Development of the SP machine

Vasile Palade*  J Gerard Wolff†

July 4, 2017

Abstract

This paper describes the main things that need to be done to develop the SP machine, based on the SP theory of intelligence and its realisation in the SP computer model. The SP machine may be developed initially as a software virtual machine with high levels of parallel processing, hosted on a high-performance computer, or driven by high-parallel search processes in any of the leading search engines. An easy-to-use user interface is needed with facilities for visualisation of knowledge structures and processing. The system needs to be generalised to work with patterns in two dimensions, including the display of multiple alignments with 2D patterns. Research is needed into how the system may discover low-level features in speech and visual images. Existing strengths of the SP system in the processing of natural language may be developed towards the understanding of natural language and its production from meanings. This may be done most effectively in conjunction with the development of existing strengths of the SP system in unsupervised learning. Existing strengths of the SP system in pattern recognition may be developed for computer vision. Further work is needed on the representation of numbers and the performance of arithmetic processes in the SP system. A computer model is needed of SP-neural drawing on the existing conceptual model. When the SP machine is relatively mature, new hardware may be developed to exploit opportunities to increase the efficiency of computations. There is potential for the SP machine

*Dr Vasile Palade, MEng (Tech. Univ. of Bucharest), PhD (University of Galați), IEEE Senior Member; Reader in Pervasive Computing, Department of Computing, Coventry University, UK; vasile.palade@coventry.ac.uk; +44 (0) 2477 659190; +44 (0) 7912 043982; Skype: vapalade; Web: bit.ly/1xNM5xr, bit.ly/1Buyk9E.
†Dr Gerry Wolff, BA (Cantab), PhD (Wales), CEng, MIEEE, MBCS; CognitionResearch.org, Menai Bridge, UK; ggw@cognitionresearch.org; +44 (0) 1248 712962; +44 (0) 7746 290775; Skype: gerry.wolff; Web: www.cognitionresearch.org.
to be applied on relatively short timescales in such areas as information storage and retrieval, with intelligence, software engineering with or without automation or semi-automation, and information compression.

Keywords: information compression, artificial intelligence, natural language processing, pattern recognition, computer vision, neuroscience.

1 Introduction

The SP theory of intelligence and its realisation in the SP computer model is a unique attempt to simplify and integrate observations and concepts across artificial intelligence, mainstream computing, mathematics, and human learning, perception and cognition, with information compression as a unifying theme. It is described in outline in Appendix A with pointers to where fuller information may be found.

There are many potential benefits and applications of the SP system, described in several peer-reviewed papers, referenced in Appendix A.6.

The SP system has several distinctive features and advantages compared with AI-related alternatives [27]. Probably the most distinctive feature is a concept of multiple alignment, borrowed and adapted from bioinformatics. A key advantage of the multiple alignment framework as it has been developed in the SP system is its versatility in the representation of knowledge and in aspects of intelligence, and its potential for the seamless integration of diverse kinds of knowledge and diverse aspects of intelligence, in any combination (Appendix A.5).

To distinguish multiple alignment in bioinformatics from multiple alignment as it has been developed in the SP system, the latter will be referred to as SP-multiple-alignment.

1.1 The SP machine

To realise the potential benefits and applications of the SP system, it is envisaged that the SP computer model will provide the basis for the development of an industrial-strength SP machine, as shown schematically in Figure 1.

The main purpose of this paper is to describe what appear to be the main things to be done to develop the full potential of the SP machine.

Initially, it will be developed as a high-parallel software virtual machine, hosted on an existing high-performance computer, and with an easy-to-use user interface. This may have a dual function: 1) to serve directly in practical
Figure 1: A schematic view of how the SP machine may develop from the SP theory and the SP computer model. Adapted, with permission, from Figure 6 in [23].

applications; and 2) to serve as a vehicle for further research, to explore what can be done with the SP machine and to create new versions of it.

At some stage, there is likely to be a case for the development of new hardware, dedicated to structures and processes in the SP system, and with potential for substantial gains in efficiency and performance ([24, Section IX], [22, Section III]).

1.2 Presentation

After a summary of our research strategy (Section 2), several sections describe things that need to be done in the development of the SP machine, including a description of problems to be solved, and potential solutions to those problems. Some areas of application may yield benefits on relatively short timescales (Section 14).

Four of the sections are about pieces of “unfinished business” in the development of the SP machine, outlined in [20, Section 3.3]: processing information in two or more dimensions (Section 6); recognition of perceptual features in speech and visual images (Section 7); unsupervised learning (Section 9); and processing numbers (Section 11).
1.3 An invitation

In accordance with the saying that “A camel is a horse designed by a commit-
tee”, the development of a scientific theory, like writing a novel or composing
a symphony, is a task that is not easily shared. Now that the SP theory is rel-
atively mature, it should become easier progressively for other researchers to
work on the several avenues that now need to be explored, without treading
on each others’ toes.

We would very much welcome the involvement of other researchers and
would be happy to discuss possibilities, and the necessary facilities, including
software.

2 Research strategy

Because of its importance, we say again that this programme of research is a
unique attempt to simplify and integrate observations and concepts across ar-
tificial intelligence, mainstream computing, mathematics, and human learn-
ing, perception and cognition, with information compression as a unifying
theme.

This long-term objective is now showing potential to produce dividends
in spades:

- The strengths of SP-multiple-alignment in the simplification and inte-
gration of observations and concepts across a broad canvass is a major
discovery with clear potential in the long-sought-after quest for general,
human-level artificial intelligence, and for developing an understanding
of human intelligence.

- As described in Appendix [A.6] discovering the strengths of the SP-
multiple-alignment concept has been a bit like hitting the jackpot on a
fruit machine, releasing a cascade of potential benefits and applications.

2.1 Maintain a strong focus on simplicity and power

The long view of this research contrasts with, for example, most research on
deep learning in artificial neural networks where undoubted successes obscure
several weaknesses in the framework (Appendix [A.5]), suggesting that deep
learning is likely to be a blind alley in any search for general human-level
artificial intelligence.

For these kinds of reasons, we urge researchers working with the SP con-
cepts to maintain a strong focus on maintaining a favourable combination
of conceptual simplicity with descriptive or explanatory power, resisting the temptation to take short cuts or to introduce ideas that do not integrate well with the SP framework. That said, we believe the following kinds of development, which are not mutually exclusive, would be reasonable:

- There may be opportunities to develop SP capabilities with industrial strength for practical applications, without corrupting the core concepts (Section 14). An example is the potential of the SP machine to serve as a database management system with versatility and intelligence [19].

- There may be a case on occasion to develop a hybrid system as a stopgap to facilitate practical applications, pending the development of a solution that is theoretically clean. An example in computer vision would be the use of existing procedures for the detection of low-level features in images (such as lines and corners) pending an analysis in terms of SP concepts (Section 7).

2.2 Scheduling

As we shall see, some things are probably best done before others. These ‘ground-clearing’ tasks are described early in what follows. When those tasks have been completed, it should become easier to develop two or more aspects of the SP machine in parallel, in tasks described in later subsections.

When the SP system has been brought close to the point where it may prosper in a commercial environment, perhaps via applications that may be developed on relatively short timescales (Section 14), companies may wish to refine the system for one or more markets.

3 The creation of a high-parallel SP machine

The proposed developments will begin with SP71, the latest version of the SP computer model, described in outline in Appendix A.3. Instructions for obtaining the source code are in Appendix B.

To get things going, we believe that the first stage, as outlined in this main section, will be to develop the SP machine with parallel processing, and then, in the two following sections, to create a user interface that is easy to use and to facilitate the visualisation of knowledge structures and the processing of knowledge.
3.1 Is parallel processing really needed?

