The potential of the *SP-Multiple-Alignment* concept as the 'double helix' of intelligence

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Abstract

This paper introduces the concept of *SP-Multiple-Alignment* within the *SP Theory of Intelligence* (SPTI) and its realisation in the *SP Computer Model* (SPCM). The significance of this concept is that it combines relative Simplicity with relatively large Power in the description and explanation of several aspects of human intelligence. Thus SP-Multiple-Alignment within the SPTI and SPCM provides a relatively firm foundation for the development of human level intelligence, aka 'Artificial General Intelligence'. SP-Multiple-Alignment has the potential to be as significant for an understanding of intelligence as is the concept of DNA for an understanding of biology. It may prove to be the 'double helix' of intelligence!

1 Introduction

This paper is an introduction to the concept of *SP-Multiple-Alignment* within the *SP Theory of Intelligence* (SPTI) and its realisation in the *SP Computer Model* (SPCM).

The SP-Multiple-Alignment concept is a *major discovery* within a programme of research aiming to find or create a framework for the development of human-level intelligence, aka 'Artificial General Intelligence'.

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1.1 Getting a grip on the problem

The first step in the search for that general framework was the creation of a program for finding good full and partial matches between two sequences of atomic symbols. This is described in [18, Appendix A]. The reasons for this choice were:

- *Information compression*:
  - Pioneering research by Fred Attneave [1, 2], Horace Barlow [3, 4], and others shows that much of the workings of brains and nervous systems may be understood as compression of information. That evidence, and much other evidence for the same conclusion, is described in [27].
  - It seemed likely that 'good' full and partial matches between sequences of symbols would also be ones that would allow compression of information via the merging or 'unification' of sections that match each other.
- Intuitively, it seemed likely that several aspects of intelligence might be understood as a search for good full and partial matches between patterns.
- *The potential for two or more good answers*:
  - Although, when this project began, many programs existed (and still exist) for finding good full and partial matches between sequences of symbols, it appeared that none of them could deliver more than a single best answer.
  - But intuition suggested that human intelligence normally entails the discovery of two or more answers of varying degree of success. Hence, the program that was developed in this programme of research was designed to find two or more reasonably good alternative solutions, or only one if alternative answers could not be found.

1.2 A key discovery: the potential of 'multiple sequence alignments' or something like them

Having developed a program for finding good full and partial matches between two sequences of symbols, it seemed that there might be some value in looking at programs for finding good full and partial matches between two *or more* sequences of symbols. This kind of analysis, called 'multiple sequence alignment', is used by biochemists in the analysis of DNA sequences and in the analysis of sequences of amino-acid residues.

These programs are designed to analyse two, three, four, or more sequences simultaneously and to show each of the best results as an arrangement of the two or more sequences next to each other, with judicious ‘stretching’ of sequences in a computer to align symbols that match each other from one sequence to another.

An example of a ‘good’ multiple sequence alignment of five DNA sequences is shown in Figure 1.

```
  G G A     G     C A G G G A G G A     T G     G   G G A
  | | |     |     | | | | | | | | |     | |     |   | | |
  G G | G   G C C C A G G G A G G A     | G G C G   G G A
  | | |     | | | | | | | | | | | |     | |     |   | | |
A | G A C T G C C C A G G G | G G | G C T G     G A | G A
  | | |           | | | | | | | | |   |   |     |   | | |
  G G A A         | A G G G A G G A   | A G     G   G G A
  | |   |         | | | | | | | |     |   |     |   | | |
  G G C A         C A G G G A G G     C   G     G   G G A
```

Figure 1: A ‘good’ multiple sequence alignment amongst five DNA sequences. Reproduced from [18, Figure 3.1].

From studying this kind of multiple sequence alignment and creating different examples ‘manually’ with a word processor, I began to realise that multiple sequence alignments, or something like them, could provide a versatile model for different aspects of AI.

1.3 Developing the SP-Multiple-Alignment concept

The concept of multiple sequence alignment was structured well enough to suggest how it might be useful in studies of human cognition or AI, but it was far from being usable in the embryonic SPTI.

To create a new SP-Multiple-Alignment concept for the understanding of intelligence, and for diverse applications of AI, required an extended period of development in which each idea about how the system might work was programmed into a version of the SPCM and then tested with appropriate data, across a range of potential areas of application.

For each idea, notes were taken, describing the idea and its successes or failures within a corresponding version of the SPCM, with ideas for how the original problems might be overcome, and the shortcoming in the model being addressed.

Although the SP-Multiple-Alignment concept as it is now (described in Section 2.3, below) may seem straightforward, its development took several years' work. Tha process of development required the creation and testing of *hundreds* of versions of the SPCM.

Apart from the SP-Multiple-Alignment concept itself, the process of developing the display of SP-Multiple-Alignments was a major challenge in which two-years' work was abandoned because an unworkable framework had been adopted.

2 The SP Theory of Intelligence and its realisation in the SP Computer Model

This section introduces the *SP Theory of Intelligence* and its realisation in the *SP Computer Model* with sufficient detail to ensure that the rest of the paper is intelligible. More detail may be found in the paper [20], and there is a much fuller account of the system in the book *Unifying Computing and Cognition* [18].

2.1 High level view of the SPTI

The SPTI is conceived as a brain-like system as shown in Figure 2, with *New* information (green) coming in via the senses (eyes and ears in the figure), and with some or all of that information compressed and stored as *Old* information (red), in the brain.

As described in more detail below, the processing of New information to create Old information is central in how the SPTI works, and it is central in all aspects of intelligence that are modelled by the SPTI, and apparently in all its potential applications.

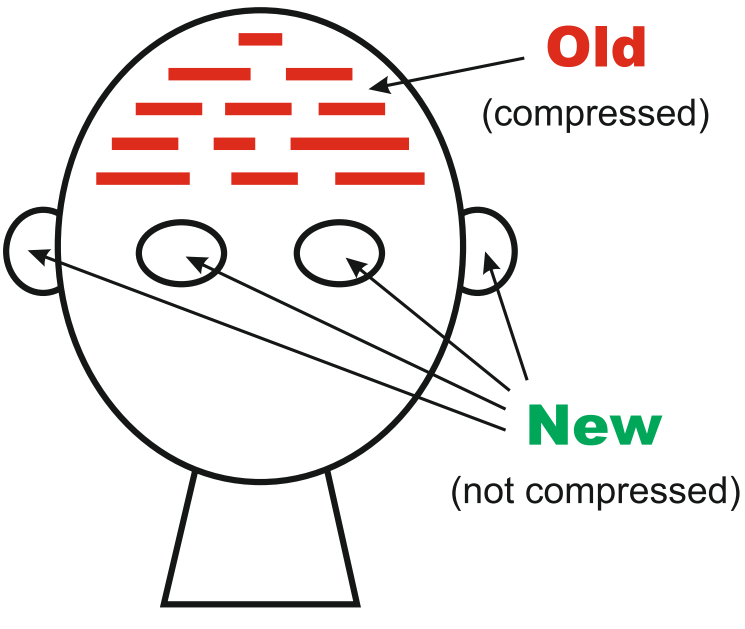

Figure 2: Schematic representation of the SPTI from an 'input' perspective. Reproduced from Figure 1 in [20].

2.2 *SP-patterns* and *SP-symbols*

In the SPTI, all kinds of knowledge are represented by *SP-patterns*, where an SP-pattern is an array of *SP-symbols* in one or two dimensions.

