April 2022

Working Note A - Part 1

1. Introduction

The following note outlines and extends the conjecture and illustrative conceptual frameworks provided in the Main Essay (the Essay).[1]

Because it was finalised in 1997 the Essay does not refer explicitly to either of two subsequent important developments in the discourse on consciousness: phenomenal self-model approaches and approaches entailing the predictive processing paradigm (PPP).[2]

Even so, many of the concepts underlying these two approaches are present in the Essay. This Working Note, beginning with Part 1, aims to show how the novel way concepts relating to self models and predictive processing were presented in the Essay can be recast in contemporary terms, and extended and integrated to yield further insights into how human subjective experience is made.[3]

The note begins with a brief – largely optional – guide to the front-end contents of the Essay cast to provide a sense of the illustrative conceptual frameworks the Essay offers. The note then shows how what the Essay calls *association complexes*, *association matrices*, and the *action cycle* – and the way these have been proposed to operate – can be recast and improved using concepts and terminology provided within the PPP and with reference to some of the key neurological insights that underpin the PPP.[4]

This re-expression and augmentation – though still highly speculative – allows for description of a more robust, more empirically-based set of illustrative concepts than was possible at the time the Essay was drafted and points more clearly to the kinds of information processing architecture and steps that could be central to genesis of a moment-by-moment subjective sense of being a physical self operating in a physical world. It also provides a PPP-compatible underpinning for work subsequent to the Essay – including the Introductory Summary[5], and the notes *How is Free Will Possible?* and *The Construction of Phenomenal Time*[6] – placing these in a contemporary context.

2. Sections 1 to 5 of the Essay

The concepts presented in Sections 1 to 5 of the Essay are recapitulated in clear terms in the Introductory Summary,[5] which should be read ahead of this note. There the case is made that to begin to understand how ongoing *physical self-awareness* (broadly meaning *consciousness*)[7] can be generated, it must be accepted that consciousness in human beings arises through implementation of a phenomenal self-model.[8] These sections also describe how application of the specific self-model approach adopted in the Essay can answer a number of questions raised by the Mind-Body Problem.[9]

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[1] The Main Essay is at http://teleodyne.com/main_essay.pdf. For wider context see http://teleodyne.com/.

[2] The term 'predictive processing paradigm' (PPP) will be used here in a broad sense to cover the general domains of hierarchical processing, generative and recognition models, active inference and candidate neurological structures that may underpin implementation of these. For some key references see footnote 4 below.

[3] The phenomenal self-model proposal made in the Essay is cast in fairly straightforward terms. Meanwhile, the information processing dynamics and architecture it describes as underpinning real time propagation of the proposed self-model – in particular, association complexes, association matrices and the action cycle – strongly align with ideas in the PPP, even though the former were intended in 1997 only as illustrative concepts rather than descriptions able evidently to be related to actual neurological systems. As such, association complexes and matrices should not be taken literally and, for contemporary purposes, should continue to be considered conceptual devices able now to provide a better grip on how the PPP can be integrated with self-model theories of subjectivity.

[4] Key references drawn upon to achieve this include: Mesulam, M. M. (1998) From Sensation to Cognition. *Brain 121* 1013-1052; Friston, K. (2003) Learning and Inference in the Brain. *Neural Networks 16* 1325-1352; Friston, K. (2010) The Free-Energy Principle: A Unified Brain Theory? *Nature Reviews Neuroscience 11* 127-138; Hohwy, J. (2020) New Directions in Predictive Processing. *Mind & Language 35* 209-223; and Ramstead, M.J.D. et al. (2020) A Tale of Two Densities: Active Inference is Enactive Inference *Adaptive Behaviour 28* pp225-239.

[5] See https://teleodyne.com/intro_summary.html and for a more complete picture, https://teleodyne.com/Psyche_D.pdf.

[6] For *How is Free Will Possible?* see https://teleodyne.com/free_will.pdf and for *The Construction of Phenomenal Time* see https://teleodyne.com/time.pdf.