Before we apply parallel processing in the SP machine, we need to establish that parallel processing is really necessary.

A substantial advantage of the SP system, compared with, for example, deep learning in artificial neural networks [11], is that, on the strength of evidence to date, the SP machine is likely to be very much less demanding of computational resources than deep learning systems [27, Section V-E]. And there appears to be potential to speed up processing by the judicious use of indexing, as outlined in Section 3.4.

More generally, there appears to be potential in the SP system for very substantial gains in computational efficiency compared with conventional computers: by the use of a technique called “model-based coding” for the efficient transmission of data [23, Section VIII]; and by exploiting the statistical information which is gathered as a by-product of how the system works [23, Section IX].

So it is reasonable to ask whether the existing computer model (SP71) might be speedy enough as it is, without the need for parallel processing? Here are some answers to that question which are not mutually exclusive:

- Although, as mentioned above, the SP machine has the potential to be relatively frugal in its computational demands, its full potential in that respect will probably not be fully realised until new hardware has been developed to take full advantage of opportunities in the structure and workings of the SP system.

- The afore-mentioned gains in efficiency in the transmission of information via model-based coding, will not be fully realised until unsupervised learning in the SP system is more fully developed.

- Although, with AI problems, the SP system is likely to be much more efficient than deep learning systems, AI problems are normally quite computationally demanding compared with, for example, school-level mathematics. For those kinds of reasons, parallel processing is likely to be needed to achieve acceptable run times when the SP machine is applied to what is normally the relatively demanding task of learning in unsupervised mode, and perhaps also to such things as pattern recognition and the processing of natural languages.

- When the SP machine has been generalised to work with two-dimensional patterns, it is likely that parallel processing will be needed to speed up
processing in what is likely to be the computationally-intensive process of finding good full or partial matches between two 2D patterns (Section 6.1).

- Parallel processing will almost certainly be needed if the SP machine is to become an industrial-strength database management system with intelligence, as described in [19].

3.2 How to apply parallel processing

The effective application of parallel processing will require careful analysis of the SP71 computer model (Appendix A.3) to identify parts of the program where parallel processing may be applied.

At this stage, it seems likely that parallel processing may be applied most effectively via a MapReduce technique, as, for example, in these two parts of the program:

- With the building of SP-multiple-alignments (Appendix A.3.2), a recurring operation is searching for good full or partial matches between one “driving” pattern and each of a set of “target” patterns (Appendix A.3.1), where the set of target patterns may become very large.

Here, the “map” phase would be applying the search in parallel to each pairing of a driving pattern with a target pattern, while the “reduce” phase would be identifying the most successful matches and selecting a subset for further processing.

- With unsupervised learning, each pattern in a relatively large set of New patterns is processed via a search for SP-multiple-alignments that allow the given New pattern to be encoded economically.

Here, the “map” phase would be the application of the search process to all the New patterns in parallel, and the “reduce” phase would be a process of sifting and sorting to create one or more alternative grammars for the set of New patterns.

No doubt, there will be other opportunities for applying the MapReduce technique in the SP machine. There may also be opportunities for the use of other techniques such as pipelining.

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1See “MapReduce”, Wikipedia, bit.ly/2oG42kY, retrieved 2017-06-15.
2See “Pipeline (computing)”, Wikipedia, bit.ly/2sq4ful, retrieved 2017-06-21.
3.3 Computing environments for the application of parallel processing

In broad terms in this development, there seem to be two main kinds of computing environment that may be used for the application of parallel processing:

- **A stand-alone computer cluster.** A server with one or more multi-core chips and appropriate software would probably work well. Compared with most supercomputing facilities, this kind of computer cluster would give researchers unfettered access to develop programs and to test them frequently, without restrictions.

- **High-parallel search mechanisms in a search engine.** An interesting alternative would be to replace the low-level search mechanisms in the SP machine with high-parallel search mechanisms in an existing search engine. This would supercharge the SP machine with the power of the given search engine, adding intelligence to it. Initially, the intelligence would comprise the capabilities of the SP71 computer model, but there would be clear potential for many enhancements across most aspects of intelligence.

With regard to the second of these options, the SP machine, hosted on any given search engine, may provide human-like intelligence with access to all the knowledge that has been indexed in the underlying search engine. Looking further ahead, all search engines may be adapted in this way, and some of the processing may be offloaded to PCs and other computers around the world, in the manner of volunteer computing projects such as SETI@home and Folding@home.

With developments like that, the internet would, in effect, become a giant brain with potential for human-like intelligence.

Many benefits may flow from artificial intelligence like that, in the internet and beyond. But there are also potential dangers and other problems which will need careful scrutiny and much debate.

3.4 Indexing as a means of speeding up processing

A prominent feature of the SP system, both in the way it does unsupervised learning and the way it builds SP-multiple-alignments, is a process of searching for symbols that match each other, which is normally part of a process of searching for full or partial matches between patterns.
Since these things are often done repeatedly with the same sets of New and Old patterns, there is potential for substantial gains in computational efficiency by recording matches as they are found and using that information to by-pass searching in later processing. The record of matches that have been found is, if effect, and index into the data. This may be done with matches between individual symbols, and may perhaps also be done for matches between patterns.

A similar idea may be applied in SP-neural, as outlined in Section 12.2.

4 Development of an easy-to-use user interface

The user interface for the SP71 computer model is the product of ad hoc developments in response to evolving needs, without any attempt at a coherent and streamlined design.

This has not mattered for the one user (JGW) who originated each feature and has learned the workings of the user interface as it evolved. However, as the SP system is opened up to new users, a more intuitive and easy-to-use user interface is needed, taking advantage of advanced graphical techniques that are available now.

Since all users, both local and remote, may access the SP machine via a web browser, and to eliminate the need for users to download any software, it is envisaged that the new user interface will be developed using HTML5 or any of its successors.

5 Development of visualisation of structures and processes

An important concern with artificial intelligence is that it should be possible to inspect and understand how an AI system stores its knowledge and how it reaches its conclusions. This is important where an AI system may have an impact on the safety of people or where its performance and conclusions may have a bearing on court cases.

A major strength of the SP system is that all its knowledge is open to inspection and it provides an audit trail for all its processing [23, Section XI].

Although this information is provided by the system, there is probably scope for improving its presentation, so that structures and processes can be seen easily and so that users can find easily what they are looking for.
6 Processing information in two or more dimensions

It has been recognised for some time that the SP machine should be generalised to work with information in two dimensions and probably more [13, Section 13.2.1]. How this may be done is discussed in the following subsections.

6.1 Introduction of two-dimensional patterns

The main motive for introducing 2D patterns into the SP system is to facilitate the representation and processing of such things as photographs, paintings, drawings, and diagrams. They may also serve in the representation and processing of procedures that operate in parallel [22, Sections V-G, V-H, and V-I, and Appendix C]. And, as we shall see in the next subsection, 2D patterns can play a useful part in the representation and processing of 3D structures.

It is a simple enough matter to add 2D patterns to the SP system. What is more challenging is how to generalise such things as the building of SP-multiple-alignments with 2D patterns, how to represent SP-multiple-alignments of 2D patterns on a 2D computer screen or a printed page, and unsupervised learning with 2D patterns.

We can get some clues from how digital photographs that overlap each other may be stitched together to create a panorama. However, it seems unlikely that software that is designed for the stitching together of overlapping pictures will have the flexibility needed to achieve the 2D equivalent of the processes in SP71 that can find good full and partial matches between two patterns, including situations where there are substantial differences between the patterns (Appendix A.3.1).