An SP-symbol is simply a mark from an alphabet of alternatives where each SP-symbol can be matched in a yes/no manner with any other SP-symbol.

An SP-symbol does not have any hidden meaning, such as 'add' for the symbol '+' in arithmetic, or 'multiply' for the symbol '×', and so on. Any meaning attaching to an SP-symbol is provided by one or more other SP-symbols with which it is associated.

This kind of simplicity, combined with the relatively simple but powerful concept of SP-Multiple-Alignment (Section 2.3) is the key to the seamless integration of diverse aspects of AI and diverse kinds of intelligence-related knowledge, in any combination (Section 4.1.4).

Examples of SP-patterns may be seen in Figure 3, as described in the caption to the figure.

2.2.1 Two-dimensional SP-patterns

At present, the SPCM works only with one-dimensional SP-patterns but it is envisaged that the SPCM will be generalised to work with two-dimensional SP-patterns, as well as one-dimensional SP-patterns. It is envisaged that 2D SP-patterns may be of any shape, not necessarily simple rectangles

The addition of 2D SP-patterns should open up the system for the representation and processing of diagrams and pictures. As described in [13, Sections 6.1 and 6.2)], 2D SP-patterns may serve in the representation of structures in three dimensions. And 2D SP-patterns may also have a role in the representation and processing of parallel streams of information, as described in [21, Sections V-G, V-H, and V-I, and Appendix C]. SP-patterns in one or two dimensions may also serve in representing the time dimension in videos and the like.

2.2.2 ID SP-Symbols and C SP-symbols

For some purposes, there is a distinction between 'ID' SP-symbols and 'C' SP-symbols. The former serve in the identification and classification of SP-patterns, while the latter serve to represent the communicative contents of an SP-pattern.

As an example, the SP-pattern '`!N !Ns !4 w e s t !#N`' in the SP-grammar in Figure 4 (Section 2.3) contains the ID SP-symbols '`N`', '`Ns`', '`4`', and '`#N`' at the ends of the SP-pattern, and it contains the C SP-symbols '`w`', '`e`', '`s`', and '`t`' in the middle of the SP-pattern.

Notice that the character '`!`' at the beginning of each of the ID SP-symbols '`N`', '`Ns`', '`4`', and '`#N`' serves to mark each SP-symbol as an ID SP-symbol in its current context but it is not part of the SP-symbol. The same SP-symbols may appear in other contexts without the preceding '!' character.

2.3 The *SP-Multiple-Alignment* concept

The SP-Multiple-Alignment concept is described in outline here. More detail may be found in [18, Section 3.4] and [20, Section 4].

2.3.1 The SP-Multiple-Alignment concept, Simplicity, and Power

The SP-Multiple-Alignment concept is largely responsible for the intelligence-related and other strengths of the SPTI, summarised in Section 4. Although it is far from being trivially simple, the SP-Multiple-Alignment concept is remarkably simple as the source of most of the strengths of the SPTI. In short, the relative Simplicity of the SPTI combined with its high descriptive and explanatory Power, is largely due to the SP-Multiple-Alignment concept.

In the light of the foregoing remarks, it is appropriate to say that *the SP-Multiple-Alignment concept is a major discovery with the potential to be as significant for an understanding of intelligence as is the concept of DNA for an understanding of biology. It may prove to be the 'double helix' of intelligence!*

2.3.2 Organisation of the SP-Multiple-Alignment concept

As we have seen (Section 1.2), the SP-Multiple-Alignment concept in the SPTI has been borrowed and adapted from the concept of 'multiple sequence alignment' in bioinformatics. An example of an SP-Multiple-Alignment is shown in Figure 3.

```
0                       t h e                p l u m      s                      a r e         r i p e           0
                        | | |                | | | |      |                      | | |         | | | |
1                       | | |          Nrt 6 p l u m #Nrt |                      | | |         | | | |           1
                        | | |           |             |   |                      | | |         | | | |
2                       | | |    N Npl Nrt           #Nrt s #N                   | | |         | | | |           2
                        | | |    |  |                       |                    | | |         | | | |
3                  D 17 t h e #D |  |                       |                    | | |         | | | |           3
                   |          |  |  |                       |                    | | |         | | | |
4            NP 0a D          #D N  |                       #N #NP               | | |         | | | |           4
             |                      |                           |                | | |         | | | |
5            |                      |                           |       V Vpl 11 a r e #V      | | | |           5
             |                      |                           |       |  |           |       | | | |
6            |                      |                           |  VP 1 V  |           #V A    | | | | #A #VP    6
             |                      |                           |  |       |              |    | | | | |   |
7 S Num    ; NP                     |                          #NP VP      |              |    | | | | |  #VP #S 7
     |     |                        |                                      |              |    | | | | |
8   Num PL ;                       Npl                                    Vpl             |    | | | | |         8
                                                                                          |    | | | | |
9                                                                                         A 21 r i p e #A        9
```

Figure 3: The best SP-Multiple-Alignment created by the SPCM that achieves the effect of parsing a sentence (‘`t h e p l u m s a r e r i p e`’) into its parts and sub-parts, as described in the text. The sentence in row 0 ia a New SP-pattern, while each of the rows 1 to 9 contains a single Old SP-pattern, drawn from a relatively-large repository of Old SP-patterns, in the SP-grammar shown in Figure 4. Reproduced from Figure A2 in [16].

The main components of the SP-Multiple-Alignment concept, illustrated in the Figure 3, are these:

- Row 0 contains one New SP-pattern representing information that has been received recently from the system's environment (Section 2.1). Sometimes row 1 contains more than one New SP-pattern. In this case, the SP-pattern in row 1 is a sentence but in other SP-Multiple-Alignments the New SP-pattern may represent any other kind of information.

- Each of rows 1 to 9 contains a single Old SP-pattern, drawn from a relatively large repository of Old SP-patterns. In this case, that repository of Old SP-patterns is the SP-grammar shown in Figure 4, and each Old SP-pattern in the SP-Multiple-Alignment and in the SP-grammar represents a grammatical structure including words. More generally, Old SP-patterns may represent any other kind of information.

In this example, the SP-Multiple-Alignment is shown with SP-patterns in rows, but as we shall see, SP-Multiple-Alignments may also be shown with SP-patterns in columns instead of rows. The choice depends largely on what fits best on the page.

```
!S Num ; NP #NP VP !#VP #S
!NP !0 NP #NP Q #Q !#NP
!NP !0a D #D N #N !#NP
!VP !1 V #V A #A !#VP
!Q !1 P #P NP #NP !#Q
!N !Ns !2 i t !#N
!N !Ns !3 s h e !#N
!N !Ns !4 w e s t !#N
!N !Ns !5 o n e !#N
!Nrt !7 w i n d !#Nrt
!Nrt !6 p l u m !#Nrt
!N !Npl !8 s i x !#N
!N !Npl !9 s e v e n !#N
!N !Npl Nrt #Nrt s !#N
!V !Vs !10 d o e s !#V
!V !Vs !10a i s !#V
!V !Vpl !11 a r e !#V
!V !Vpl !12 p l a y !#V
!V !Vpl !13 d o !#V
!P !14 w i t h !#P
!P !15 f r o m !#P
!P !16 o f !#P
!D !17 t h e !#D
!D !18 a !#D
!A !19 s t r o n g !#A
!A !20 w e a k !#A
!A !21 r i p e !#A
!Num !SNG !; Ns Vs
!Num !PL !; Npl Vpl
```

Figure 4: In this SP-grammar, each SP-pattern starts and ends with SP-symbols representing a grammatical category which are called ‘ID’ SP-symbols. The character ‘!’ in the SP-grammar serves to mark a symbol as being an ‘ID-symbol’ (Section 2.2) and, in each SP-pattern, the unmarked SP-symbols are ‘C’ or ‘contents’ SP-symbols.

