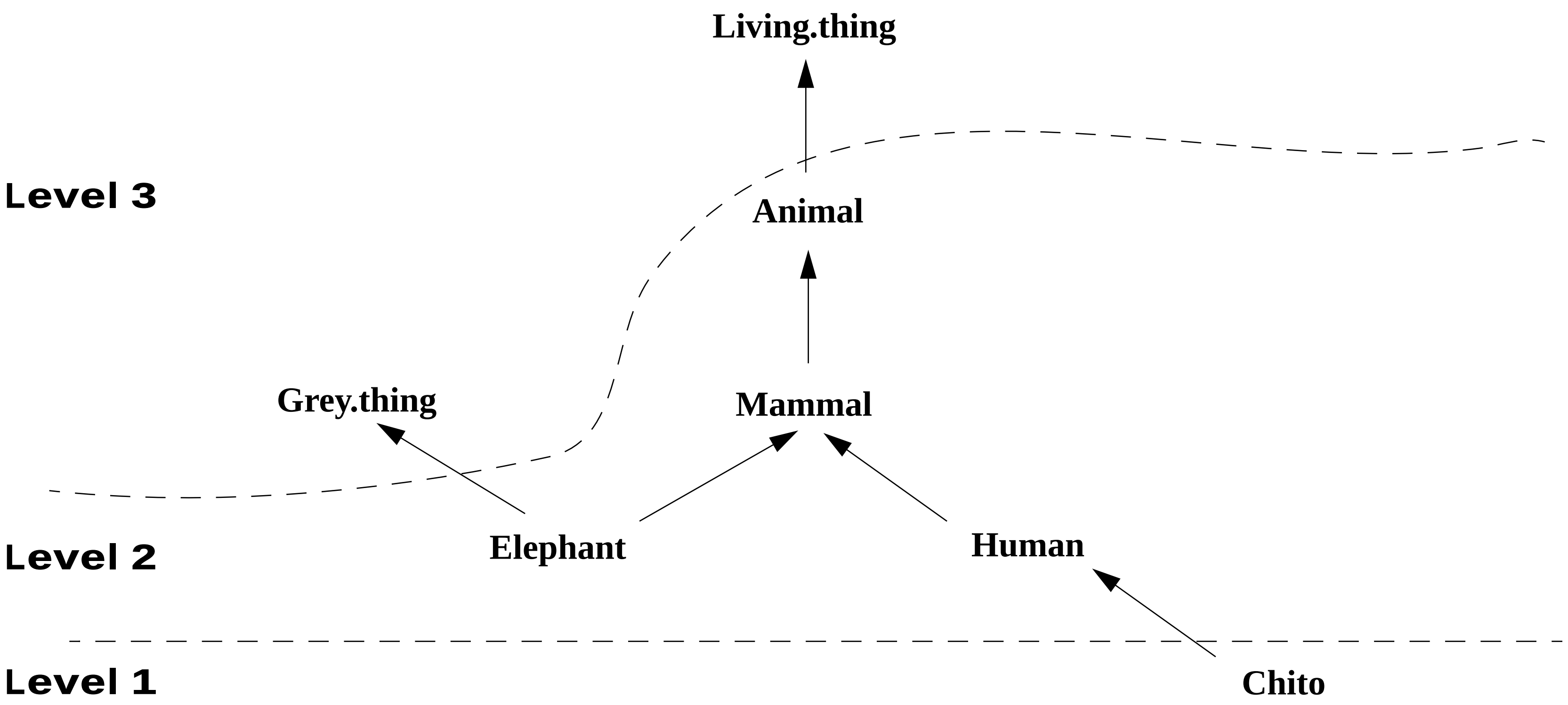

FIGURE 1: An Inheritance Hierarchy has three conceptual levels.

Inheritance Theory (continued)

- **Common Terminology: is a, is not a, negative links, positive links, polarity of a path, inheritable, un-inheritable, etc.**

FIGURE 2: Two simple Inheritance Hierarchies.