Generalising the pattern-matching processes in SP71 to work well with 2D patterns is likely to be a significant challenge. It is likely also that any reasonably good solution will absorb quite a lot of computing power. To achieve useful speeds in processing, it is likely that high levels of parallel processing will be required (Section 3).

6.2 Modelling structures in three dimensions

At first sight, the obvious way to model 3D structures in the SP system is to add 3D patterns to the system. But that is probably a step too far, partly because of the complexity of matching patterns in three-dimensions and the
difficulty of representing SP-multiple-alignments of 3D patterns, and partly for reasons described here:

“Patterns in one or two dimensions may serve well enough to represent concepts with three or more dimensions. There is a long tradition of representing buildings and other engineering artifacts with two-dimensional plans and elevations.” [18, Section 13.2.2].

and

“Although the human brain is clearly a three-dimensional structure, there is a distinct tendency for it to be organised into layers of cells such as those found in the cortex and in the lateral geniculate body. Although these are often folded into three dimensions, they are topologically equivalent to two-dimensional sheets. ... these sheets of neurons would provide a natural home for SP patterns.” ibid.

The case for using 2D patterns as a means of building and representing 3D structures is also strengthened by the existence of applications that work like that, such as “Big Object Base” [bit.ly/1gwulf6], “Camera 3D” [bit.ly/1iSEqZu] and “PhotoModeler” [bit.ly/MDj70X] and also Google’s “Streetview” [3] which builds 3D models of street plans from 2D photographs. There is relevant discussion in [21, Sections 6.1 and 6.2].

6.3 Modelling structures in four or more dimensions

Although there are four dimensions in our everyday experience—three dimensions of space and one of time—it seems likely that, normally, we don’t attempt to integrate them in the manner of Einstein’s space-time but concentrate on a subset of the four dimensions, such as the succession 2D images on our retinas as we walk through a building or drive around a town. It seems likely that, for most applications, that kind of partial integration would work well enough.

If for any reason there is a need to represent structures in five or more dimensions, it is probably best to borrow techniques used by mathematicians for dealing with such structures.

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3See “Google Street View”, [Wikipedia, bit.ly/1TYQmLR] retrieved 2017-06-15.
7 Recognition of low-level perceptual features in speech and images

As noted in Appendix A.2, the SP system is designed to represent and process stored knowledge and sensory data expressed as atomic symbols in SP patterns. So at first sight, it should be able work with any digital information, meaning information that is founded on the atomic symbols ‘0’ and ‘1’. But there are two main complications:

- Much digital information drawn relatively directly from the environment is encoded as, for example, hexadecimal numbers representing such things as levels of brightness in an image. Until the SP system can deal effectively with numbers (Section 11), it will fail to interpret such information in an appropriate manner.

- In principle, all such encoded information may be translated into a more “primitive” kind of representation in which, for example, the brightness in any given portion of an image would be represented by the density of ‘0’s or ‘1’s, much as in old-style black and white newspaper photograph [18, Section 2.2.3]. But it is not clear at present how the SP system would work in processing information of that kind.

In general, the SP system works best with symbols representing structures or entities that are significant in human perception. Thus:

“For the SP system to be effective in the processing of speech or visual images, it seems likely that some kind of preliminary processing will be required to identify low-level perceptual features, such as, in the case of speech, phonemes, formant ratios or formant transitions, or, in the case of visual images, edges, angles, colours, luminances or textures.” [20 Section 3.3].

In broad terms, there are two ways in which the developing SP machine may bridge the gap which is likely to exist between information that is drawn relatively directly from the environment and the kinds of structures just mentioned:

- As a stop-gap measure, preliminary processing of sensory data may done by conventional methods to yield the kinds of low-level perceptual entities with which the SP system can operate.
• Given the power and generality of the principles that lie a the heart of the SP theory, it seems likely that, pending some further research, the SP system, without stop-gap measures, will be able to process all kinds of information in a meaningful way, including “raw” sensory data and data that has been encoded using numbers.

Perhaps we should worry less about maintaining conceptual purity. For example:

“The issue of representation lies at the heart of the debate between the logic-inspired and the neural-network-inspired paradigms for cognition. In the logic-inspired paradigm, an instance of a symbol is something for which the only property is that it is either identical or non-identical to other symbol instances. It has no internal structure that is relevant to its use; and to reason with symbols, they must be bound to the variables in judiciously chosen rules of inference. By contrast, neural networks just use big activity vectors, big weight matrices and scalar non-linearities to perform the type of fast intuitive inference that underpins effortless commonsense reasoning.” [5, p. 441]

Although the SP system is very different from most logic-inspired systems (except for all-or-nothing matching amongst SP symbols), it is, at its current stage of development, somewhat choosy about its inputs compared with many artificial neural networks. Although this is, superficially, an advantage for artificial neural networks, we believe that the SP system will be more satisfactory in the long run, for reasons given in Appendix A.5.

Given the generality of information compression and the already-demonstrated versatility of SP-multiple-alignment as a means of achieving information compression, we believe it is likely that the SP-multiple-alignment framework will accommodate low-level features in speech and images. Although there may be a case for adopting stop-gap solutions in some applications (Section 2), there is also a need to explore how the SP system may be applied in these areas.

4Contrary to what is said in the quotation, it is often the case that a symbol in logic-inspired systems, such as a variable in a system like Prolog, is not “something for which the only property is that it is either identical or non-identical to other symbol instances”.

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8 The processing of natural language

A major strength of the SP-multiple-alignment framework is that it lends itself well to the representation and processing of natural language:

- As can be seen in Figure 7 in Appendix A.2 and in many other examples in [18, 20], the building of SP-multiple-alignments can achieve the effect of parsing a sentence into its parts and sub-parts.

- The SP-multiple-alignment concept exhibits versatility in the representation and processing of several kinds of non-syntactic knowledge (Appendix A.5). Any of these may represent the semantics or meanings of a sentence.

- As noted in Appendix A.5, the fact that one relatively simple framework may serve in the representation and processing of diverse kinds of knowledge means that there is potential for their seamless integration in any combination. More specifically in the present context, there is clear potential for the seamless integration of the syntax and semantics of natural language.

- Preliminary examples described in [18, Section 5.7] show how this may work in both the semantic interpretation of a simple sentence ([18, Figure 5.18]) and in the production of a sentence from its meanings ([18, Figure 5.19]).

- The potential of the SP system for the seamless integration of diverse kinds of knowledge and diverse aspects of intelligence (Appendix A.5) means that there is clear potential for the integration of natural language with other aspects of intelligence such as pattern recognition, reasoning, planning, and problem solving.

In order to demonstrate parsing via SP-multiple-alignment, the semantic interpretation of a sentence, or the production of a sentence from meanings, it has been necessary to construct appropriate grammars by assembling collections of SP patterns manually. This has been acceptable in the process of developing the SP-multiple-alignment framework and demonstrating what it can do, but it is likely to be far too slow and prone to error in the further development of natural language processing in the SP system.

To make progress with the processing of natural language in the SP system, it will be necessary to develop this area in conjunction with the development of unsupervised learning in the SP system, as described in the next section.
9 Unsupervised learning

In the light of observations in the previous section, the discussion of unsupervised learning in this section concentrates mainly on unsupervised learning of the syntax and semantics of natural language. Success in this area is likely to generalise to other areas and, in any case, “semantics” is a broad concept that embraces most kinds of knowledge.