2.3.3 How SP-Multiple-Alignments are built up

Here is a summary of how SP-Multiple-Alignments like the one shown in Figure 3 are built up:

1. At the beginning of processing, the SPCM has the afore-mentioned store of Old SP-patterns (Figure 4).

   When the SPCM is more fully developed, those Old SP-patterns would have been learned from raw data, but for now they are supplied to the program by the user.

2. The next step is to read in the New SP-pattern, '`t h e p l u m s a r e r i p e`', shown in row 0 of Figure 3.

3. Then the program searches for 'good' matches between the New SP-pattern and Old SP-patterns, where 'good' matches are ones that yield relatively high levels of compression of the New SP-pattern in terms of Old SP-pattern(s) with which it has been unified.

4. In later stages, the program searches for matches between rows established in earlier stages. One of many examples in Figure 3 is the matches between rows 4 and 7.

5. As can be seen in the figure, matches are identified at early stages between (parts of) the New SP-pattern and the Old SP-patterns '`D 17 t h e #D`', '`Nrt 6 p l u m #Nrt`', '`V Vpl 11 a r e #V`', and '`A 21 r i p e #A`'. Although this is not shown in this example, the SPCM also searches for matches *within* the New SP-pattern.

6. In SP-Multiple-Alignments, IC may be achieved by collapsing the whole SP-Multiple-Alignment into a single sequence of symbols and thus unifying matching patterns within the SP-Multiple-Alignment, like the match between '`t h e`' in the New SP-pattern and the same three letters in the Old SP-pattern '`D 17 t h e #D`'. In practice, this is not done explicitly but only notionally to achieve a measure of IC for the whole SP-Multiple-Alignment and for each partial SP-Multiple-Alignment created in the course of building the whole SP-Multiple-Alignment.

7. The unification of '`t h e`' with '`D 17 t h e #D`' yields the unified SP-pattern '`D 17 t h e #D`', with exactly the same sequence of SP-symbols as the second of the two SP-patterns from which it was derived.

8. As processing proceeds, similar pair-wise matches and unifications eventually lead to the creation of SP-Multiple-Alignments like that shown in Figure 3. At every stage, all the SP-Multiple-Alignments that have been created are evaluated in terms of IC, and then the best SP-Multiple-Alignments are retained and the remainder are discarded. In this case, the final 'winner' is the SP-Multiple-Alignment shown in Figure 3.

9. This process of searching for good SP-Multiple-Alignments in stages, with selection of good partial solutions at each stage, is an example of heuristic search. This kind of search is necessary because there are too many possibilities for anything useful to be achieved by exhaustive search. By contrast, heuristic search can normally deliver results that are reasonably good within a reasonable computational complexity, but it cannot guarantee that the best possible solution has been found.

10. A simple but important detail is that any SP-pattern in an SP-grammar, each one of which occurs only once in the SP-grammar, may appear two or more times in any SP-Multiple-Alignment.

2.3.4 Discontinuous constituents and their representation in an SP-Multiple-Alignment

Regarding the SP-Multiple-Alignment shown in Figure 3, an aspect not mentioned so far is the role of the SP-pattern shown in row 8.

Clues to the role of that SP-pattern lie in the SP-symbols '`PL`', '`Npl`', and '`Vpl`' within the SP-pattern in row 8. The first of these SP-symbols, '`PL`', shows that the sentence has a 'plural' form. The second of those SP-symbols, '`Npl`', marks the subject noun, '`p l u m s`' as having the plural form. And the third of those SP-symbols, '`Vpl`', marks the main verb as having the plural form.

So in summary, the role of the SP-pattern in row 8, which is the last SP-pattern in the SP-grammar in Figure 4, is to encode the syntactic rule in English and many other natural languages that if the subject of the sentence has a plural form, then the main verb should also have a plural form.

As can be seen in the SP-grammar in Figure 4, the last but one SP-pattern, '`!Num !SNG !; Ns Vs`', is the one that would be called into play to show the dependency between a singular subject noun and a singular main verb.

These dependencies are called 'discontinuous' because they can jump over any amount of intervening structure.

Arguably, this method for representing discontinuous dependencies in syntax is more elegant than the standard computer science method using variables, described in, for example, [6, Chapter 12]. The method illustrated in Figure 3 and described in [18, Section 5.4] has the merit of growing seamlessly out of the SP-Multiple-Alignment method for representing and processing linguistic information (amongst other kinds of information), without the need for any *ad hoc* addition to the method.

2.4 Versatility of the SP-Multiple-Alignment concept

As noted in the caption to Figure 3, although the SP-Multiple-Alignment in the figure achieves the effect of parsing the sentence into its parts and sub-parts, *the beauty of the SP-Multiple-Alignment concept is that it is largely responsible for the versatility of the SPTI in intelligence-related areas* (summarised in Sections 4.1 and 4.2), *and in other areas less closely related to intelligence* (summarised in Section 4.3).

The SP-Multiple-Alignment concept is the last of seven variants of 'IC via the matching and unification of patterns' described in [14], and it has been shown in that paper to be a generalisation of the other six variants described in the paper. This generalisation is probably the main reason for the versatility of the SPTI described above.

2.4.1 Production of a sentence

The way in which a code SP-pattern may be said to represent all or part of a New SP-pattern is described here. In brief, it means that the full or partial New SP-pattern may be recreated by treating the code SP-pattern as if it was a New SP-pattern and processing it with the SPCM in exactly the same way as any New SP-pattern.

This can be seen in Figure 5. All the words of the sentence '`t h e p l u m s a r e r i p e`' can be seen in the SP-Multiple-Alignment in the right order, thus recreating the whole sentence. Notice how, within the workings of the SPCM, individual code SP-symbols serve to pick out the words or other structures with which they are associated: '`PL`' picks out the SP-pattern for plural sentences (in row 8), '`0a`' picks out the SP-pattern for noun phrases (in row 4), '`17`' picks out '`D 17 t h e #D`', and so on.

This process of reconstructing a sentence from its code may be seen as an example of what may appear paradoxically to be 'decompression by compression' described in [18, Section 3.8], with a resolution of the paradox.

```
0 S     PL      0a   17                    6                          1       11            21                #S 0
  |     |       |    |                     |                          |       |             |                 |
1 S Num |  ; NP |    |                     |                   #NP VP |       |             |             #VP #S 1
     |  |  | |  |    |                     |                    |  |  |       |             |              |
2    |  |  | |  |    |                     |                    |  VP 1 V     |        #V A |          #A #VP    2
     |  |  | |  |    |                     |                    |       |     |        |  | |          |
3    |  |  | |  |    |                     |                    |       V Vpl 11 a r e #V | |          |         3
     |  |  | |  |    |                     |                    |          |              | |          |
4    |  |  | NP 0a D |        #D N         |                #N #NP         |              | |          |         4
     |  |  |       | |        |  |         |                |              |              | |          |
5    |  |  |       D 17 t h e #D |         |                |              |              | |          |         5
     |  |  |                     |         |                |              |              | |          |
6    |  |  |                     |     Nrt 6 p l u m #Nrt   |              |              | |          |         6
     |  |  |                     |      |             |     |              |              | |          |
7    |  |  |                     N Npl Nrt           #Nrt s #N              |              | |          |         7
     |  |  |                        |                                      |              | |          |
8   Num PL ;                       Npl                                    Vpl             | |          |         8
                                                                                          | |          |
9                                                                                         A 21 r i p e #A        9
```

Figure 5: The best SP-Multiple-Alignment created by the SPCM that achieves the effect of decoding the code SP-pattern, '`S PL 0a 17 6 1 11 21 #S`', resulting in the recreation of the sentence '`t h e p l u m s a r e r i p e`', as described in the text. The SP-pattern in row 0 ia a New SP-pattern representing the encoding of the sentence, while each of the rows 1 to 9 contains a single Old SP-pattern, drawn from the repository of Old SP-patterns shown in Figure 4.

