# Common Sense Computing: from the Society of Mind to Digital Intuition and Beyond


Erik Cambria[1], Amir Hussain[1], Catherine Havasi[2], and Chris Eckl[3]

[1] Dept. of Computing Science and Maths, University of Stirling, Scotland, UK
[2] MIT Media Lab, MIT, Massachusetts, USA
[3] Sitekit Labs, Sitekit Solutions Ltd, Scotland, UK
{eca,ahu}@cs.stir.ac.uk,havasi@media.mit.edu,chris.eckl@sitekit.net
http://sentic.net



**Abstract.** What is Common Sense Computing? And why is it so important for the technological evolution of humankind? This paper presents an overview of past, present and future efforts of the AI community to give computers the capacity for Common Sense reasoning, from Minsky's Society of Mind to Media Laboratory's Digital Intuition theory, and beyond. Is it actually possible to build a machine with Common Sense or is it just an utopia? This is the question this paper is trying to answer.



**Key words:** AI, Semantic networks, NLP, Knowledge base management


## 1 Introduction

What magical trick makes us intelligent? - Marvin Minsky was wondering more than two decades ago - The trick is that there is no trick. The power of intelligence stems from our vast diversity, not from any single, perfect principle [1]. Human brain in fact is a very complex system, maybe the most complex in nature. The functions it performs are the product of thousands and thousands of different subsystems working together at the same time. Such a perfect system is very hard to emulate: nowadays in fact there are plenty of expert systems around but none of them is actually intelligent, they just have the veneer of intelligence. The aim of Common Sense Computing is to teach computers the things we all know about the world and give them the capacity for reasoning on these things.

## 2 The Importance of Common Sense

Communication is one of the most important aspects of human life. Communicating has always a cost in terms of energy and time, since information needs to be encoded, transmitted and decoded. This is why people, when communicating with each other, provide just the useful information and take the rest for granted. This 'taken for granted' information is what we call Common Sense: obvious things people normally know and usually leave unstated.

We are not talking about the kind of knowledge you can find in Wikipedia but all the basic relationships among words, concepts, phrases and thoughts that allow people to communicate with each other and face everyday life problems. It is a kind of knowledge that sounds obvious and natural to us but it is actually daedal and multifaceted: the illusion of simplicity comes from the fact that, as each new group of skills matures, we build more layers on top of them and tend to forget about the previous layers.

Today computers lack this kind of knowledge. They do only what they are programmed to do: they only have one way to deal with a problem and, if something goes wrong, they get stuck. This is why nowadays we have programs that exceed the capabilities of world experts but are not one able to do what a three years old child can do. Machines can only do logical things, but meaning is an intuitive process: it cannot be reduced to zeros and ones.

To help us work, computers must get to know what our jobs are. To entertain us, they need to know what we like. To take care of us, they have to know how we feel. To understand us, they must think as we think. We need to transmit computers our Common Sense knowledge of the world because soon there will not be enough human workers to perform the necessary tasks for our rapidly aging population. To face this AI emergency, we will have to give them physical knowledge of how objects behave, social knowledge of how people interact, sensory knowledge of how things look and taste, psychological knowledge about the way people think, and so on. But having a database of millions of Common Sense facts will not be enough: we will also have to teach computers how to handle this knowledge, retrieve it when necessary, learn from experience, in a word we will have to give them the capacity for Common Sense reasoning.

## 3 The Birth of Common Sense Computing

It is not easy to state when exactly Common Sense Computing was born. Before Minsky many AI researchers started to think about the implementation of a Common Sense reasoning machine: the very first one was maybe Alan Turing when, in 1950, he first raised the question "can machines think?". But he never managed to answer that question, he just provided a method to gauge artificial intelligence: the famous Turing test.

### 3.1 The Advice Taker

The notion of Common Sense in AI is actually dated 1958, when John McCarthy proposed the 'advice taker' [2], a program meant to try to automatically deduce for itself a sufficiently wide class of immediate consequences of anything it was told and what it already knew. McCarthy stressed the importance of finding a proper method of representing expressions in the computer and developed the idea of creating a property list for each object in which are listed the specific things people usually know about it. It was the first attempt to build a Common Sense knowledge base but, more important, it was the epiphany of the need of Common Sense to move forward in the technological evolution.

### 3.2 The Society of Mind Theory of Human Cognition

While McCarthy was more concerned with establishing logical and mathematical foundations for Common Sense reasoning, Minsky was more involved with theories of how we actually reason using pattern recognition and analogy. These theories were organized in 1986 with the publication of The Society of Mind, a masterpiece of AI literature containing an illuminating vision of how the human brain works.