It is pertinent to mention that thinking in this area draws on an earlier programme of research (summarised in [16]) developing computer models of how a child learns his or her first language or languages. The emphasis on hierarchical structures in those models proved entirely unsuitable for the SP programme of research, so that it was necessary to develop an entirely new conceptual framework—SP-multiple-alignment—to meet the goals of the SP research.

Our emphasis on unsupervised learning in the SP machine is because of the belief that most human learning is achieved without the benefit of any kind of “teacher” or anything equivalent (cf. [2]), and because of our belief that other kinds of learning, such as supervised learning, reinforcement learning, learning by being told, and learning by imitation, may be seen as special cases of unsupervised learning [22, Sections V-A.1 and V-A.2].

Probably the best place to start in developing unsupervised learning in the SP computer model is with two weaknesses in the SP71 model, outlined here:

“A limitation of the SP computer model as it is now is that it cannot learn intermediate levels of abstraction in grammars (eg, phrases and clauses), and it cannot learn the kinds of discontinuous dependencies in natural language syntax that are described in [20, Sections 8.1 to 8.3] and [18, Section 5.4]). I believe these problems are soluble and that solving them will greatly enhance the capabilities of the system for the unsupervised learning of structure in data ....” [20, Section 3.3].

Pending further analysis, it looks as if the problems with SP71 in discovering structures such as phrases and clauses in the syntax of natural language, and in discovering discontinuous dependencies in that syntax, may both be solved in some such manner as what follows.

Since the building of SP-multiple-alignments is an integral part of unsupervised learning in the SP system (Appendix A.3.3), and since every stage in the process of building an SP-multiple-alignment yields an encoding of
one or more New patterns in terms of the Old patterns in the SP-multiple-alignment, better results may be obtained by applying the learning processes to those encodings as well as to the original patterns.

Probably, the best way to build up an understanding of what needs to be done is to work with unsegmented samples of relatively simple English-like languages generated by artificial grammars. If or when good insights and good results can be obtained with that kind of material, the system may be tested and refined with more challenging material, as described in the next three subsections.

9.1 Learning the syntax of natural language

Following the steps outlined above, it seems possible now to bring the SP system to a stage of development where it can derive plausible grammars for the syntax of natural language via the application of unsupervised learning to unsegmented textual samples of natural language. This would be a major achievement since, to our knowledge, no other system can perform at that level. Incidentally, for reasons given in [20, Section 6.2], there are likely to be subtle but important differences between grammars derived from natural language texts without meanings and the kinds of grammars that we learn as children, where syntax and semantics are developed in tandem.

It seems likely that success with this task would smooth the path for success with the tasks described next.

9.2 The unsupervised learning of non-syntactic kinds of knowledge

A key idea in the SP theory as it is now, which is a working hypothesis in the SP programme of research, is that one set of principles applies across the representation and processing of diverse kinds of knowledge, where “processing” includes unsupervised learning [23, Section III].

Hence, we anticipate that if we can find good solutions for the unsupervised learning of syntax, it is likely that, with or without some further development, they would generalise to the learning of non-syntactic, semantic structures. With the learning of visual structures, it would be necessary for there to be a robust solution to the previously-mentioned problem of finding good full and partial matches between 2D patterns (Section 6.1).
9.3 Learning syntactic/semantic structures

A prominent feature of the environment in which most young children learn their first language or languages is that, very often, they can hear the speech of adults or older children at the same time as they can see or hear what people are talking about: “Lunch is on the table”, “Here’s our bus coming”, and so on.

It appears that this kind of environment is needed to enable young children to work out the meanings of words and grammatical forms, and something similar would be needed for experiments with the SP system. But there appears to be a problem:

“The logician W. V. O. Quine asks us to imagine a linguist studying a newly discovered tribe. A rabbit scurries by, and a native shouts, ‘Gavagai!’ What does gavagai mean? Logically speaking, it needn’t be ‘rabbit.’ It could refer to that particular rabbit (Flopsy, for example). It could mean any furry thing, any mammal, or any member of that species of rabbit (say, Oryctolagus cuniculus), or any member of that variety of that species (say, chinchilla rabbit). It could mean scurrying rabbit, scurrying thing, rabbit plus the ground it scurries upon, or scurrying in general. It could mean footprint-maker, or habitat for rabbit-fleas. It could mean the top half of a rabbit, or rabbit-meat-on-the-hoof, or possessor of at least one rabbit’s foot. It could mean anything that is either a rabbit or a Buick. It could mean collection of undetached rabbit parts, or ‘Lo! Rabbithood again!,’ or ‘It rabbiteth,’ analogous to ‘It raineth.’ ... Somehow a baby must intuit the correct meaning of a word and avoid the mind-boggling number of logically impeccable alternatives. It is an example of a more general problem that Quine calls ‘the scandal of induction,’ which applies to scientists and children alike: how can they be so successful at observing a finite set of events and making some correct generalization about all future events of that sort, rejecting an infinite number of false generalizations that are also consistent with the original observations?” [8, pp. 147–148].

Without wishing to trivialise this problem, it appears that the SP system has potential to provide a good solution:

- By searching for recurrent patterns and attaching more weight to patterns that occur frequently and less weight to patterns that are rare, the SP system naturally homes in on the stronger correlations—such
as the correlation between the word “lunch” and what people eat at lunchtime—and discards weaker correlations—such as the correlation between the word “lunch” and whether or not it is raining outside.

• The problem of how to generalise from what one has learned, without either under-generalisation or over-generalisation, is discussed in [20, Section 5.3] and also in [27, Section V-H].

In brief, learning with the SP system from a body of data, \( \mathbf{I} \), means compressing \( \mathbf{I} \) as much as possible and then splitting the resulting body of data into two parts: a grammar which contains a single copy of each recurrent pattern in \( \mathbf{I} \); and an encoding of \( \mathbf{I} \) which contains non-recurrent parts of \( \mathbf{I} \) and brief codes or references recurrent patterns in \( \mathbf{I} \).\(^6\) Evidence to date shows that with learning of this kind, the grammar generalises in a way that we judge to be “correct” and avoids what intuitively we would judge to be under-generalisation or over-generalisation.\(^7\)

Assuming that progress can be made along the lines outlined here, another avenue that may be explored later is how children may learn the meanings of things by making inferences from their existing knowledge. For example, if a child that does not know the word “plantain” hears someone say something like: “I had plantain for lunch today. It was delicious—more tasty than potato but not overpowering”, he or she may infer quite reasonably that plantain is something that one can eat and that it is probably something starchy, like potato.\(^7\)

In this area of research—how the syntax and semantics of natural language may be learned together—it will be necessary to provide input to the SP system that is comparable with that described above. Also, it will probably be necessary for the SP system to have been generalised to work with two-dimensional patterns (Section 6.1), so that syntactic knowledge may be shown alongside semantic knowledge, with associations between them (see also discussions in [22, Sections V-G, V-H, and V-I, and Appendix C]).

9.4 Learning language from speech

Although children learn their first language or languages by hearing people talk, we have left that kind of learning to last because it is more challenging

\(^5\) Under-generalisation was overlooked in this account but the avoidance of under-generalisations is achieved in exactly the same way as the avoidance of over-generalisations.

\(^6\) Notice that recurrent patterns in \( \mathbf{I} \) may be abstract patterns as well as concrete patterns.

\(^7\) See also the discussion of generalisation in [16]
than, for example, learning grammars from text.

The main reason for the difficulty is uncertainties about the discovery of low-level features in speech, as discussed in Section 7. Solutions in that area will facilitate the learning of language from speech.

10 Computer vision

The generalisation of the SP machine to work with 2D patterns (Section 6.1) is a likely prerequisite for the development of the SP system for computer vision and as a model of human vision, as described in [21].