3 Examples of the versatility of the SP-Multiple-Alignment concept within the SPCM

As the title of this section suggests, it contains examples of SP-Multiple-Alignments showing the kinds of things that may be done with the SPCM. These examples show some of the versatility of the SP-Multiple-Alignment concept, but SP-Multiple-Alignments are very much more versatile than these few examples may suggest.

3.1 Nonmonotonic reasoning and reasoning with default values

The exanple of nonmonotonic reasoning described here, together with the parsing example in Section 2.3.2 illusrate the strength of the SP-Multiple-Alignment concept to bridge aspects of intelligence that seem, superficially, to have little in common.

Nonmonotonic reasoning is one of several kinds of probabilistic reasoning that can be done with the SPTI, outlined in Section 4.1.1.

By contrast with nonmonotic reasoning, conventional deductive reasoning is *monotonic* because deductions made on the strength of current knowledge cannot be invalidated by new knowledge. For example, the conclusion that 'Socrates is mortal', deduced from 'All humans are mortal' and 'Socrates is human', remains true for all time, regardless of anything we learn later. By contrast, the inference that 'Tweety can probably fly' from the propositions that 'Most birds fly' and 'Tweety is a bird' is *nonmonotonic* because it may be changed if, for example, we learn that Tweety is a penguin or an ostrich.

The elements of nonmonotonic reasoning are illustrated in the following SP-Multiple-Alignments.

```
0         1         2               3

                                    Default
                    Bd ------------ Bd
bird ------------ bird
          name --- name
Tweety - Tweety
          #name -- #name
                    f ------------ f
                                    canfly
                    #f ----------- #f
                    warm-blooded
                    wings
                    feathers
                    ...
                    #Bd ---------- #Bd
                                    #Default

0         1         2               3
```

Figure 6: The first of the three best SP-Multiple-Alignments formed by the SPCM with 'bird Tweety' in New and SP-patterns in Old as described in the text. The relative probability of this SP-Multiple-Alignment is calculated as 0.66. Reproduced from [20, Figure 17].

In Figure 6, a bird called 'Tweety' (columns 0 and 1) is identified as a bird (column 2) and, as such, it is assumed that it can (probably) fly (column 3). This inference is probabilistic because, as described below, there are two other SP-Multiple-Alignments that can be formed from the information that Tweety is a bird (columns 0 and 1). The SPTI calculates the relative probability of this SP-Multiple-Alignment as 0.66 (calculated from an imaginary frequency of occurrence assigned to each of the Old SP-patterns).

In Figure 7, a bird called 'Tweety' (columns 0 and 1) is identified as a bird (column 2), and as an ostrich (column 3). In this case, we know that Tweety,

```
0         1         2                3

                                     O
                                     ostrich
                    Bd ----------- Bd
bird ------------ bird
          name --- name
Tweety - Tweety
          #name -- #name
                    f ------------ f
                                     cannotfly
                    #f ----------- #f
                    warm-blooded
                    wings
                    feathers
                    ...
                    #Bd ---------- #Bd
                                     ...
                                     #O

0         1         2                3
```

Figure 7: The second of the three best SP-Multiple-Alignments formed by the SPCM with 'bird Tweety' in New and patterns in Old as described in the text. The relative probability of this SP-Multiple-Alignment is calculated as 0.22. Reproduced from [20, Figure 18].

as an ostrich, would not be able to fly (column 3), but because this SP-Multiple-Alignment is only one of three alternative SP-Multiple-Alignments created from the same New information, the result is less than certain. The relative probability of this SP-Multiple-Alignment is calculated as 0.22.

```
0         1         2                3

                                     P
                                     penguin
                    Bd ----------- Bd
bird ------------ bird
          name --- name
Tweety - Tweety
          #name -- #name
                    f ------------ f
                                     cannotfly
                    #f ----------- #f
                    warm-blooded
                    wings
                    feathers
                    ...
                    #Bd ---------- #Bd
                                     ...
                                     #P

0         1         2                3
```

Figure 8: The last of the three best SP-Multiple-Alignments formed by the SPCM with 'bird Tweety' in New and SP-patterns in Old as described in the text. The relative probability of this SP-Multiple-Alignment is 0.12.

Figure 8, is much the same as Figure 7 except that, in this case, Tweety is a penguin and, as such, he (or she) would not be able to fly. The relative probability of this SP-Multiple-Alignment is calculated as 0.12.

Figure 9 is different from the previous three SP-Multiple-Alignments because, in this case, column 0 tells us that Tweety is a penguin, not a bird. Now there is a sharp change in the probability calculated by the SPTI: the relative probability calculated by the SPCM is 1.0 because there are no alternatives SMAS created from that New information in column 0. The same would apply if column 0 was 'ostrich Tweety'.

These examples illustrate nonmonotonic reasoning as outlined at the beginning of this section because the inferences that are made about Tweety and his (or her)

```
0          1         2               3

                                     P
penguin ------------------------- penguin
                     Bd ----------- Bd
                     bird
           name --- name
Tweety -- Tweety
           #name -- #name
                     f ------------ f
                                     cannotfly
                     #f ----------- #f
                     warm-blooded
                     wings
                     feathers
                     ...
                     #Bd ---------- #Bd
                                     ...
                                     #P

0          1         2               3
```

Figure 9: The best SP-Multiple-Alignment formed by the SPCM with 'penguin Tweety' in New and SP-patterns in Old as described in the text. The relative probability of this SP-Multiple-Alignment is 1.0.

ability to fly can change, depending on the information about Tweety that is supplied. This is much more in keeping with way people normally reason than is classical logic and its procrustean rules that prevents inferences from changing as we learn more about Tweety.

3.2 Planning

The planning example described in this section, together with the parsing and reasoning examples described in Sections 2.3.2 and 3.1, provide other examples of the strength of the SP-Multiple-Alignment concept to bridge aspects of intelligence that seem, superficially, to have little in common.