[7] The term 'consciousness' is notoriously imprecise and was not as widely in use in the late 1980s when the first sections of the Essay were written. The phrase 'physical self-awareness' was used in the Essay for two reasons. First, it allows for better definition, having been in 1997 a more-or-less new phrase able to be defined in the terms provided in the Essay itself. Secondly, as the Essay contends (at its footnote 1 and Section 2), physical self-awareness is here literally intended to mean the subjective and conscious sense of being and operating from one subjective moment to the next as a *physical* body in a *physical* world. (1) I believe this to be the form of consciousness that precedes – and forms the foundation for – all other key aspects of human 'consciousness', such as a subjective awareness of oneself as a social as well as physical being. For a further perspective on this see pp12-13 in *The Construction of Phenomenal Time* at https://teleodyne.com/time.pdf.

[8] The term 'phenomenal self-model' was not in use when I wrote the Essay. At that time I had not seen any reference to this type of 'self-model'. To my knowledge the idea of a 'phenomenal self-model' was first publicly introduced by Thomas Metzinger in Metzinger, T., ed. *Neural Correlates of Consciousness - Empirical and Conceptual Questions*, pp289 MIT Press 2000, before full exposition in Metzinger, T. *Being No One*, pp9 MIT Press 2003.

[9] A clear description of the Mind-Body Problem is provided in Section 1.1 at https://plato.stanford.edu/entries/dualism/.

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Importantly, these sections introduce a new form of notation – entailing definition and use of the terms B_i, W_i, B_r and W_r – to provide well-defined expression of the distinction between the physical body (denoted B_r) as it *actually* acts within and on the physical world (denoted W_r) and the physical body as it *perceives itself* (denoted B_i) to be acting within and on its *perceived* physical world (denoted W_i).[10]

I believe that drawing an explicit distinction of this type, between a proposed single world that can be described as absolute reality, W_r – equivalent in the PPP to a realm of 'hidden states' that gives rise to the 'hidden causes' of sensory input[11] – and the 'realities' we each subjectively experience in the form of our internally generated phenomenal worlds – our individual W_is – will prove crucial to finding an efficient description of the higher-level concepts needed to explain 'consciousness'.

More specifically, I believe that without a notation to allow a well-defined expression of a distinction between W_r and W_i – which are key to the self-model approach described in the Essay – it will be far more difficult for investigators to describe how normal subjective experience of being a person operating as a physical self in a physical world can be generated.[12,13]

Readers who wish to move straight to new material and minimise review of ideas presented in the Essay should now – having first read the Introductory Summary[5] and *How is Free Will Possible?*[6] – go directly to Section 9 and leave until later, and as required, any review of the Essay or of Sections 3 to 8 below.

3. Section 6.1 of the Essay

The Notation for Dynamic Fields is a set of definitions for the notation and diagrams subsequently used in the body of the Essay. These have no substantial content in and of themselves but allowed a degree of precision and relative brevity that was needed for efficient and adequate description of the ideas presented in the main body of the Essay.[14] This material will, through development of the ideas presented in this note, be very largely superseded by drawing on ideas from the PPP.

4. Section 6.2 of the Essay

This section marries the notation defined in Section 6.1 to the ideas presented in earlier sections of the Essay to then describe with greater precision than could be achieved with prose the key information flows to be discussed in the Essay.

This is primarily a descriptive exercise to serve two purposes. First, it generates familiarity with the notation and diagram conventions that are used at key points in the later text of the Essay.

Secondly, more importantly, it uses the new notation to express the uncontroversial proposition that some of the information being fed into a person's external environment – the part of W_r which is not B_r – due to their motor output will lead not only to changes in the disposition of their body, B_r, but in that external environment as well, that will then be reflected in changes in information returned to the person through their senses. In other words, a person will receive sensory input containing information about the impact that their motor output is having on their body and on the environment in which their body is operating and interacting.

5. Section 7.1 to Section 7.8 of the Essay

If it is accepted that a self-model must lie at the heart of the information processing machinery that generates physical self-awareness, the crucial challenge becomes describing how such a self-model can be generated and maintained – including in real time – and how the processes that do that are able to deliver a moment-by-moment subjective sense of physical self-awareness. In my view such a moment-by-moment subjective sense of physical self-awareness will form the foundation for the totality of a person's conscious experience.[7](1)

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[10] The notation B_i, W_i, B_r, W_r etc. is fully equivalent to subsequently used notation B[i], W[i], B[r], W[r] etc. where the latter is used in almost all work subsequent to the Essay, including throughout this note. The change was originally made to allow ease of use in basic text editors (and see Appendix 1 for a list of further relevant definitions, at https://teleodyne.com/working_note_A_appendix_1.pdf).