An important part of this development will be the unsupervised learning or discovery of objects and classes, as discussed in [21] Section 5 and Section 9.2 below. This will include work on the discovery of low-level features in images, as discussed in Section 7.

11 Processing numbers

“The SP model works with atomic symbols, such as ASCII characters or strings of characters with no intrinsic meaning. In itself, the SP system does not recognise the arithmetic meaning of numbers such as “37” or “652” and will not process them correctly. However, the system has the potential to handle mathematical concepts if it is supplied with patterns representing Peanos axioms or similar information [18 Chapter 10]. As a stop-gap solution in the SP machine, existing technologies may provide whatever arithmetic processing may be required.” [20 Section 3.3].

In view of evidence that mathematics may be seen as a set of techniques for compression of information, and their application [20], and bearing in mind that the SP system works entirely via the compression of information, and in view of the potential of the SP system as a vehicle for ‘computing’ ([18 Chapter 4], [24 Section 6.6], [30]), and as a vehicle for mathematics [18 Chapter 10], there is clear potential in the SP machine for the performance of arithmetic and related computations.

Pending the development of capabilities for arithmetic in the SP machine, it seems reasonable to use an existing “maths coprocessor” or similar facility, as an adjunct to the SP machine, much as is done in many database management systems today.

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8See “Coprocessor”, Wikipedia, bit.ly/2rYawia retrieved 2017-06-23.
12 SP-neural

At present, the SP-neural part of the SP theory (Appendix A.4) exists only as a conceptual model, described in some detail in [26].

To flesh out this conceptual model, it is really necessary to create a computational version of it. As with the SP71 computer model, this will help to guard against vagueness in the theory; it will serve as a means of testing ideas to see whether or not they work as anticipated, and it will be a means of demonstrating what the model can do.

Probably, the best place to start would be to create a computer model of the building of an SP-multiple-alignment in SP-neural, as discussed in [26, Section 4] and illustrated schematically in Figure 2.

The development of unsupervised learning in the computer model of SP-neural is probably best left until later, if or when there is a satisfactory SP-neural model of the building of the neural equivalent of SP-multiple-alignments. This is because the building of SP-multiple-alignments is an important part of unsupervised learning in the SP system. We make some remarks about unsupervised learning in Section 12.3.

In the figure, each alphanumeric symbol surrounded by a solid-line envelope represents a neural symbol (Appendix A.4), and each group of neural symbols surrounded by a broken-line envelope represents a pattern assembly (Appendix A.4, [26, Section 4.2]).

In the figure, nerve fibre connections between neural symbols are represented with lines which may be solid or broken. The solid lines represent neural connections in part of the SP-multiple-alignment shown in [26, Figure 2], while the broken lines represent other neural connections that are not part of that SP-multiple-alignment.

12.1 Inhibition

This section considers the potential role of inhibitory processes in the new computer model, starting with some background.

12.1.1 Background

In [26, Section 9], there is a brief review of what appears to be a substantial role for inhibitory signals between neurons in the workings of brains and nervous systems. A tentative general rule from this research is that When, in neural processing, two or more signals [that interact] are the same, they tend to inhibit each other, and when they are different, they don’t [26, p. 19], with the implication that “The overall effect should be to detect redundancy
Figure 2: A schematic representation of part of the process of building an SP-
multiple-alignment in SP-neural, as discussed in [26 Section 4]. Reproduced
with permission from Figure 3 in [26].
in information and to reduce it, whilst retaining non-redundant information, in accordance with the central principle in the SP theory—that much of computing and cognition may, to a large extent, be understood as information compression.” *(ibid.)*

A related idea is that the rate of firing of neurons correlates only indirectly with the strength of stimulation, and that when stimulation is steady, neurons typically fire at a constant rate which is the same regardless of the strength of the stimulation. This can be seen in Figure 3 which shows variations in the rate of firing of a sensory cell (*ommatidium*) in the eye of the horseshoe crab (*Limulus*) in response to variations in the intensity of the light that is falling on it.

![Figure 3](image)

Figure 3: Variation in the rate of firing of a single ommatidium of the eye of a horseshoe crab in response to changing levels of illumination. Reproduced from [9, p. 118.], with permission from the Optical Society of America.

On the left of the figure, where the light level is low, the ommatidium fires at a steady rate of about 20 impulses per second. When a light is switched on, there is sharp upswing in the rate of firing, but this soon settles back to the same 20 impulses per second rate as before. When the light is switched off, there is a sharp downswing in the rate of firing followed by a rapid return to the previous steady rate.

This pattern of responses can be explained via inhibitory connections
which dampen down responses when stimulation is steady \[14\]. Similar effects occur in the spatial dimension and it appears that similar explanations apply.

### 12.1.2 Developments

In the building of an SP-multiple-alignment, modelling such things as the parsing of a sentence or the recognition of a pattern, things are a bit different from what has been described in the previous subsection. Instead of trying to detect and remove redundancy between neighbouring elements in a sequential or spatial pattern, the aim is to detect redundancies between two independent patterns, such as a New pattern (as, for example, ‘\textsc{Information}’) and an Old pattern (such as ‘\textsc{Information}’), or between two partial SP-multiple-alignments at later stages of processing.

Bearing in mind the putative idea that the role of inhibition is to detect and remove redundancies in information, a possible scheme is shown in Figure \ref{fig:inhibition} with a key to the meanings of symbols in the caption to the figure.

This is how the scheme may work:

- In accordance with what was said about the results of neural processing shown in Figure \ref{fig:neural}, it is envisaged that, without incoming signals, the four neural symbols shown at the top of the figure will fire at a steady intermediate rate.

- If a signal comes in from the neural symbol marked ‘a’ at the bottom of the figure, this will have an inhibitory effect on the neural symbol marked ‘a’ at the top of the figure. Likewise for the other two neural pairings, ‘b’ with ‘b’, and ‘c’ with ‘c’.

- If all three of ‘a’, ‘b’, and ‘c’, in the pattern assembly have been inhibited in this way, there will be reduced inhibitory signals transmitted to the “identifier” (ID) neural symbol marked ‘X’ in the figure.

- Since the ID neural symbol is receiving reduced inhibitory signals, its rate of firing will increase. This may be interpreted as recognition of the pattern ‘a b c’. That increase in the rate of firing may be transmitted to higher-level pattern assemblies that contain ‘X’ as a “reference” to the pattern ‘a b c’. This may lead to similar processes of recognition at higher levels.

\footnote{Although the two sources that have been referenced have authority in this area, they do not explain the principles very well. A clearer account may be found in [14, pp. 65–75].}
Figure 4: A schematic representation of one possible neural scheme for detecting redundancies between an incoming pattern ('a b c'), shown at the bottom of the figure and a stored pattern that matches it, shown above. Key: a letter inside an unbroken envelope represents a neural symbol; a group of neural symbols surrounded by a broken-line envelope represents a pattern assembly; lines between neural symbols ending in a blob (a filled circle) represent nerve fibres carrying signals towards the blob, with an inhibitory impact on the neural symbol that is receiving the signals;
A possible weakness in the account just given is that, in line with what was said about Figure 3, we may suppose that the rate of firing of the ‘X’ would quickly settle back to the average rate of firing, but there is nothing to ensure that that would happen. Issues like this may be clarified with a working model.

What about the ordering of symbols? With the scheme as just described, the pattern assembly ‘X a b c’ would respond as strongly to an input pattern ‘b c a’—assuming that there were corresponding neural connections in place—as it would to the input pattern ‘a b c’.