Given New information about the desired start and finish of a traveller by air and a repository of Old information about direct flights between cities, the SPCM can work out alternative routes that may be taken. Five possibilities are shown in Figures 10 to 14

```
0           1          2            3

Beijing -- Beijing
           0
           Delhi --- Delhi
                     15a
                     Cape-Town - Cape-Town
                                 13
New-York ----------------------- New-York

0           1          2            3

(a)
```

Figure 10: This and the following four figures show SP-Multiple-Alignments representing a selection of routes between Beijing and New York. They are amongst the best SP-Multiple-Alignments found by the SPCM with 'Beijing New-York' in New and SP-patterns showing one-way air links between individual cities as described in the text.

```
0          1         2       3

Beijing -- Beijing
           0
           Delhi --- Delhi
                     17
                     Paris - Paris
                             27
New-York ------------------- New-York

0          1         2       3

(b)
```

Figure 11: See Figure 10.

```
0          1           2           3

Beijing -- Beijing
           1
           Melbourne - Melbourne
                       22
                       Zurich ---- Zurich
                                   23a
New-York ------------------------- New-York

0          1           2           3

(c)
```

Figure 12: See Figure 10.

```
0          1         2           3          4

Beijing -- Beijing
           0
           Delhi --- Delhi
                     15a
                     Cape-Town ------------ Cape-Town
                                            14
                                 Paris ---- Paris
                                 25a
New-York ----------------------- New-York

0          1         2           3          4

(d)
```

Figure 13: See Figure 10.

```
0          1          2           3           4

Beijing ------------------------- Beijing
                                  1
                                  Melbourne - Melbourne
                                              10a
                      Cape-Town ------------- Cape-Town
                      14
           Paris ---- Paris
           25a
New-York - New-York

0          1          2           3           4

(e)
```

Figure 14: See Figure 10.

3.3 Problem solving

Horace Barlow foresaw that '... the operations needed to find a less redundant code have a rather fascinating similarity to the task of answering an intelligence test, ...' [4, p. 210]. In support of his prescient observation, this section shows how IC at the core of the SPCM may solve a modified version of the kind of puzzle that is popular in intelligence tests.

Figure 15 shows an example of this type of puzzle. The task is to complete the relationship '`A is to B as C is to ?`' using one of the geometric patterns '`D`', '`E`', '`F`' or '`G`' in the position marked with '`?`' in the figure. For this example, the 'correct' answer is clearly '`E`'. Quote marks have been used for the word 'correct' because, in some problems of this type, there may be two or more alternative answers where there is uncertainty about which answer is the right one.

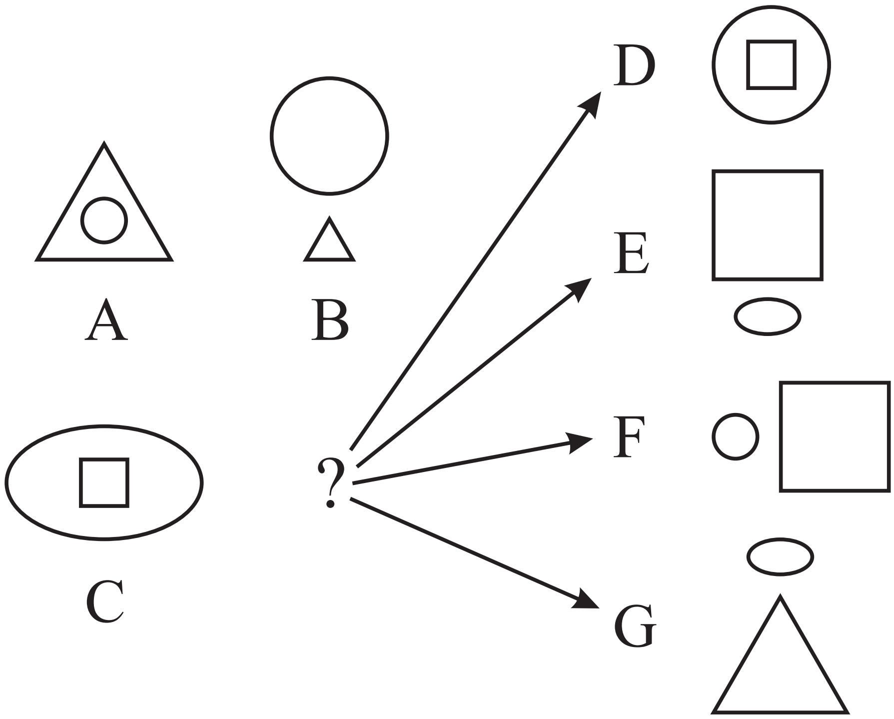

Figure 15: A geometric analogy problem.

Normally, these tests use simple geometric patterns like those shown in Figure 15 but because the SPCM has not yet been developed to process two-dimensional SP-patterns, the geometric patterns are described textually as, for example, in '`small square inside large ellipse`', '`small square inside large circle`', and so on.

Computer-based methods for solving this kind of problem have existed for some time (e.g., Evans's [8] well-known heuristic algorithm). In more recent work [5, 10], AIT principles have been applied to good effect. The proposal here is that, within the general framework of Ockham's razor, this kind of problem may be understood in terms of the SP concepts.

Given that the diagrammatic form of the problem has been translated into textual patterns as described above, this kind of problem can be cast as a problem of partial matching, well within the scope of the SPCM.

Figure 16 shows the best SP-Multiple-Alignment created by the SPCM with New information in column 0 corresponding to the geometric patterns '`A`' and '`B`' in Figure 15, and the Old SP-patterns shown in Figure 17 corresponding to the geometric patterns '`D`', '`E`', '`F`' and '`G`' in Figure 15.

```
0           1

            C2
small ---- small
circle     square
inside --- inside
large ---- large
triangle   ellipse
; -------- ;
            E
large ---- large
circle     square
above ---- above
small ---- small
triangle   ellipse
            #C2

0           1
```

Figure 16: The best SP-Multiple-Alignment found by the SPCM for the SP-patterns in New and Old as described in the text.

As can be seen from the figure, the best SP-Multiple-Alignment found by the SPCM shows, in column 2, the combination of textual patterns corresponding to a combination of geometric patterns '`C`' and '`E`' in Figure 15, and of course this is the 'correct' answer as noted above.

As can be seen from the figure, finding the best SP-Multiple-Alignment from these New and Old SP-patterns depends on the ability of the SPCM to find good partial matches between SP-patterns.

```
C1 small square inside large ellipse ;
     D small square inside large circle #C1
C2 small square inside large ellipse ;
     E large square above small ellipse #C2
C3 small square inside large ellipse ;
     F small circle left-of large square #C3
C4 small square inside large ellipse ;
     G small ellipse above large rectangle #C4.
```

Figure 17: Textual patterns corresponding to the combination of 'C' on the bottom left of Figure 15 with one of 'D', 'E', 'F', or 'G' down the right side of the figure. These serve as Old SP-patterns as described in the text.

4 The main strengths of the SP Theory of Intelligence

In this book, the word 'strengths', applied to the SPTI, is intended to mean strengths that have been demonstrated with the SPCM and potential strengths that are more than mere speculations.[1]

Intelligence-related aspects of the SPTI are described quite fully in [20, Sections 5–12], and even more fully in [18, Chapters 5–9].

The first subsection here outlines the strength of the SPTI via the global concepts of Simplity and Power.

The two subsections that follow (Sections 4.1 and 4.2)) summarise the intelligence-related strengths of the SPTI, and the one after that (Section 4.3) summarises some other potential benefits and applications of the SPTI, less closely related to AI.

4.1 Aspects of intelligence exhibited by the SP Computer Model

The next four subsections describe intelligence-related features of the SPCM.

4.1.1 Intelligence in the SP Computer Model: excluding probabilistic reasoning)

The strengths of the SPTI in intelligence-related functions and other attributes are summarised in this section, excluding probabilistic reasoning which is given a separate subsection because of its importance.

[1]This section is based on [14, Appendix A].

- *Compression and Decompression of Information.* In view of substantial evidence for the importance of IC in human learning, peception, and cognition [27], IC should be seen as an important feature of human intelligence.