[11] Relevant references to 'hidden states' and 'hidden causes' – sometimes referred to in PPP literature as being 'out there' (presumably in W_r) – are provided for example in Friston, K. J. (2010) The Free-Energy Principle: A Unified Brain Theory? *Nature Reviews Neuroscience 11* 127-138, Parr, T. & Friston, K. J. (2018) The Anatomy of Inference: Generative Models and Brain Structure *Front. Comput. Neurosci. 12* 90, Ramstead, M.J.D. et al. (2020) A Tale of Two Densities: Active Inference is Enactive Inference *Adaptive Behaviour 28* pp225-239 and Friston, K. J. et al. (2020) Sentience and the Origins of Consciousness: From Cartesian Duality to Markovian Monism. *Entropy 22* 516.

[12] The reasoning behind this assertion is provided under the entry for 24-Jan-1998 at https://teleodyne.com/Psyche_D.pdf.

[13] Appendix 1 lists key definitions, ideas and notational definitions used here and in the Essay: https://teleodyne.com/working_note_A_appendix_1.pdf.

[14] There are no doubt better notation conventions that could have been used, but this was the best I was able to develop under the time constraints and font availability with which I was working in the 1990s. Much of the notation is a rough loan from set theory.

Sections 7.1 to 7.8 begin with a crucial set of assertions. Namely, that in waking newborn infants (who will have very little sensory-motor coordination and are likely to have only rudimentary physical self-awareness, and quite broad, ill-defined subjective states):

(1) There will be a neurological system that 'records' over time all *sensory and proprioceptive input* – designated κ *input* – and as a logical consequence also records, as a subset of that, all input that arises as a result of the newborn's *motor output*. At this new-born stage the barely conscious child is likely to be almost completely unable *consciously* to recognise what part of the sensory input refers to its body and what parts refers to other aspects of its external environment.[15]

(2) There will also be a neurological system that generates motor output – designated ϕ *output* – where *most* of that motor output will, *in the infant*, be 'decoupled' from information that is being received through the newborn's senses.[16] This is just to say that little of the total motor output will be driven deterministically by sensory input.[17] In practical terms this means that in the newborn infant – as observed in reality – most motor output will be in the form of apparently non-purposive uncoordinated movements.[18]

(3) There will, at the same time, be a neurological system that measures the newborn's evolving internal physiological state and generates signals – based on that state – which can be called *visceral input*.[19] The magnitude and type of visceral input – designated ρ *input* – will depend on the extent to which the infant needs food, water, warmth and so forth.[20] The Essay proposes that these visceral input signals might be relatively simple. They will have a quality which derives from the component of the infant's physiological state to which they refer, and a magnitude which can be positive, negative or zero. For example, with quality on the left:

- Hunger: negative
- Thirst: negative
- Sweet taste: positive
- Warmth: positive
- Breathlessness: negative

6. Section 7.9 to Section 7.12 of the Essay

The Essay then postulates that in the newborn child there will be a neurological means by which the moment-by-moment sensory input, motor output and visceral input will all by some means be 'recorded' *together* to form what the Essay calls *association complexes*. This process of integrated recording will then proceed as the child grows, with massive accumulation of association complexes taking place as the months and early years go by.[21]

The Essay proposes that these recordings (i.e. association complexes) will have certain key properties, namely that:

(1) Association complexes will be recorded with varying degrees of *firmness*; where greater firmness means greater relative strength, definition and durability of the recording. In other words, experiences will not be recorded with equal intensity – and some will be recorded far more *firmly* than others.[22]

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[15] The facility for such 'recognition' will arise as physical self-awareness itself develops and is important to emergence of consciousness.

[16] A small subset of motor output will be highly coupled to sensory input. This takes the form of reflexes, which are dealt with in the Essay at Section 7.4. Conscious, voluntary, purposive human movement is not reflexive, and how it might arise is discussed at length in the Essay.

[17] The decoupling referred to here, which is to say that most of the motor output will in *not be determined* by the sensory input, has fundamental implications for the problem of free will. This issue is not tackled in the Essay, but for more on this see, *How is Free Will Possible?* at http://teledyne.com/free_will.pdf.