It looks as if the weakness in that idea is the assumption contained within it, and it appears that the concept of a typographic pattern, provides an answer. As was quoted in [26, Section 5.4]:

“Receptors in the retina and body surface are organized as two-dimensional sheets, and those of the cochlea form a one-dimensional line along the basilar membrane. Receptors in these organs communicate with ganglion cells and those ganglion cells with central neurons in a strictly ordered fashion, such that relationships with neighbors are maintained throughout. This type of pattern, in which neurons positioned side by side in one region communicate with neurons positioned side-by-side in the next region, is called a typographic pattern.” [13, p. 504], emphasis in the original.

12.2 Implementation of the SP-neural computer model

The SP-neural computer model may be developed with these main features:

- **The C++ computer language.** For reasons given in Appendix C, the model is probably best implemented using the C++ computer language.

- **Neural symbols as a class.** Neural symbols would be implemented as a C++ class. For each instance of the class, this would provide the following features:
  
  - **Inhibitory connections between neurons.** The means of sending an inhibitory message to zero or more other neural symbols. The paths for such messages may be regarded as nerve-fibre connections between neural symbols like the one between neural symbol
‘a’ near the bottom of Figure 4 and neural symbol ‘a’ near the top, and likewise for the two other pairs of neural symbols in the figure.

– **Indexing of symbols that match each other.** If the nerve-fibre connections just mentioned are only ever between a pair of symbols that match each other, such as, for example, between ‘textttN’ as the ID neural symbol in a pattern assembly like ‘textttN d o g’ (the word ‘dog’ belongs in the class ‘noun’), and ‘textttN’ as part of the contents of a pattern assembly like ‘textttS N V’ (a sentence in its simplest form is a noun followed by a verb), then the list of connections in each neural symbol is, in effect, an index of matching symbols, much like the index proposed for the abstract part of the SP theory, described in Section 3.4.

This line of thinking suggests that many neural connections in the brain, perhaps all of them, are, in effect, direct connections between neural symbols with a role that is very much like that of an index in any ordinary database management system, or the very large indices that are maintained in search engines for the internet.

– **Inhibition of ID neural symbols.** Within each pattern assembly, each neural symbol would have the means of sending an inhibitory message to ID neural symbol at the far left of the pattern assembly, as shown in Figure 4. Notice that any one neuron can only ever be in one pattern assembly, or none. Hence, any one neuron only ever needs to be able to send inhibitory messages to an ID neural symbol in the pattern assembly of which it is a part.

– **Subclasses of the neural symbol class.** There may be a case for providing two subclasses of the neural symbol class: one for *C neural symbols* (each of which may be part of the contents of a pattern assembly) and one for *ID neural symbols* (each of which may serve as an identifier for a pattern assembly). These features of SP-neural are described in [18, Section 11.3.2].

- **Pattern assemblies as a class.** Pattern assemblies would also be implemented as a C++ class. For each instance of the class, it would provide the means of storing zero or more ID-neural-symbols and zero or more

——The term *C-neuron* (meaning “C neural symbol”), introduced in [18, Section 11.3.2], and the term *ID-neuron* (meaning “ID neural symbol”), introduced in the same place, should probably be dropped. This is because neural symbols are not necessarily single neurons—they may be small clusters of neurons.
C-neural-symbols, perhaps using linked lists. It may also store other information such as the number of times the pattern assembly has been recognised in a given set of New patterns.

12.3 Unsupervised learning in SP-neural

How unsupervised learning may be achieved in SP-neural is considered mainly in [26, Section 10] with some related observations in Section 11 of that paper. Here, we have no new insights to add to that account except to underscore the point that:

“... in any or all of short-term memory, working memory, and long-term memory, SP-neural may achieve the necessary speed in the creation of new structures, combined with versatility in the representation and processing of diverse kinds of knowledge, by the switching on and off of synapses in pre-established neural structures and their inter-connections ...” and that this would be “somewhat like the way in which an ‘uncommitted logic array’ (ULA) may, via small modifications, be made to function like any one of a wide variety of ‘application-specific integrated circuits’ (ASICs), or how a ‘field-programmable gate array’ (FPGA) may be programmed to function like any one of a wide variety of integrated circuits.” [26, Section 11].

13 New hardware

As was mentioned in the Introduction, there may, at some stage, be a case for the development of new hardware, dedicated to structures and processes in the SP system, and with potential for gains in efficiency and performance ([23, Section IX], [22, Section III]).

Since searching for matching patterns is an important part of how the SP system works, gains in efficiency may be achieved by concentrating search where good results are most likely to be found: “If we want to find some strawberry jam, our search is more likely to be successful in a supermarket than it would be in a hardware shop or a car-sales showroom.” [23, Section IX-A.2], and the statistical knowledge in the system flows directly from the central role of information compression in the workings of the SP system, and from the intimate relationship that is known to exist between information compression and concepts of prediction and probability [12, 12, 6].
Gains in efficiency from the use of indices (Section 3.4) may be at least partly via the encoding of statistical aspects of the data that are being processed.

New hardware may be developed for either or both of the two versions of the SP system: the abstract version embodied in the SP71 computer model, and SP-neural as outlined in Appendix A.4, and discussed in Section 12.

14 Applications that may be realised on relatively short timescales

Sources of information about potential applications of the SP machine are detailed in Appendix A.6.

Here, in brief, are some of the applications that may be developed on relatively short timescales:

- **The SP machine as an intelligent database system.** With the application of parallel processing and indexing (Section 3) and the creation of a “friendly” user interface (Section 4), the SP machine should begin to be useful as an intelligent database system, with several advantages over ordinary database systems, as described in [19].

- **Software engineering.** As outlined in [24, Section 6.6], and described in more detail in [30], the SP system may be applied with advantage in software engineering in two main ways:
  
  - In conjunction with an existing programming environment, replacing an ordinary database management system with an SP intelligent database system as indicated in the previous bullet point.
  
  - As a programming environment in its own right. As before, the SP system may serve as an intelligent database system but, here, there would be seamless integration with the SP system as a programming environment.

In both of these options, the SP system would provide a more streamlined way of representing such things as entity-relationship models, compared with the relative inefficiencies of using a relational database for that purpose. And the SP system lends itself well to the use of object-oriented concepts for the structuring of knowledge.

With the second option, there is also potential for the application of unsupervised learning for the automatic or semi-automatic creation of software.
Information compression. Since information compression is central in how the SP system works, the SP machine is likely to prove useful in situations where compression of information is the main requirement. It may, for example, be a useful means of reducing the size of “big data”, with corresponding benefits in storage and transmission of those data [23, Section VII].

15 Conclusion

This paper is about the main things that need to be done to develop a mature version of the SP machine, starting with the SP71 computer model. After a summary of our research strategy, we describe the main tasks in what we think is roughly the order they should be tackled:

1. Starting with the SP71 computer model, create a high-parallel version of the SP machine as a software virtual machine hosted on a high-performance computer. An interesting alternative would be to create the SP machine as a software virtual machine driven by high-parallel search processes in any of the leading search engines. If this were extended to all search engines, there would be potential to convert the internet into something that would, in effect, be a giant brain!

2. Create a user interface for the SP machine that is easy to use.

3. Closely related to the previous task is the development of the SP system’s existing strengths in the visualisation of the structure of stored knowledge and in the provision of an audit trail for all processing.

4. As the basis for such things as computer vision, the SP machine will need to be generalised to work with patterns in two dimensions as well as the 1D patterns of the SP71 model.