- *Natural Language Processing.* Under the general heading of 'Natural Language Processing' are capabilities that facilitate the learning and use of natural languages. These include:

  - *Hierarchies of Classes and Sub-Classes.* The ability to structure syntactic and semantic knowledge into hierarchies of classes and sub-classes, and into parts and sub-parts.
  - *Integration of Syntactic and Semantic Knowledge.* The ability to integrate syntactic and semantic knowledge.
  - *Discontinuous Dependencies in Syntax.* The ability to encode discontinuous dependencies in syntax such as the number dependency (singular or plural) between the subject of a sentence and its main verb, or gender dependencies (masculine or feminine) in French—where 'discontinuous' means that the dependencies can jump over arbitrarily large intervening structures (Section 2.3.4, Figure 3).

    Also important in this connection is that different kinds of dependency (e.g., number and gender) can co-exist without interfering with each other, and discontinuous dependencies provide an effective means of encoding the intricate structure of English auxiliary verbs.
  - *Representation of Recursive Structures in Syntax.* The ability to accommodate recursive structures in syntax (see, for example,).
  - *The Production of Natural Language.* A point of interest here is that the SPCM provides for the production of language as well as the analysis of language, and it uses exactly the same processes for IC in the two cases—in the same way that the SPCM uses exactly the same processes for both the compression and decompression of information.

- *Recognition and Retrieval.* Capabilities that facilitate recognition of entities or retrieval of information include:

  - *Recognition or Retrieval Via Partial Matches.* The ability to recognise something or retrieve information on the strength of a good partial match between features as well as an exact match.
  - *Recognition or Retrieval Via Classes and Subclasses, and Via Parts and Subparts.* Recognition or retrieval within a Class-Inclusion Hierarchy with 'inheritance' of attributes, and recognition or retrieval within an hierarchy of parts and sub-parts.

- *'Semantic' Kinds Of Information Retrieval.* 'Semantic' kinds of information retrieval—retrieving information via 'meanings'.
- *Computer Vision.* Computer Vision [13], including visual learning of 3D structures.

- *Planning and Problem Solving.* Capabilities here include:
  - . The ability to plan a route, such as for example a flying route between cities A and B, given information about direct flights between pairs of cities including those that may be assembled into a route between A and B.
  - . The ability to solve geometric analogy problems, or analogues in textual form.

- *Unsupervised Learning.* Chapter 9 of [18] describes how the SPCM may achieve unsupervised learning from a body of 'raw' data, **I**, to create an *SP-grammar*, **G**, and an **Encoding** of **I** in terms of **G**, where the encoding may be referred to as **E**. At present the learning process has shortcomings summarised in [20, Section 3.3] but it appears that these problems may be overcome.

  In its essentials, unsupervised learning in the SPCM means searching for one or more 'good' SP-grammars, where a good SP-grammar is a set of SP-patterns which is relatively effective in the economical encoding of **I** via an SP-Multiple-Alignment.

  This kind of learning includes the discovery of segmental structures in data (including hierarchies of segments and subsegments) and the learning classes (including hierarchies of classes and subclasses).

4.1.2 Intelligence in the SP Computer Model: probabilistic reasoning

As described in [18, Chapter 7], several kinds of probabilistic reasoning flow from one relatively simple framework: the concept of SP-Multiple-Alignment:

- *One-Step 'Deductive' Reasoning.* A simple example of *modus ponens* syllogistic reasoning goes like this:
  - If something is a bird then it can fly.
  - Tweety is a bird.
  - Therefore, Tweety can fly.

- *Abductive Reasoning.* In brief, abductive reasoning means seeking the simplest and most likely conclusion from a set of observations, something which sits comfortably within the SPTI framework.

- *Probabilistic Networks and Trees.* One of the simplest kinds of system that supports reasoning in more than one step (as well as single step reasoning) is a 'decision network' or a 'decision tree'. In such a system, a path is traced through the network or tree from a start node to two or more alternative destination nodes depending on the answers to multiple-choice questions at intermediate nodes. Any such network or tree may be given a probabilistic dimension by attaching a value for probability or frequency to each of the alternative answers to questions at the intermediate nodes.

- *Reasoning With 'Rules'.* SP-patterns may serve very well within the SPCM for the expression of such probabilistic regularities as 'sunshine with broken glass may create fire', 'matches create fire', and the like. Alongside other information, rules like those may help determine one or more of the more likely scenarios leading to the burning down of a building, or a forest fire.

- *Nonmonotonic Reasoning.* An example showing how the SPTI can perform nonmonotonic reasoning is described in Section 3.1. The conclusion that 'Socrates is mortal', deduced from 'All humans are mortal' and 'Socrates is human' remains true for all time, regardless of anything we learn later. By contrast, the inference that 'Tweety can probably fly' from the propositions that 'Most birds fly' and 'Tweety is a bird' is nonmonotonic because it may be changed if, for example, we learn that Tweety is a penguin. Section 3.1 shows how this works with SP-Multiple-Alignments.

- *'Explaining Away'.* This means 'If A implies B, C implies B, and B is true, then finding that C is true makes A less credible.' In other words, finding a second explanation for an item of data makes the first explanation less credible.

There is also potential in the system for:

- *Spatial Reasoning.* The potential is described in [21, Section IV-F.1].

- *What-If Reasoning.* The potential is described in [21, Section IV-F.2].

4.1.3 Intelligence in the SP Computer Model: the representation and processing of several kinds of intelligence-related knowledge

Although SP-patterns are not very expressive in themselves, they come to life in the SP-Multiple-Alignment framework within the SPCM. Within the SP-Multiple-

Alignment framework, they provide relevant knowledge for each aspect of intelligence mentioned in Sections 4.1.1 and 4.1.2.

More specifically, they may serve in the representation and processing of such things as: the syntax of natural languages; Class-Inclusion Hierarchies (with or without cross classification); Part-Whole Hierarchies; discrimination networks and trees; if-then rules; entity-relationship structures [19, Sections 3 and 4]; relational tuples [19, Sections 3] and concepts in mathematics, logic, and computing, such as 'function', 'variable', 'value', 'set', and 'type definition' ([18, Chapter 10], [23, Section 6.6.1], [24, Section 2]).

As noted in Section 2.2, the addition of two-dimensional SP-patterns to the SPCM is likely to expand the capabilities of the SPTI to include the representation and processing of structures in two-dimensions and three-dimensions, and the representation of procedural knowledge with parallel processing.

4.1.4 Intelligence in the SP Computer Model: the seamless integration of diverse aspects of intelligence, and diverse kinds of knowledge, in any combination

An important additional feature of the SPCM, alongside its versatility in aspects of intelligence, including diverse forms of reasoning and its versatility in the representation and processing of diverse kinds of intelligence-related knowledge, is that *there is clear potential for the SPTI to provide for the seamless integration of diverse aspects of intelligence and diverse forms of knowledge, in any combination.*

This appears to be because those several aspects of intelligence, and several kinds of intelligence-related knowledge, all flow from a single coherent framework: SP-patterns and SP-symbols (Section 2.2), and the SP-Multiple-Alignment concept (Section 2.3).

It appears that this kind of seamless integration is *essential* in any artificial system that aspires to AGI.

Figure 18 shows schematically how the SPTI, with the SP-Multiple-Alignment at centre stage, exhibits versatility in diverse aspects of intelligence, and diverse kinds of intelligence-related knowledge, and their seamless integration.