[18] This decoupled motor output is defined in the Essay as *transient non-reflexive motor output* at pp28-29 and would *not* constitute all motor output.

[19] The illustrative concept of visceral input can be considered broadly to relate to the actuality of interoceptive input.

[20] In the newborn child visceral input will be part of what drives transient non-reflexive motor output (pp32 Essay).

[21] As noted above, in 1997 the predictive processing paradigm (PPP) was undeveloped and key work of Karl Friston and others was not available: for example, Friston, K. (2003) Learning and Inference in the Brain *Neural Networks 16* 1325-1352. In terms of PPP, an association complex – which was intended in the Essay purely to be an illustrative concept – can now be seen as broadly illustrative of *recognition* and *generative models* built by estimating the *hidden causes* of κ and $\beta + \delta$ inputs. Note that in the Essay sensory, s, and proprioceptive, p, inputs are combined into κ input (see pp58 and footnote 41 Essay) while interoceptive inputs in the form of β and δ are derived from visceral input v (pp30-31 Essay).

[22] Within the PPP, a degree of *firmness* could be considered to correspond to the degree of weighting placed on the *priors* held in the association complex, with weighting zero equivalent to no recording. This weighting would matter from a PPP perspective when the complex is 'replayed' (see below).

(2) The degree of firmness with which an entire association complex is recorded will be proportional to the magnitude and the rate of change in the visceral input that takes place *at the end* of the recording period. In other words, if a series of sensory inputs and motor outputs leads to a situation where a major and rapid change in visceral input occurs – which the Essay defines as a ‘goal state’ or *g state*[23] – a correspondingly firm association complex will be recorded. This recorded complex will hold together – purely by means of association – all the sensory experiences and actions which led to this big change in visceral input. This simply means that a strong neurological impression will be left with the infant in terms of what it saw and what it did over some period of time leading into either a strong positive or negative change in its physiological state. The length of the recording – the *recording period* – will also be dependent on the magnitude of the change in visceral input, with a longer recording period accompanying a higher magnitude of change.

(3) Association complexes can be ‘replayed’. Thus, if a given association complex has been recorded due to a strong positive change in visceral input, then there will be a strong predisposition in the infant to replay – i.e. to re-enact – the motor output from that complex if a set of sensory and visceral inputs *sufficiently similar* to those that were received at the time of the original recording is again encountered.[24] In other words, if similar sensory and visceral input arises, then the association complex will be replayed. This will entail the generation and expression of the relevant recorded motor output. If the same positive change in visceral input is then attained, the firmness of the recording of the relevant association complex will be intensified (positive reinforcement). At the same time, replay of association complexes will be the primary process which, with development, will lead to increasing levels of sensory-motor coordination.[25]

(4) The sensory and proprioceptive input recorded as κ input in every association complex will be encoded as a time series of sets of values in an unchanging – neurologically pre-determined – array of *global variables* referred to in the Essay as *κ global variables*. These are called ‘global variables’ because they will be universal to the sensory and proprioceptive component of all association complexes held by a given infant.[26] In other words, it is envisaged that there is a large, but finite, number of global variables each of which can take on a range of values. Every record of every momentary sensory input on every association complex, will be encoded as a single set of values – defined in the Essay as a *κ tick*[27] – in these κ global variables.[28]

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[23] Such a major change in visceral input is referred to in the Essay as a *goal state*, or *g state*. Such states can be positive (some form and degree of pleasure is the correlated subjective experience) or negative (some form and degree of pain is the correlated subjective experience). To clarify: what is being proposed here is that a type of neurological input can be formed to reflect the physical needs and desires of the infant. For example, if the infant is becoming increasingly hungry then the magnitude of negative visceral input associated with low blood nutrients will begin to ramp up. This magnitude will continue to grow until nutrients are replenished. At that point – as food is ingested and digestion begins – there will be a sharp drop off in the magnitude of the negative visceral input, perhaps all the way to zero. There may also then be an inflection into a positive magnitude of visceral input associated with the pleasant taste of food and a feeling of fullness etc. Such a rapid change in visceral input is defined in the Essay as a *g state*. The example just described is a positive g state. A different example would be where the infant hurts itself. Then there will be a sudden increase in a negative visceral input corresponding subjectively to the type of pain that such a misadventure would cause. This would be a negative g state. Both g states are defined as occurring when there is a rapid, major and temporally sustained change in the magnitude of visceral input.