Inheritance Theory (continued)

- **Negative paths introduce complications analogous to introducing negation in logic programs.**

- **The *principle of specificity*, more specific information should override less specific information.**

Inheritance Theory: Exceptions

- **An exception is the negation of an inheritable structural link in a hierarchy.**

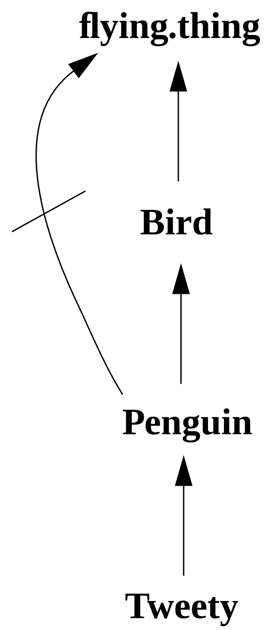

FIGURE 3: An Inheritance Hierarchy with an exception.

Inheritance Theory: Redundancy

- **Redundant links can cause side effects.**

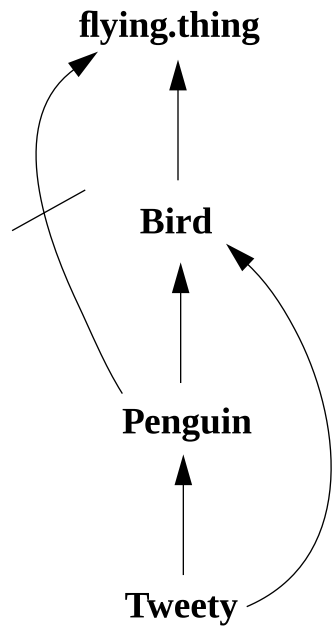

FIGURE 4: An Inheritance Hierarchy containing a redundant link.

Inheritance Theory: Ambiguity

- **Is Nixon a pacifist or not?**

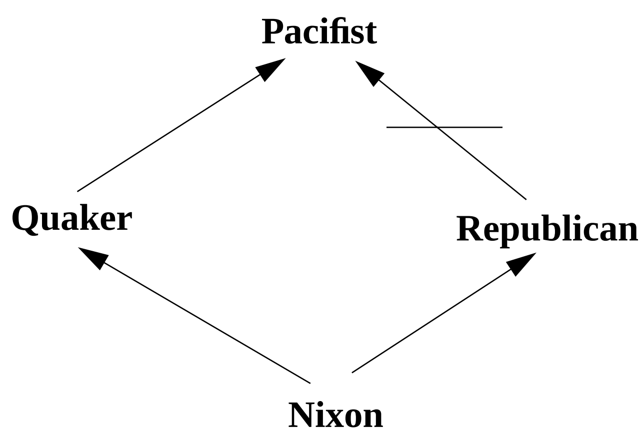

FIGURE 5: An ambiguous Inheritance Hierarchy.

Inheritance Theory: Ambiguity (cont.)

- **What's a doctor to do?**

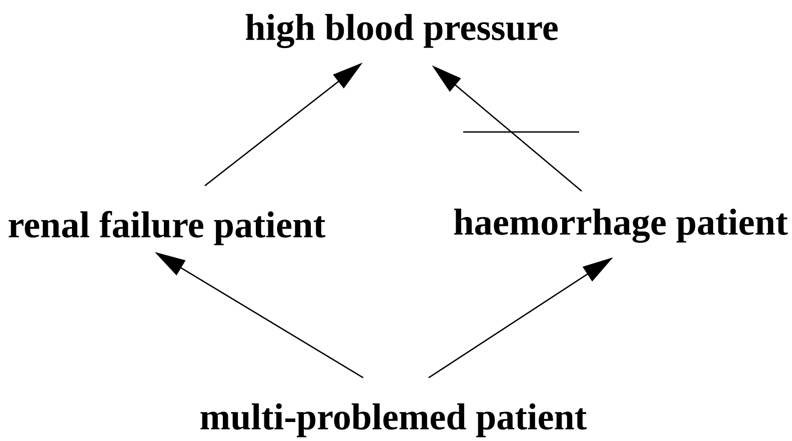

FIGURE 6: An Inheritance Hierarchy with evidence-based properties.