Minsky sees the mind made of many little parts called 'agents', each mindless by itself but able to lead to true intelligence when working together. These groups of agents, called 'agencies', are responsible to perform some type of function, such as remembering, comparing, generalizing, exemplifying, analogizing, simplifying, predicting, and so on. The most common agents are the so called 'K-lines' whose task is simply to activate other agents: this is a very important issue since agents are all highly interconnected and activating a K-line can cause a significant cascade of effects. To Minsky, in fact, mental activity ultimately consists in turning individual agents on and off: at any time only some agents are active and their combined activity constitutes the 'total state' of the mind.

K-lines are a very simple but powerful mechanism since they allow entering a particular configuration of agents that formed a useful society in a past situation: this is how we build and retrieve our problem solving strategies in our mind, this is how we should develop our problem solving strategies in our programs.

## 4 Towards Programs with Common Sense

Minsky's theory was welcomed with great enthusiasm by the AI community and gave birth to many attempts to build Common Sense knowledge bases and exploit them to develop intelligent systems, e.g., Cyc and WordNet.

### 4.1 The Cyc Project

Cyc [3] is one of the first attempts to assemble a massive knowledge base spanning human Common Sense knowledge. Initially started by Doug Lenat in 1984, this project utilizes knowledge engineers who handcraft assertions and place them into a logical framework using CycL, Cyc's proprietary language.

Cyc's knowledge is represented redundantly at two levels: a frame language distinction (epistemological level), adopted for its efficiency, and a predicate calculus representation (heuristic level), needed for its expressive power to represent constraints. While the first level keeps a copy of the facts in the uniform user language, the second level keeps its own copy in different languages and data structures suitable to be manipulated by specialized inference engines. Knowledge in Cyc is also organized into 'microtheories', resembling Minsky's agencies, each one with its own knowledge representation scheme and sets of assumptions.

### 4.2 WordNet

Begun in 1985 at Princeton University, WordNet [4] is a database of words, primarily nouns, verbs and adjectives. It has been one of the most widely used resources in computational linguistics and text analysis for the ease in interfacing it with any kind of application and system.

The smallest unit in WordNet is the word/sense pair, identified by a 'sense key'. Word/sense pairs are linked by a small set of semantic relations such as synonyms, antonyms, is-a superclasses, and words connected by other relations such as part-of. Each synonym set, in particular, is called synset: it consists in the representation of a concept, often explained through a brief gloss, and represents the basic building block for hierarchies and other conceptual structures in WordNet.

## 5 From Logic Based to Common Sense Reasoning

Using logic-based reasoning can solve some problems in computer programming. However, most real-world problems need methods better at making decisions based on previous experience with examples, or by generalizing from types of explanations that have worked well on similar problems in the past.

In building intelligent systems we have to try to reproduce our way of thinking: we turn ideas around in our mind to examine them from different perspectives until we find one that works for us. Since computers appeared, our approach to solve a problem has always consisted in first looking for the best way to represent the problem, then looking for the best way to represent the knowledge needed to solve it and finally looking for the best procedure for solving it.

This problem-solving approach is good when we have to deal with a specific problem but there's something basically wrong with it: it lead us to write only specialized programs that cope with solving only that kind of problem.

### 5.1 The Open Mind Common Sense Project

Initially born from an idea of David Stork, the Open Mind Common Sense (OMCS) project [5] is a kind of second-generation Common Sense database: knowledge is represented in natural language, rather than using a formal logical structure, and information is not handcrafted by expert engineers but spontaneously inserted by online volunteers.

The reason why Lenat decided to develop an ad-hoc language for Cyc is that vagueness and ambiguity pervade English and computer reasoning systems generally require knowledge to be expressed accurately and precisely. But, as expressed in the Society of Mind, ambiguity is unavoidable when trying to represent the Common Sense world. No single argument in fact is always completely reliable, but if we combine multiple types of arguments we can improve the robustness of reasoning as well as we can improve a table stability by providing it with many small legs in place of just one very big leg.

This way information is not only more reliable but also stronger: if a piece of information goes lost we can still access the whole meaning, exactly as the table keeps on standing up if we cut out one of the small legs. Diversity is in fact the key of OMCS project success: the problem is not choosing a representation in spite of another but it is finding a way for them to work together in one system.

### 5.2 Acquiring Common Sense by Analogy

In 2003 Timothy Chklovski introduced the cumulative analogy method [6]: a class of analogy-based reasoning algorithms that leverage existing knowledge to pose knowledge acquisition questions to the volunteer contributors.