[24] If the association complex was recorded due to a strong negative change in visceral input then the opposite effect would occur, as with an aversion, and there would be strong avoidance of replaying the association complex. If avoidance was impossible the aversion would be deepened if the negative change in visceral input was again experienced (negative reinforcement).

[25] Under the PPP, this process of ‘replaying’ more-or-less corresponds to *active inference*, where the generative model (the association complex) is used to generate the motor output based on previous recordings, initiated at the time the complex was first recorded and reinforced and error-corrected in its subsequent uses. Refinement of sensory-motor coordination – through refinement of the generative model – will flow from operation of an ‘action cycle’ which is described later in the Essay (pp56-57) and see later in this note for description of a PPP-consistent parallel to the action cycle called the ‘recognition cycle’.

[26] *κ global variables* are the full set of variables in which κ input – which is defined in the Essay as sensory input, including proprioceptive input – is recorded. Conceptually, κ global variables can be likened to the general coordinates used in physics to define a configuration space.

[27] Similarly, as per footnote 26, a κ tick can be likened to a point in the configuration space that has κ global variables as its general coordinates.

[28] This idea is crucial because the recording of all sensory input in terms of one set of global variables/general coordinates eventually, through neurological development, can be translated directly into the human capacity subjectively to experience waking sensory input in the phenomenal form of being at the centre of a world made up of specific objects and events all arising within one single, unified space-time continuum (pp74-76 Essay). It is also an idea that can be translated into the PPP and its related neurology along lines proposed later in this note.

The development of the illustrative idea of association complexes is novel in its formulation but draws heavily on familiar work on conditioning, most notably that of Pavlov, Thorndike and Skinner (referenced at footnote 30). The idea is also broadly concordant with the concept of *recognition models* and *generative models* that have been developed in the context of the PPP.[21]

The operation of association complexes is illustrated in the Essay using the diagram shown in Figure 1:

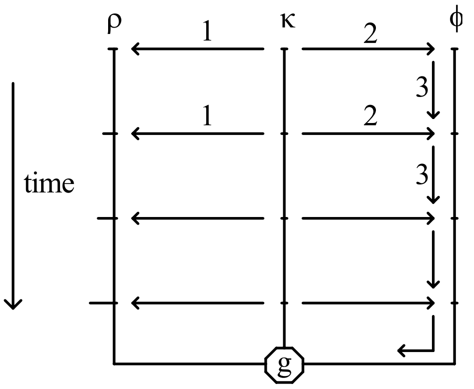

Figure 1

The g state (see above, and footnote 23) is at the bottom centre. The recordings of sensory and proprioceptive input, motor output and visceral input are represented as parallel time series – of κ ticks, *ϕ ticks* and *ρ ticks* – along the respective *κ, ϕ* and *ρ forks* of the complex.

The arrows in the diagram show the sequence in which the complex is 'replayed' as the infant, once again, seeks to attain a desired g state (Section 7.10 of the Essay).

- First, sensory (and visceral) input similar to that recorded at the earlier time the association complex was first made is once again encountered.
- This elicits a positive change in the visceral input (arrow 1).
- It also drives a replay of the recorded motor output (arrows 2 and 3).
- This then brings the infant to the next position in its environment, which ought to correspond to a next point – i.e. a next κ tick – of sensory input similar to that recorded earlier, at the time that the association complex was made. If this is achieved a further positive change in visceral input will occur, with increased magnitude represented by the wider line draw at the relevant ρ tick.
- This process then repeats itself, bringing the subject to home in on the positive g state shown at the bottom of the diagram by 'travelling down' the association complex.
- In the Essay this overall process – the operation of an association complex to take B_r to a goal state – is called *κϕρ coordination*.[29] Each cycle of 1, 2, 3 is called one κϕρ coordination *beat*. These beats would run end-on-end as shown in the diagram.