Inheritance Theory: Concatenation

- ***Downward concatenation*** **in a hierarchy with the sequence of links** $x_1 \to x_2 \to \ldots \to x_n$ **will permit the path** $x_1 \to x_n$ **or** $x_1 \not\to x_n$ **only if** $x_2 \to x_n$ **or** $x_2 \not\to x_n$ **are permitted respectively.**

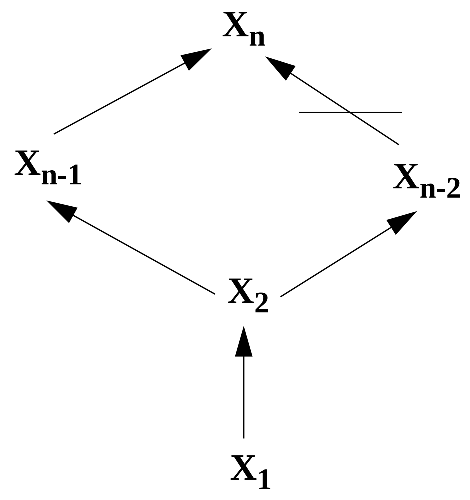

FIGURE 7: Example Inheritance Hierarchy.

Inheritance Theory: Concatenation (cont.)

- ***Upward concatenation*** **in a hierarchy with the sequence of links** $x_1 \to x_2 \to \ldots \to x_n$ **will permit the path** $x_1 \to x_n$ **or** $x_1 \not\to x_n$ **only if** $x_1 \to x_{n-1}$ **or** $x_1 \not\to x_{n-2}$ **respectively.**

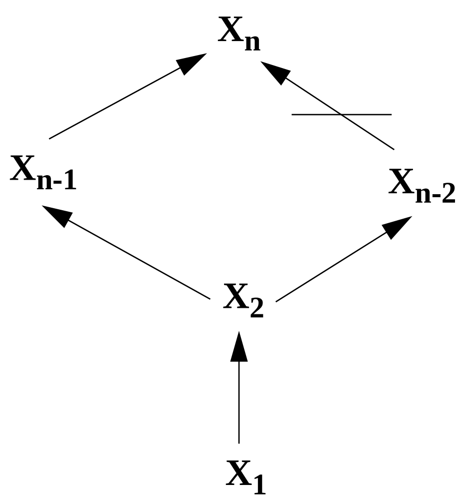

FIGURE 8: Example Inheritance Hierarchy.

Inheritance Theory: Reasoners

- **What about *Credulous* and *Skeptical* reasoners?**

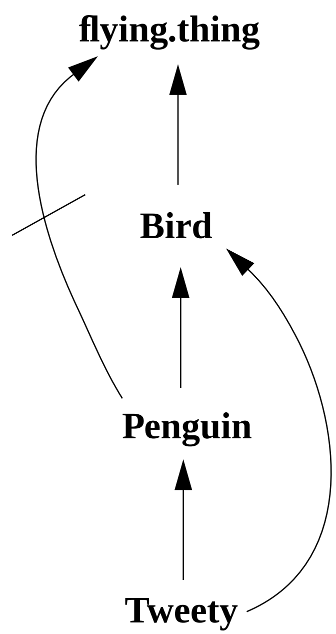

FIGURE 9: An Inheritance Hierarchy for Tweety the land loving bird.

Inheritance Theory: Pre-emption

- ***Pre-emption*** **supports the idea that more specific information should override less specific information.**

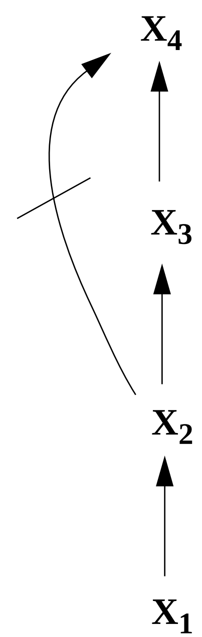

FIGURE 10: An example Inheritance Hierarchy.