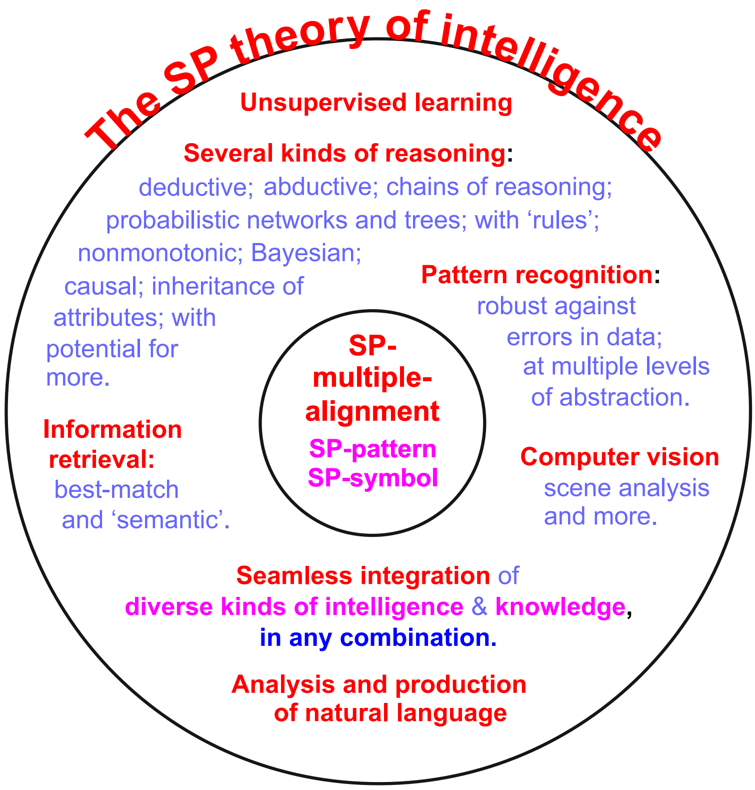

Figure 18: A schematic representation of versatility and seamless integration in the SPTI, with the SP-Multiple-Alignment concept, and the SP-pattern and SP-symbol concepts, centre stage.

4.2 Other aspects of intelligence relating to the SP Theory of Intelligence

This section describes some other evidence for the intelligence-related validity of the SPTI.

4.2.1 The clear potential of the SP Theory of Intelligence to solve twenty significant problems in artificial intelligence research

Strong evidence in support of the SPTI has arisen, indirectly, from the book *Architects of Intelligence* by science writer Martin Ford [9]. To prepare for the book, he interviewed several influential experts in AI to hear their views about AI research, including opportunities and problems in the field. He writes [9, p. 2]:

> The purpose of this book is to illuminate the field of artificial intelligence—as well as the opportunities and risks associated with it—by having a series of deep, wide-ranging conversations with some of the world's most prominent AI research scientists and entrepreneurs.

In the book, Ford reports what the AI experts say, giving them the opportunity to correct errors he may have made so that the text is a reliable description of their thinking.

This source of information has proved to be very useful in defining problems in AI research that influential experts in AI deem to be significant. This has been important from the SP perspective because, with 17 of those problems and three others—20 in all—there is clear potential for the SPTI to provide a solution.

Since these are problems with broad significance, not micro-problems of little consequence, the clear potential of the SPTI to solve them is a major result from the SP programme of research, demonstrating much of the power of the SPTI.

The peer-reviewed paper [32] describes those 20 significant problems, how the SPTI may solve them, with pointers to where fuller information may be found. *Because of the dominant position today of DNNs in AI research, most of these problems in that research are also problems with DNNs.*

The following summary describes each of the problems briefly with a summary of how the SPTI may solve it, together with an addition to point 14 below (about the importance of IC in intelligence). In addition, there is the same kind of summary for a twenty-first problem not mentioned in [32]:

1. *The Symbolic Versus Sub-Symbolic Divide.* The need to bridge the divide between symbolic and sub-symbolic kinds of knowledge and processing [32, Section 2]. The concept of an SP-symbol can represent a relatively large symbolic kind of thing such as a word or a relatively fine-grained kind of thing such as a pixel.

2. *Errors in Recognition.* The tendency of DNNs to make large and unexpected errors in recognition [32, Section 3]. The overall workings of the SPTI and its ability to correct errors in data suggests that it is unlikely to suffer from these kinds of error.

3. *Natural Languages.* The need to strengthen the representation and processing of natural languages, including the understanding of natural languages and the production of natural language from meanings [32, Section 4]. The SPTI has potential in the representation and processing of several aspects of natural language.

4. *Unsupervised Learning.* Overcoming the challenges of unsupervised learning. Although DNNs can be used in unsupervised mode, they seem to lend themselves best to the supervised learning of tagged examples [32, Section 5]. Learning in the SPTI is entirely unsupervised.

   It is clear that most human learning, including the learning of our first language or languages [15], is achieved via unsupervised learning, without needing tagged examples, or reinforcement learning, or a 'teacher', or other form of assistance in learning (*cf.* [11]).

   Incidentally, a working hypothesis in the SP programme of research is that unsupervised learning can be the foundation for all other forms of learning, including learning by imitation, learning by being told, learning with rewards and punishments, and so on.

5. *Generalisation, Over-Generalisation, and Under-Generalisation.* The need for a coherent account of generalisation, over-generalisation (under-fitting) [32, Section 6], and under-generalisation (over-fitting).

   Although this is not mentioned in Ford's book [9], there is the related problem of reducing or eliminating the corrupting effect of errors in the data which is the basis of learning. The SPTI provides a coherent account of generalisation, and the correction of over- and under-generalisations, and avoiding the corrupting effect of errors in data.

6. *One-Shot Learning* (Section 4.2.1, [32, Section 7]). Unlike people, DNNs are ill-suited to the learning of usable knowledge from one exposure or experience. The ability to learn usable knowledge from a single exposure or experience is an integral and important part of the SPTI.

7. *Transfer Learning.* Although transfer learning—incorporating old learning in newer learning—can be done to some extent with DNNs [12, Section 2.1], DNNs fail to capture the fundamental importance of transfer learning for

people, or the central importance of transfer learning in the SPCM [32, Section 8]. Transfer learning is an integral and important part of how the SPTI works.

8. *Reduced Demands for Data and Computational Resources Compared With DNNs* ([32, Section 9]). How to increase the speed of learning by DNNs, and how to reduce the demands of DNNs for large volumes of data, and for large computational resources [32, Section 9]. The ability of the SPTI to learn from a single exposure or experience, and the fact that transfer learning is an integral part of how it works, is likely to mean greatly reduced computational demands of the SPTI.

9. *Transparency.* The need for transparency in the representation and processing of knowledge [32, Section 10]. By contrast with DNNs, which are opaque in how they represent knowledge, and how they process it, the SPTI is entirely transparent in both the representation and processing of knowledge.

10. *Probabilistic Reasoning.* How to achieve probabilistic reasoning that integrates with other aspects of intelligence [32, Section 11]. The SPTI is entirely probabilistic in all its inferences, including the forms of reasoning described in [18, Chapter 7].

11. *Commonsense Reasoning an Commonsense Knowledge.* Unlike probabilistic reasoning, the area of commonsense reasoning and commonsense knowledge is surprisingly challenging [32, Section 12]. With qualifications, the SPTI shows some promise in this area [16, 25].