5. The generalisation just mentioned would include the development of processes for the discovery of good full and partial matches between 2D patterns (and between a 2D pattern and a 1D pattern) and for the display of SP-multiple-alignments comprising two or more 2D patterns (with or without 1D patterns).

6. An investigation is needed into whether or how the SP machine, with or without some modification, may discover low-level features in speech and visual images, of the kind that appear to be significant in human perception.
7. Existing strengths of the SP system in the processing of natural language may be developed towards the goal of creating an SP machine that can understand natural language and produce natural language from meanings. This is likely to be a major project or programme of research, with several stages, in conjunction with the development of unsupervised learning (next). Likely stages include: experiments with the unsupervised learning of artificial languages; unsupervised learning of plausible grammars from unsegmented samples of natural language text; unsupervised learning of plausible structures for various kinds of non-syntactic knowledge; unsupervised learning of syntactic/semantic structures; and unsupervised learning from speech.

8. Residual problems with the existing processes for unsupervised learning need to be solved. These weaknesses are failure of the system to discover structures with intermediate levels of abstraction, and failure to discover discontinuous dependencies in structure. A solution to these problems will clear the path for the development of unsupervised learning in conjunction with the processing of natural language, as described in the previous bullet point.

9. Existing strengths of the SP system in pattern recognition may be developed for computer vision, guided by the insights in [21].

10. On the strength of evidence to date, it seems likely that the representation of numbers and the performance of arithmetic processes may be accommodated within the SP framework. Pending success in those areas, stop-gap solution may be employed where needed.

11. Somewhat independent of other developments described in this paper, would be the development of a computer model of SP-neural, drawing on the information and insights described in [26] and perhaps also in [18, Chapter 11]. An important part of this development would be to see whether or how inhibitory processes have the important role that seems likely from evidence that is available now, and, if not, to provide some reasons why.

12. At some stage when the SP machine is relatively mature, it is envisaged that new hardware would be developed, mainly to exploit opportunities to increase the efficiency of computations, most notably by taking advantage of statistical information that the SP system gathers as a by-product of how it works.
There is potential for the SP machine to be applied on relatively short timescales in such areas of application as information storage and retrieval, with intelligence, software engineering, and information compression.

A Outline of the SP system

To help ensure that this paper is free standing, the SP system is described in outline here with enough detail to make the rest of the paper intelligible.

As stated in the Introduction and in Section 2, the SP programme of research is a unique attempt to simplify and integrate observations and concepts across artificial intelligence, mainstream computing, mathematics, and human learning, perception and cognition, with information compression as a unifying theme.

The SP system is described most fully in [18] and more briefly in [20].

The SP theory is conceived as a brain-like system as shown schematically in Figure 5. The system receives New information via its senses and stores some or all of it in compressed form as Old information.

![Figure 5: Schematic representation of the SP system from an ‘input’ perspective.](image)

Information compression is central in the SP system because of substantial evidence for the importance of information compression in the workings of brains and nervous systems described in [28]. In this connection, the name “SP” is short for Simplicity and Power. This is because information compression may be seen to be a process of maximising the simplicity of a body of information, \( I \), by extracting redundancy from \( I \), whilst retaining as much as possible of its non-redundant descriptive power.
A.1 SP-multiple-alignments

In the SP system, information compression is achieved largely via the powerful concept of SP-multiple-alignment, a concept that has been adapted from bioinformatics. As illustrated in Figure 6, a multiple alignment in bioinformatics is an arrangement of two or more DNA sequences or amino-acid sequences so that, by judicious “stretching” of sequences in a computer, symbols that match each other are brought into line. A “good” multiple alignment is one in which a relatively large number of matching symbols have been aligned.

Figure 6: A ‘good’ multiple alignment amongst five DNA sequences. Reproduced with permission from Figure 3.1 in [18].

Because there is normally an astronomically large number of alternative ways in which multiple alignments may be arranged, heuristic methods are needed to build multiple alignments in stages, discarding all but the best few partial multiple alignments at the end of each stage. With such methods, it is not normally possible to guarantee that a theoretically ideal multiple alignment has been found, only multiple alignments that are “reasonably good”.

The following subsections describe how the multiple alignment concept has been adapted to become the concept of SP-multiple-alignment.

A.2 Patterns, symbols, and multiple alignments in the SP system

In the SP system, all kinds of knowledge are represented with arrays of atomic symbols in one or two dimensions, termed patterns. Of course, a 1D pattern is the same as a sequence in bioinformatics. At present, the SP computer model works only with 1D patterns but it is envisaged that it will be generalised to work with 2D patterns (Section 3).
In themselves, SP patterns are not very expressive. But within the SP-multiple-alignment framework they become very versatile as a means of representing diverse kinds of knowledge [31, Section 4.2].

The main change to the multiple alignment concept in the SP system is that, in each SP-multiple-alignment, one or more of the sequences (often only one) is a New pattern and the rest are Old, and a “good” SP-multiple-alignment is one in which the New information may be encoded economically in terms of the Old information, as described in [18, Section 2.5] and in [20, Section 4.1].

Examples of SP-multiple-alignments created by the SP computer model are shown in Figures 7 and 8.

The first of these shows how the parsing of a sentence may be modelled within the SP-multiple-alignment framework. In the figure, row 0 shows a New SP pattern representing the sentence to be parsed while rows 1 to 8 show Old SP patterns, one per row, representing grammatical structures including words. Row 8 shows the grammatical dependency between the plural subject of the sentence (marked with ‘textttNp’) and the plural main verb (marked with ‘textttVp’).

![Figure 7](image)

In the SP-multiple-alignment shown in Figure 8, column 0 shows a New SP pattern representing something to be recognised while columns 1 to 4 show Old SP patterns, one per row, representing categories of entity. This way of representing SP-multiple-alignments is entirely equivalent to the way in which the SP-multiple-alignment in Figure 7 has been represented. The choice between them depends entirely on what fits best on the page.

Figure 7: (a) The best SP-multiple-alignment created by the SP computer model with a store of Old patterns like those in rows 1 to 8 (representing grammatical structures, including words) and a New pattern (representing a sentence to be parsed) shown in row 0. Adapted with permission from Figures 1 in [19].
Figure 8: The best SP-multiple-alignment found by the SP model, with the New pattern ‘white-bib eats furry purrs’ shown in column 1, and a set of Old patterns representing different categories of animal and their attributes shown in columns 1 to 4. Reproduced with permission from Figure 15 in [20].
By convention, the New pattern is always shown in column (or row) 0 and Old patterns are shown in other columns (or rows). In some applications there is more than 1 New pattern in column (row) 0.

A.3 The SP71 computer model

The latest version of the SP computer model is SP71. Instructions for obtaining the source code are in Appendix B.

There is no comprehensive description of SP71, but SP70, a very similar and slightly earlier version of the program is described quite fully in [18]. More detailed citations are given in the three subsections that follow.

At the level of detail we shall be considering, the description of SP70 in [18] is an accurate description of SP71. In what follows, it will be regarded as a description of SP71.

A.3.1 Finding good full and partial matches between patterns in SP71

In the foundations of the SP computer model is a process for finding good full and partial matches between two SP patterns (sequences of symbols) that works well even when there are substantial differences between the two patterns. This is described quite fully in [18, Appendix A].

This technique is similar in its effects to standard “dynamic programming” methods for comparing sequences [15, 10] but with these main advantages [18, Section 3.10.3.1]:

- It can match arbitrarily long sequences without excessive demands on memory.
- For any two sequences, it can find a set of alternative matches (each with a measure of how good it is) instead of a single ‘best’ match.
- The ‘depth’ or thoroughness of the searching can be controlled by parameters.