Inheritance Theory: Pre-emption (cont.)

- ***On-path Pre-emption*, a path may pre-empt another only if the pre-empted path contains a redundant link that would short circuit part of the pre-emptor.**

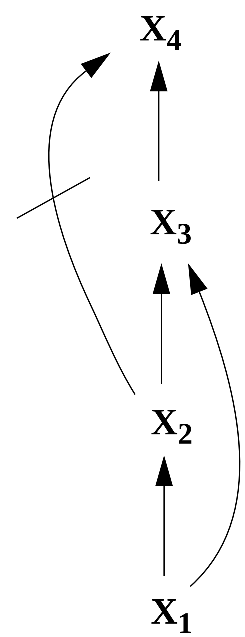

FIGURE 11: An example Inheritance Hierarchy demonstrating on-path pre-emption.

Inheritance Theory: Pre-emption (cont.)

- ***Off-path Pre-emption*, if no redundant link exists or if the redundant link is interrupt by another node, a path that explicitly gives information overrides non-explicit paths.**

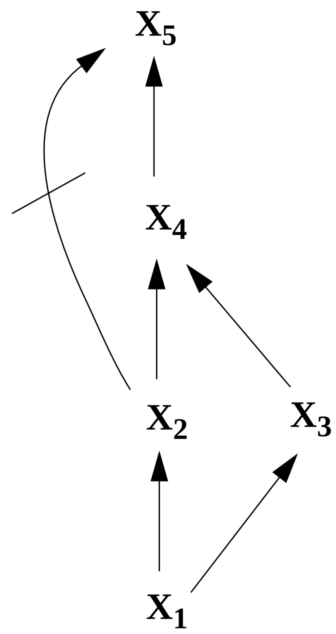

FIGURE 12: An example Inheritance Hierarchy demonstrating off-path pre-emption.

Inheritance Theory: Directions of Reasoning

- **There are *Skeptical Downward/Upward Reasoners* and *Credulous Downward/Upward Reasoners*.**

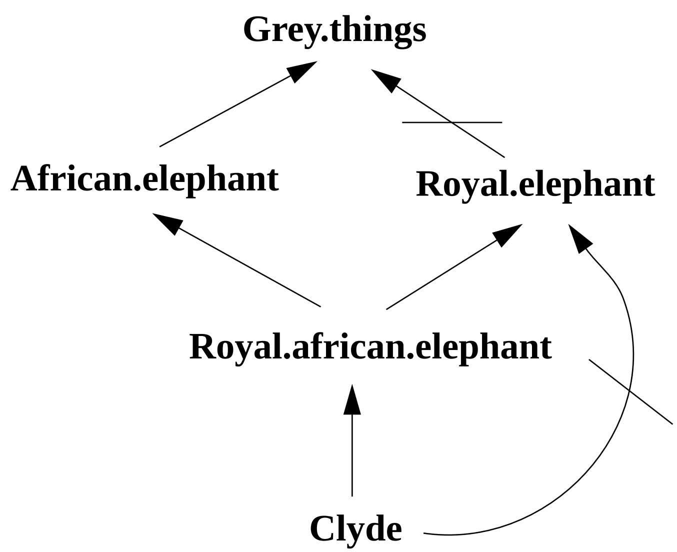

FIGURE 13: Directions of Path-Based Reasoning.

Inheritance Theory: Mistaken Folk Theorem

- Translating a hierarchy into first-order logic isn't necessarily done on a link by link basis.

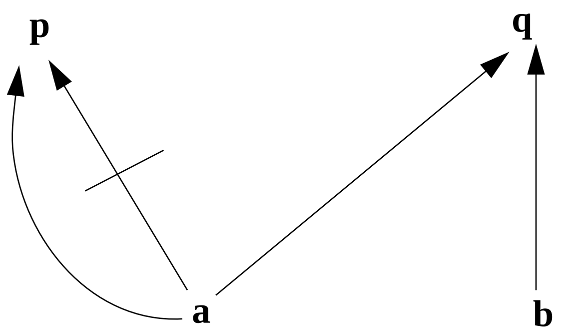

FIGURE 14: Folk Theorem Counterexample.