12. *How to Minimise the Risk of Accidents with Self-Driving Vehicles.* Notwithstanding the hype about self-driving vehicles, there are still significant problems in minimising the risk of accidents with such vehicles [32, Section 13]. The SPTI has potential in this area [30].

13. *Compositionality in the Representation of Knowledge.* DNNs are not well suited to the representation of Part-Whole Hierarchies or Class-Inclusion Hierarchies in knowledge [32, Section 14]. By contrast, the SPTI has robust capabilities in this area.

14. *Establishing the Importance of Information Compression in AI Research.* There is a need to spread the word about the significance of IC in both human learning, peception, and cognition and AI [32, Section 15]. The importance of IC in human learning, peception, and cognition is described in [27] and its importance in the SPTI is described in this and most other publications about the SPTI.

A point which deserves emphasis which was not mentioned in [32] is that, while there is some recognition amongst other researchers of the importance of IC in machine learning, there appears to be little or no recognition of the importance of IC in other aspects of intelligence. The importance of IC in the SPTI across all aspects of intelligence, in keeping with evidence for the importance of IC in human learning, peception, and cognition [27], is a major strength of the SPTI compared with other theories of intelligence.

15. *Establishing the Importance of a Biological Perspective in AI Research.* There is a need to raise awareness of the importance of a biological perspective in AI research [32, Section 16]. This is very much part of the SPTI research and publicity for that research.

16. *Distributed Versus Localist Representations for Knowledge.* A persistent issue in studies of human learning, peception, and cognition and in AI is whether knowledge in brains is represented in distributed or localist form, and which of those two forms works best in AI systems [32, Section 17]. DNNs employ a distributed form for knowledge, but the SPTI, which is firmly in the localist camp, has distinct advantages compared with DNNs. This reinforces other evidence for localist representations in brains.

17. *The Learning of Structures From Raw Data.* DNNs are weak in the learning of structures from raw data [32, Section 18]. By contrast, this is a clear advantage in the workings of the SPTI.

18. *The Need to Encourage Top-Down Strategies in AI Research.* Most AI research has adopted a bottom-up strategy, but this is failing to deliver generality in solutions [32, Section 19]. In the quest for AGI, there are clear advantages in adopting a top-down strategy.

19. *Overcoming the Limited Scope For Adaptation in Deep Neural Networks.* An apparent problem with DNNs is that, unless many DNNs are joined together, each one is designed to learn only one concept, and the learning is restricted to what can be done with a fixed set of layers [32, Section 20]. By contrast, the SPTI, like people, can learn multiple concepts, and these multiple concepts are often in hierarchies of classes or in Part-Whole Hierarchies. This adaptability is largely because, via the SP-Multiple-Alignment concept, many different SP-Multiple-Alignments may be created in response to one body of data.

20. *The Problem of Catastrophic Forgetting.* Although there are somewhat clumsy workarounds for this problem, an ordinary DNN is prone to the problem of catastrophic forgetting, meaning that new learning wipes out old learning

[32, Section 21]. There is no such problem with the SPTI which may store new learning independently with old learning, or form composite structures which preserve both old and new learning, in the manner of transfer learning (above).

21. *A Weakness of DNNs Not Mentioned in [32].* A matter which has become increasingly clear with further thought is that, despite the impressive things that have been done with DNNs,[2] DNNs are relatively restricted in the aspects of intelligence that, without augmentation, they can model. They show little of the versatility of the SPTI in modelling diverse aspects of intelligence (Sections 4.1 and 4.2), and in its other strengths (Section 4.3).

4.2.2 The SP Theory of Intelligence as a foundation for the development of artificial general intelligence

More evidence in support of the SPTI is presented in the peer-reviewed paper [16]. The paper argues that, since AGI is a long way from being achieved, we should assess AI projects and products as *foundations* for the development of AGI, not in terms of AGI itself. It is argued that, in those terms, the SPTI scores higher than AI products such as 'Gato' from DeepMind or 'DALL·E 2' from OpenAI, largely because of the powerful SP-Multiple-Alignment concept and how it combines parsimony with intelligence-related versatility, and also because the central role for IC in the SPTI accords with the central role for IC in human learning, peception, and cognition [27].

4.2.3 Commonsense reasoning and commonsense knowledge

An interesting aspect of AI is the challenging area of 'commonsense reasoning and commonsense knowledge', outlined under the fourth bullet point in Section 4.3.1 and described quite fully by Ernest Davis and Gary Marcus in [7].

Preliminary and unpublished papers about how the SPTI may be applied in this area of research may be downloaded via links from [26, 25].

4.3 Some other potential benefits and applications of the SP Theory of Intelligence

The three following subsections describe other potential benefits and applications of the SPTI.

[2] Forming part of a system that has beaten the best human players at the game of Go, and forming part of a system that has automated the difficult task of working out likely 3D structures for sequences of amino-acid residues.

4.3.1 A Summary of papers about potential benefits and applications of the SP Theory of Intelligence

Here's a summary of peer-reviewed papers that have been published about potential benefits and applications of the SPTI:

1. *Overview.* The SPTI promises deeper insights and better solutions in several areas of application including: unsupervised learning, natural language processing, autonomous robots, computer vision, intelligent databases, software engineering, information compression, medical diagnosis and big data. There is also potential in areas such as the semantic web, bioinformatics, structuring of documents, the detection of computer viruses, data fusion, new kinds of computer, and the development of scientific theories. The theory promises seamless integration of structures and functions within and between different areas of application [23].

2. *The Development of Intelligence in Autonomous Robots.* The SPTI opens up a radically new approach to the development of intelligence in autonomous robots [21].

3. *The Management of Big Data.* There is potential in the SPTI for the management of big data in the following areas: overcoming the problem of variety in big data; the unsupervised learning or discovery of 'natural' structures in big data; the interpretation of big data via pattern recognition, parsing and more; assimilating information as it is received, much as people do; making big data smaller; economies in the transmission of data; and more [22].

4. *Commonsense Reasoning and Commonsense Knowledge.* Largely because of research by Ernest Davis and Gary Marcus (see, for example, [7]), the challenges in this area of AI research are now better known. Preliminary work shows that the SPTI has promise in this area (Section 4.2.3).

5. *An Intelligent Database System.* The SPTI has potential in the development of an intelligent database system with several advantages compared with traditional database systems [19].

6. *Medical Diagnosis.* The SPTI may serve as a vehicle for medical knowledge and to assist practitioners in medical diagnosis, with potential for the automatic or semi-automatic learning of new knowledge [17].

7. *Natural Language Processing.* The SPTI has strengths in the processing of natural language ([20, Section 8], [18, Chapter 5]).

8. *Sustainability.* The SP Machine (derived from the SPCM), has the potential to reduce demands for energy from IT, especially in AI applications and in the processing of big data, in addition to reductions in CO_2 emissions when the energy comes from the burning of fossil fuels. There are several other possibilities for promoting sustainability [28].

9. *Transparency.* The SPTI with the SPCM provides an audit-trail for all its processing, and complete transparency in the way its output is structured [31].

10. *Vision, Both Artificial and Natural.* The SPTI opens up a new approach to the development of computer vision and its integration with other aspects of intelligence, and it throws light on several aspects of natural vision [13, 29].

5 Conclusion

In this paper, I have attempted to show that the SP-Multiple-Alignment concept combines conceptual Simplicity with descriptive and explanatory Power. As such, it may, as note in Section 2.3.1, prove to be as significant for an understanding of intelligence as is DNA in biology. It may prove to be the 'double helix' of intelligence.

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