Chklovski's Learner first determines what other topics are similar to the topic the user is currently inserting knowledge for, then it uses cumulative analogy to generate and present new specific questions about this topic. Because each statement consists of an object and a property, the entire knowledge repository can be visualized as a large matrix, with every known object of some statement being a row and every known property being a column.

Cumulative analogy is performed by first selecting a set of nearest neighbors, in terms of similarity, of the treated concept and then by projecting known properties of this set onto not known properties of the concept and presenting them as questions. The replies to the knowledge acquisition questions formulated by analogy are immediately added to the knowledge repository, affecting the similarity calculations.

### 5.3 ConceptNet

In 2004 Hugo Liu and Push Singh, refined the ideas of the OMCS project in ConceptNet [7], a semantic resource structurally similar to WordNet, but whose scope of contents is general world knowledge in the same vein as Cyc. While WordNet is optimised for lexical categorisation and Cyc is optimised for formalised logical reasoning, ConceptNet is optimised for making practical context-based inferences over real-world texts.

In ConceptNet, WordNet's notion of node in the semantic network is extended from purely lexical items (words and simple phrases with atomic meaning) to include higher-order compound concepts, e.g., 'satisfy hunger' or 'follow recipe', to represent knowledge around a greater range of concepts found in everyday life. Most of the facts interrelating ConceptNet's semantic network in fact are dedicated to making rather generic connections between concepts.

This type of knowledge can be brought back to Minsky's K-lines as it increases the connectivity of the semantic network and makes it more likely that concepts parsed out of a text document can be mapped into ConceptNet. In ConceptNet version 2.0 a new system for weighting knowledge was implemented, which scores each binary assertion based on how many times it was uttered in the OMCS corpus, and on how well it can be inferred indirectly from other facts. In ConceptNet version 3.0 [8] users can also participate in the process of refining knowledge by evaluating existing statements.

### 5.4 Digital Intuition

The best way to solve a problem is to already know a solution for it but if we have to face a problem we have never met before we need to use our 'intuition'. Intuition can be explained as the process of making analogies between the current problem and the ones solved in the past to find a suitable solution. Minsky attributes this property to the so called 'difference-engines', a particular kind of agents which recognize differences between the current state and the desired state and act to reduce each difference by invoking K-lines that turn on suitable solution methods.

To emulate this 'reasoning by analogy' we use AnalogySpace [9], a process which generalizes Chklovski's cumulative analogy. In this process, ConceptNet is first mapped into a sparse matrix and then truncated Singular Value Decomposition (SVD) is applied over it to reduce its dimensionality and capture the most important correlations. The entries in the resulting matrix are numbers representing the reliability of the assertions and their magnitude increases logarithmically with the confidence score. Applying SVD on this matrix causes it to describe other features that could apply to known concepts by analogy: if a concept in the matrix has no value specified for a feature owned by many similar concepts, then by analogy the concept is likely to have that feature as well.

This process is naturally extended by the 'blending' technique [10], a new method to perform inference over multiple sources of data simultaneously, taking advantage of the overlap between them. This enables Common Sense to be used as a basis for inference in a wide variety of systems and applications so that they can achieve Digital Intuition about their own data.

## 6 Applications of Common Sense Computing

We are involved in an EPSRC project whose main aim is to further develop and apply the above-mentioned technologies in the field of Common Sense Computing to build a novel intelligent software engine that can auto-categorise documents, and hence enable the development of future semantic web applications whose design and content can dynamically adapt to the user.

### 6.1 Enhancing the Knowledge Base

The key to perform Common Sense reasoning is to find a good trade-off for representing knowledge: since in life no two situations are ever the same, no representation should be too concrete, or it will not apply to new situations, but, at the same time, no representation should be too abstract, or it will suppress too many details. ConceptNet already supports different representations by maintaining different ways of conveying the same idea with redundant concepts, but we plan to enhance this multiple representation by connecting ConceptNet with dereferenceable URIs and RDF statements to enlarge the Common Sense knowledge base on a different level.

We also plan to improve ConceptNet by giving a geospatial reference to all those pieces of knowledge that are likely to have one and hence make it suitable to be exploited by geographic oriented applications. The 'knowledge retrieval' is one of the main strengths of ConceptNet: we plan to improve it by developing games to train the semantic network and by leveraging on social networking.

We also plan to improve ConceptNet on the level of what Minsky calls 'self-reflection', i.e., on the capability of reflecting about its internal structure and cognitive processes. ConceptNet currently focuses on the kinds of knowledge that might populate the A-brain of a Society of Mind: it knows a great deal about the kinds of objects, events and other entities that exist in the external world, but it knows far less about how to learn, reason, and reflect.