Inheritance Theory: Ambiguity

- **How does it apply to credulous or skeptical reasoners?**

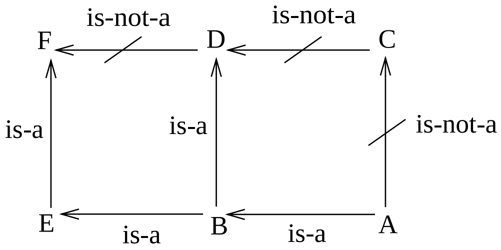

FIGURE 15: Inheritance Hierarchy with Ambiguity.

Inheritance Theory: Ambiguity (Continued)

- ***Ambiguity Blocking Inheritance*** **hopes to stop ambiguity at a later time.**

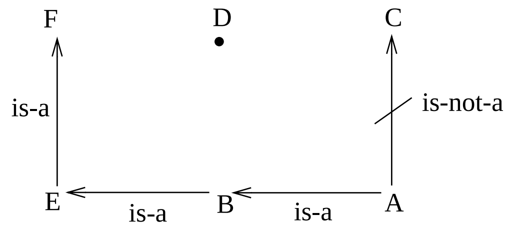

FIGURE 16: Ambiguity Blocking Inheritance applied to Figure 1.

Inheritance Theory: Ambiguity (Continued)

- ***Ambiguity Propagation Inheritance*** **takes the point of view that no real choice can be made.**

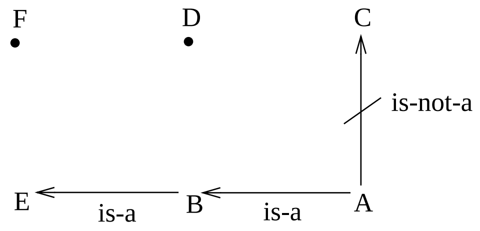

FIGURE 17: Ambiguity Propagation Inheritance applied to Figure 1.

Inheritance Reasoning: Techniques

- **NETL (Fahlman, 1979)**
- **FRL (Robert, 1977)**
- **TINA (Touretzky, 1984)**
- **TMOIS (Touretzky, 1986)**
- **EIR (Al-Asady,1993)**

Conclusion

- **The cost of commonsense reasoning.**

TABLE 1:The Complexity of Default Logic.

	Restrictions	Task	Complexity	Reference
1.	Propositional semi-normal default rules	Extension Finding	Σ_2^P*–complete*	[34], [35], [36]
2.	Propositional rules	Credulous Reasoning	Σ_2^P*–complete*	[34], [35]
3.	Propositional normal default rules with no *Pre-requisite*	Skeptical Reasoning	Π_2^P*–complete*	[34], [35]
4.	First-order rules	Credulous Reasoning	Not recursively enumerable	[8]

Conclusion (Continued)

- **The *Frame Problem*, the complication of what needs to change in the representation when new information is received.**

References

[1] Rips, L.J., Reasoning, *Annual review of psychology*, Volume 41, 1990, Pages 321-354.

[2] Kurtz, K.J., Genter, D., and Gunn, V., Reasoning, *Cognitive Science*, 1999, Pages 145-200.

[3] Aamodt, A. and Plaza, E., Cased-Based Reasoning: Foundational Issues, Methodological Variations, and System Approaches, *AI Communications*, Volume 7, Number 1, March 1994, Pages 39-59.

[4] Kolodner, J., *Case-Based Reasoning*, Morgan Kaufmann Publishers, Inc., 1993.

[5] Leake, D.B., *Case-Based Reasoning: Experiences, Lessons, and Future Directions*, AAAI Press/MIT Press, 1996.

[6] Bergmann, R. and Wolfgang, W., On the role of Abstraction in Case-Based Reasoning. *Advances in Case-Based Reasoning*, Volume 1168 of Lecture Notes in Artificial Intelligence, Springer, 1996, Pages 28-43.