A.3.2 Building SP-multiple-alignments in SP71

The way in which SP-multiple-alignments are built in SP71 is described in [18, Sections 3.9 and 3.10]. Slightly confusingly, the main subject of these sections is SP61, but this is merely a part of the SP computer model that is concerned with the building of SP-multiple-alignments.
As with multiple alignments in bioinformatics, heuristic techniques are used in the building of SP-multiple-alignments in the SP system: searching for good SP-multiple-alignments in stages with a weeding out of the lower-scoring SP-multiple-alignments at the end of each stage.

A.3.3 Unsupervised learning in SP71

Unsupervised learning in SP71 is described in [18, Sections 3.9 and 9.2], with relevant pseudocode in [18, Figures 9.1 and 9.6]. The aim here is, for a given set of New patterns, to create one or two grammars—meaning collections of Old SP patterns—that are effective at encoding the given set of New patterns in an economical manner.

The building of SP-multiple-alignments is an integral part of unsupervised learning in the SP system. It provides a means of creating Old patterns via the splitting or amalgamation of pre-existing Old patterns, and via the direct incorporation of New patterns. And it provides a means of evaluating candidate grammars in terms of their effectiveness at encoding the given set of New patterns in an economical manner.

As with the building of SP-multiple-alignments, the creation of good grammars requires heuristic search through the space of alternative grammars: creating grammars in stages and discarding low-scoring grammars at the end of each stage.

A.3.4 Varying the thoroughness of heuristic search

A useful feature of SP71 is that, with all three of the main components (Sections A.3.1, A.3.2, and A.3.3), the thoroughness of the searches may be varied by varying the amount of memory space that is available for storing intermediate results. In effect, this controls the amount of backtracking that can be done and thereby controlling the chances of escaping from local peaks in the search space.

A.4 SP-neural

Abstract concepts in the SP theory map quite neatly into groupings of neurons and their interconnections in a version of the theory called SP-neural [26]: SP symbols are realised as neural symbols (single neurons or small clusters of neurons) and SP patterns are realised as pattern assemblies. Although pattern assemblies in SP-neural are quite similar to cell assemblies as described by Donald Hebb [3], unsupervised learning in the SP system (including what is envisaged in the development of SP-neural) is quite different.
from “deep learning in artificial neural networks” [11]. The key differences are described in [26, Section 10.5].

A.5 Distinctive features and advantages of the SP system

Distinctive features and advantages of the SP system are described in [27]. In particular, Section V of that paper describes 13 problems with deep learning in artificial neural networks and how, with the SP system, those problems may be overcome.

The SP system also provides a comprehensive solution to a fourteenth problem with deep learning—“catastrophic forgetting”—meaning the way in which new learning in a deep learning system wipes out old memories [11].

Key strengths of the SP system, which owe much to the central role in the system of the SP-multiple-alignment concept, are in three inter-related features of the system:

- **Versatility in the representation of knowledge.** The SP system has proved to be a versatile framework for the representation of diverse kinds of knowledge, and there are reasons to think that it may in principle accommodate any kind of knowledge [31, Section 4.2].

- **Versatility in aspects of intelligence.** The SP system has proven strengths in several aspects of intelligence, including unsupervised learning, pattern recognition, planning, problem solving, and several kinds of reasoning, and there are reasons to think that SP-multiple-alignment may prove to be the key to general, human-like artificial intelligence. [31, Section 4.3].

- **Seamless integration of diverse kinds of knowledge and diverse aspects of intelligence, in any combination.** Since the SP system’s strengths in the representation of diverse kinds of knowledge and in diverse aspects of intelligence all flow from a single coherent source—the SP-multiple-alignment framework—there is clear potential for their seamless integration in any combination [31, Section 4.4]. This kind of integration appears to be essential in any system that aspires to human-like fluidity, versatility, and adaptability in intelligence.

\footnote{A solution has been proposed in [4] but it appears to be partial, and it is unlikely to be satisfactory in the long run.}
A.6 Potential benefits and applications of the SP system

The discovery that SP-multiple-alignments could simplify and integrate observations and concepts across a broad canvass has been a bit like hitting the jackpot on a fruit machine, releasing a cascade of potential benefits and applications, described in a book and in several peer-reviewed papers:

- The book, *Unifying Computing and Cognition* [18] describes strengths of the SP system in several areas, mainly in AI, with corresponding potential in applications that require human-like intelligence.

- The paper “The SP theory of intelligence: benefits and applications” [24] describes several potential benefits and applications of the SP system, including potential: for an overall simplification of computing systems, including software; for applications in the processing of natural language; in software engineering; in bioinformatics; and several more.

- The paper “Big data and the SP theory of intelligence” [23] describes how the SP system may help solve nine significant problems with big data.

- The paper “Autonomous robots and the SP theory of intelligence” [22] describes how the SP system may help in the development of human-like intelligence in autonomous robots.

- The paper “Application of the SP theory of intelligence to the understanding of natural vision and the development of computer vision” [21] describes, as its title suggests, how the SP system may help in the understanding of human vision and in the development of computer vision.

- The paper “Towards an intelligent database system founded on the SP theory of computing and cognition” [19] describes how the SP system may function as a database system that, in a relatively streamline manner, can accommodate a wider variety of kinds of knowledge than a conventional DBMS, with potential for aspects of intelligence as summarised in [31, Section 4.3].

- The paper “Medical diagnosis as pattern recognition in a framework of information compression by multiple alignment, unification and search” [17] describes how the SP system may serve as a repository for medical
knowledge and as a means of assisting medical practitioners in medical diagnosis.

- The paper “Commonsense reasoning, commonsense knowledge, and the SP theory of intelligence” [25] describes how the SP system can throw light on most of the problems for AI posed by Ernest Davis and Gary Marcus in modelling commonsense reasoning [1].

B Source code for the SP71 computer model

The latest version of the SP computer model is SP71. At the time of writing, the source code, written in C++ with many comments, may be obtained via instructions under the headings “Source code” and “Archiving”, near the bottom of bit.ly/1mSs5XT. More specifically, the source code may be obtained:

- In the file SP71.zip (bit.ly/1OEVPDw).
- In “Ancillary files” with “The SP theory of intelligence: an overview” under www.arxiv.org/abs/1306.3888. Apart from SP71.exe, all the files should be treated as plain text files to be opened with Wordpad, WinEdt, or the like.
- From a digital archive with: the National Museum of Computing, Block H, Bletchley Park, Milton Keynes, MK3 6EB, UK; Phone: +44 (0)1908 374708; Email: operations@tnmoc.org.
- From a digital archive with: the Library and Archives Service, Bangor University, Bangor, Gwynedd, LL57 2DG, UK; Phone: +44 (0) 1248 382981; Email: library@bangor.ac.uk.

C Choice of programming language for creating a computer model of SP-neural

As with the SP71 computer model, the best way to implement SP-neural would probably be with the C++ computer language. For present purposes, it has the following main advantages:

- It is widely used and widely available both on single-threaded and parallel-processing machines.
• Like the C programming language from which it was derived, it provides for high level ‘conceptual’ programming and, at the same time, it provides access to low-level features of the host machine if that is required.

• As a compiled programming language, its run-time efficiency is almost certainly higher than any of the programming languages that run interpretively. Since the SP system, like other AI-related systems, is intrinsically hungry for computer power (Section 3.1), run-time efficiency is important.

• It provides facilities for object-oriented design including mechanisms for the creation of hierarchies of classes with inheritance of attributes.

• There are likely to be benefits in maintaining consistency with the SP71 computer model.

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