We plan to give the semantic network the ability to self-check its consistency, e.g., by looking for words that appear together in ways that are statistically implausible and ask users for verification or keeping trace of successful learning strategies. The system is also likely to remember attempts that led to particularly negative conclusions in order to avoid unproductive strategies in the future. To this end, we plan to improve the 'negative expertise' of the semantic network, which is now just partially implemented by asking users to judge inferences, in order to give the system the capability to learn from its mistakes.

### 6.2 Understanding the Knowledge Base

Whenever we try to solve a problem, we continuously and almost instantly switch to different points of view in our mind to find a solution. Minsky argues that our brains may use special machinery, that he calls 'panalogy' (parallel analogy), that links corresponding aspects of each view to the same 'slot' in a larger-scale structure that is shared across several different realms.

ConceptNet's current knowledge representation does not allow us to think about how to implement such a strategy yet, but, once we manage to give ConceptNet a multiple representation as planned, we will have to start thinking about it. At the moment, SVD is used on the graph structure of ConceptNet to build the vector space representation of the Common Sense knowledge. Principal Component Analysis (PCA) is an optimal way to project data in the mean-square sense but the eigenvalue decomposition of the data covariance matrix is very expensive to compute. Therefore, we plan to explore new methods such as Sparse PCA, a technique consisting in formulating PCA as a regression-type optimization problem, and Random Projection, a method less reliable than PCA but computationally cheaper.

### 6.3 Exploiting the Knowledge Base

Our primary goal is to build an intelligent auto-categorization tool that exploits Common Sense to make document classification more accurate and reliable. We also plan to apply Common Sense Computing for the development of emotion-sensitive systems, namely by analysing users' emotions and attitudes to improve human-machine interaction.

In the sphere of e-games, for example, such an engine could be employed to implement conversational agents capable to react to user's frame of mind changes and thus enhance players' level of immersion. In the field of enterprise 2.0, the engine could be used to develop customer care applications capable to measure users' level of satisfaction. In the field of e-health, finally, patient opinions could be exploited to assess the quality of health services on a large scale [11].

## 7 Conclusions

It is hard to measure the total extent of a person's Common Sense knowledge, but a machine that does human-like reasoning might only need a few dozen millions of items of knowledge. Thus we would be tempted to give a positive answer to the question "is it actually possible to build a machine with Common Sense?". But, as we saw in this paper, Common Sense Computing is not just about collecting Common Sense knowledge: it is about how we represent it and how we use it to make inferences.

We made very good progress in performing this since McCarthy's 'advice taker' but we are actually still scratching the surface of human intelligence. Hence, we cannot give a concrete answer to that question – not yet. The road to the creation of a machine with the capacity of Common Sense reasoning is still long and tough but we feel that the path undertaken so far is a good one. And, even if we fail in making machines intelligent, we believe we will be able to at least teach them who we are and thus make them able to better contribute to the technological evolution of human kind.

## References


1. Minsky, M.: The Society of Mind. Simon and Schuster, New York (1986)
2. McCarthy, J.: Programs with Common Sense. In: Teddington Conference on the Mechanization of Thought Processes (1959)
3. Lenat, D., Guha, R., Pittman, K., Pratt, D., Shepherd, M.: Cyc: Towards Programs with Common Sense. Communications of the ACM 33(8), 30–49 (1990)
4. Fellbaum, C.: WordNet: An Electronic Lexical Database. MIT Press (1998)
5. Singh, P.: The Open Mind Common Sense Project. KurzweilAI.net (2002)
6. Chklovski, T.: Learner: a System for Acquiring Common Sense Knowledge by Analogy. In: K-CAP (2003)
7. Liu H., Singh, P.: ConceptNet: a Practical Common Sense Reasoning Toolkit. BT Technology Journal 22(4), 211–226 (2004)
8. Havasi, C., Speer, R., Alonso, J.: ConceptNet 3: a Flexible, Multilingual Semantic Network for Common Sense Knowledge. In: RANLP (2007)
9. Speer, R., Havasi, C., Lieberman, H.: AnalogySpace: Reducing the Dimensionality of Common Sense Knowledge. In: AAAI (2008)
10. Havasi, C., Speer, R., Pustejovsky, J., Lieberman, H.: Digital Intuition: Applying Common Sense Using Dimensionality Reduction. IEEE Intelligent Systems 24(4), 24–35 (2009)
11. Cambria, E., Hussain, A., Havasi, C., Eckl, C., Munro, J.: Towards Crowd Validation of the UK National Health Service. In: ACM WebSci, Raleigh (2010)