[7] Quillian, M.R., Semantic Memory, *Semantic Information Processing*, 1968, Pages 227-270.

[8] Reiter, R., A Logic for Default Reasoning, *Artificial Intelligence*, Volume 13, North Holland Publishing Company, 1980, Pages 81-132.

[9] Al-Asady, R., *Inheritance Theory: An Artificial Intelligence Approach*, Ablex Publishing Corporation, 1995.

[10] Schlechta, K., *Nonmontonic Logics, Basic Concepts, Results, and Techniques*, Springer, 1997.

[11] Harary, F., *Graph Theory*, Addison Wesley, 1969.

[12] Davis, E., www-formal.stanford.edu/leora/cs, New York University, September 1997.

[13] Hayes, P., and Shastri, L., www-formal.stanford.edu/leora/cs, University of West Florida and International Computer Science Institute, July, 1997.

[14] Davis, E., *Representations of Commonsense Knowledge*, Morgan Kaufmann Publishers, Inc., 1990, Pages 106-109.

[15] Barden, J., Lectures in Commonsense Reasoning, *Artificial Intelligence II*, New Mexico State University, Fall 1995.

[16] McDermott, D. and Doyle, J., Non-Monotonic Logic I, *Artificial Intelligence 13*, 1980, Pages 41-72.

[17] Ebbinghaus, H.-D., Flum, J.T., W., *Mathematical Logic*, Springer-Verlag, New York, 1980

[18] Gehrke, M., Lectures in Mathematical Logic, *Mathematical Logic*, New Mexico State University, Fall 1994.

[19] Reiter, R., On Closed World Data Bases, *Logic and Data bases*, Plenum Press, 1978, Pages 55-76.

[20] McCarthy, J., Circumscription - A form of Non-Monotonic Reasoning, *Artificial Intelligence*, Volume 13, North-Holland Publishing Company, 1980, Pages 27-39.

[21] Reiter, R., A Default Logic for Default Reasoning, *Artificial Intelligence 13*, North Holland Publishing Company, 1980, Pages 81-132.

[22] Marek, V.W., Non-monotonic Reasoning: Recent Advances, Questions and Future Directions, Invited Speaker, *8th International Workshop on Non-monotonic Reasoning*, 2000.

[23] McCarthy, J., Application of Circumscription to Formalizing Commonsense Knowledge, *Artificial Intelligence*, Volume 26, North-Holland Publishing Company, 1986, Pages 89-116.

[24] Gelfond, M., Lifschitz, V., The Stable Model Semantics for Logic Programming, *Proceedings of the 5th International Conference on Logic Programming*, The MIT Press, 1988, Pages 1070-1080.

[25] Gelder, A.V., Ross, K.A., Schlipf, J.S., The Well-Founded Semantics for General Logic Programs, *Journal of the ACM*, Volume 38, Number 3, July 1991, Page 620-650.

[26] Niemela, I., Simons, P., Smodels - An Implementation of the Stable Model and Well-Founded Semantics for Normal Logic Programs, *Proceedings of the Joint International Conference and Symposium on Logic Programming*, 1996, Pages 289-303.

[27] Rao, P., Sagonas, K., Swift, T., Warren, D., and Freire, J., XSB - A System for Efficiently Computing Well-Founded Semantics, Logic Programming and Non-Monotonic Reasoning, *Proceedings of the Fourth International Conference*, Springer, 1997, Pages 430-440.

[28] Eiter, T., Leone, N., Mateis, C., Pfeifer, G., Scarcello, F., A Deductive System for Non-Monotonic Reasoning, *Proceedings of the 4th International Conference on Logic Programming and Non-monotonic Reasoning*, Springer, 1997.

[29] Cholewinski, P., Marek, V.M., Mikitiuk, A., Truszczynski, M., Computing with Default Logic, *Artificial Intelligence*, Volume 112, Number 1 and 2, August 1999, Pages 105-146.

[30] Blum, J., A Machine-Independent Theory of the Complexity of Recursive Functions, *Journal of the ACM 14*, Volume 2, 1967, Pages 322-336.

[31] Papadimitriou, C.H., *Computational Complexity,* Addison-Wesley, 14, Volume 2, 1994, Pages 322-336.

[32] Hopcroft, J.E., Ullman, J.D., *Introduction to Automata Theory, Languages, and Computation*, Addison-Wesley, 1979.

[33] Ranjan, D., Lectures in Computability, *Theory of Computation*, New Mexico State University, Spring 1995.

[34] Gottlob, G., Complexity Results for Non-Monotonic Logics, *Journal of Logic and Computation 2*, 1992, Pages 397-425.

[35] Stillman, J., The Complexity of Propositional Default Logics, *Proceedings of the Tenth National Conference on Artificial Intelligence*, 1992, Pages 794-800.

[36] Papadimitriou, C.H., On Finding Extensions of Default Theories, *Proceedings of the International Conference on Database Theory*, 1992, Pages 276-281.

[37] Kautz, H.A. and Selman, B., Hard Problems for Simple Default Logics, *Artificial Intelligence*, 1991, Pages 243-279.

[38] Stillman J., It's Not My Default: The Complexity of Membership Problems in Restricted Propositional Default Logics, *Proceedings of the Eighth National Conference on Artificial Intelligence*, 1990, Pages 571-578.

[39] Dimopoulos, Y. and Magirou, V., A Graph Theoretic Approach to Default Logic, *Journal of Information and Computation*, Volume 112, Number 2, 1994, Pages 239-256.

[40] Baader, F. and Hollunder, B., Embedding Defaults into Terminological Knowledge Representation Formalisms, *Journal of Automated Reasoning*, Volume 14, Number 1, 1995, Pages 149-180.

[41] Apt, K.R. and Blair, H.A., Arithmetic Classification of Perfect Models of Stratified Programs, Fifth International Conference and Symposium on Logic Programming, 1988, Pages 766-779.

[42] McCarthy, J., Applications of Circumscription to Formalizing Common-sense Knowledge, *Artificial Intelligence*, Volume 26, 1986, Pages 89-116.

[43] Schlipf, J.S., Decidability and Definability with Circumscription, *Annals of Pure and Applied Logic*, Volume 35, Number 14, 1987, Pages 173-191.

[44] Eiter, T. and Gottlob, G., Propositional Circumscription and Extended Closed World Reasoning are Π_2^p, *Theoretical Computer Science*, Volume 114, 1993, Pages 231-245.

[45] Schlipf, J.S., When is Closed world Reasoning Tractable?, *Proceedings of the 3rd International Symposium on Methodology for Intelligent Systems*, 1988, Pages 485-494.

[46] Papadimitriou, C.H., On Selecting a Satisfying Truth Assignment (Extended Abstract), *Proceeding of the 32nd Annual Symposium on the Foundations of Computer Science (FOCS-91)*, 1991, Pages 163-169.

[47] Gottlob, G. and Fermuller, C.G., Removing Redundancy from a Clause, *Artificial Intelligence*, Volume 61, Number 2, 1993, Pages 263-289.

[48] Kolaitis, P.G. and Papadimitriou, C.H., Some Computational aspects of Circumscription, *Journal of the ACM*, Volume 37, 1990, Pages 1-14.

[49] Cadoli, M. and Schaerf, M., A Survey of Complexity Results for Non-Monotonic Logics, *Journal of Logic Programming*, Volume 17, 1993, Pages 127-160.

[50] Chang, C.L., Lee, R.C.T., *Symbolic Logic and Mechanical Theorem Proving*, Academic Press, 1973, Pages 7-92.

[51] Crockett, Larry, J., *The Turing Test and the Frame Problem*, Ablex Publishing Corporation, 1994.

[52] ResearchIndex, Scientific Literature Digital Library, http://citeseer.nj.nec.com.

[53] Merriam-Webster Collegiate Dictionary, http://www.m-w.com/netdict.htm.