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[29] In PPP terms, κϕρ coordination operating though 'replaying the recording' encoded in an association complex can considered to correspond to *active inference* through application of the generative model embodied in the association complex. Movement towards a g state through progressive activation of ρ ticks along the ρ fork can also be seen – and more clearly later in the Essay, in the operation of association matrices – to correspond to a *value* maximisation process (see Section 9.4 and footnote 102 below), noting that visceral input essentially serves to deliver bodily, B[r], homeostasis. Although the Essay's account up to this point does not describe the error correction elements of active inference, this is just because of the order of introduction of concepts that was adopted. The error correction processes are described later, when κϕρ coordination is further described as entailing application of a process called the *action cycle* (pp56-59 Essay). One κϕρ coordination beat forms part of one beat of the action cycle, as per pp58 Essay.

7. Section 7.13 to Section 7.20

The ideas developed in the Sections 7.9 to 7.12 are a form of restatement of ideas about conditioning.[30] The subsequent sections of the Essay show how this process of learning might be extended in a special way. Indeed, it is proposed that this extension to a higher order of learning and information processing can – at least in humans[31] – be used to explain the emergence of consciousness at the primary level of having a moment-by-moment subjective experience of oneself as a physical being interacting with, acting on, and being at the centre of a physical world.

Section 7.13 describes the hypothetical limits that would exist in simple animals in relation to the recording and replay of association complexes. These limits would hinge on the quality and quantity of neurological resources available to the animal. Paraphrasing Section 7.13, these limits will include those which are:

(1) **Scope-**related: The idea of *scope* was developed in the Essay because, in normal life, no one set of sensory inputs will ever be *exactly* the same as a previously experienced set. This means that for the neurology to 'recognise' sensory input as coming from an environment similar to that which led to the earlier recording of an association complex there would need to be some degree of 'breadth' – defined in the Essay as *scope* – in the recording of sensory input. The scope-related limit on an association complex will largely be defined by how much breadth exists in the κ fork of the complex, which essentially is the fork along which the sensory recording lies. Generally, the broader the scope, the more adaptive and generally useful an association complex would be.[32]

(2) **Proximity**-related: This is a limit to the 'length' of the κ, ϕ and ρ 'forks' of the complex. That is, the retrospective temporal length of the sensory inputs, motor outputs and visceral input changes that occurred and were able to be recorded before the moment at which there was a rapid major change in visceral input.

(3) **Volume**-related: This is a limit on raw brain[r] capacity to store association complexes.

(4) **Susceptibility**-related: This is the threshold degree of change in visceral input needed before significant firmness of recording is achieved for the association complex to significantly affect future behaviour.

Section 7.14 then describes what may be possible if these limits were to be progressively extended. The essential idea is expressed in Section 7.14, and its immediate consequences and implications are then elaborated through to Section 7.20. The key concept here may be best understood in visual terms. It has two parts. These are that:

(1) The range of sensory inputs which a person can ever expect to experience is bounded in its variability. It may vary infinitely within such bounds, but such variation will only ever take place within those bounds. This is a property of the physical world we inhabit. This world is complex only up to a certain point, and only in certain ways. This is reflected in limits to the range and type of sensory inputs a person can ever expect reasonably to encounter.[33]

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[30] In the sense of conditioning as researched by Pavlov, Thorndike and Skinner. (For example: Pavlov, I. P. *Conditioned Reflexes* Oxford University Press, 1927; Thorndike, E. L. *The Fundamentals of Learning* Teachers College Press, New York, 1932; Catanin, C. A. and Harnad, S. (Eds) *The Selection of Behavior: The Operant Behaviorism of B. F. Skinner* Appleton Century Crofts, New York, 1988.) And see: Shettleworth, S.J. *Cognition, Evolution and Behaviour* Oxford University Press, 2010.

[31] And probably in many animals.

[32] Recalling that the Essay intended these only as illustrative concepts, it is important to view the ideas of scope, proximity, volume and susceptibility essentially as a device – informed by general intuitions about reality – to allow the subsequent, more important idea of a single unified association matrix (corresponding in the PPP to single, unified and overarching generative and recognition models) to be built. The most abstract of these illustrative concepts is scope. Although a device, scope can conceptually be fairly well correlated – in PPP terms – to the breadth of probability distributions that would be covered by an association complex over possible causes of inputs – as κ and ρ – and outputs – as ϕ – able to be 'recognised' and processed into $\kappa\phi\rho$ coordination by that given complex. Once an association matrix is formed – by whatever means – these probability distributions would have become sufficiently encompassing to allow $\kappa\phi\rho$ coordination (corresponding to active inference in the PPP correlate) to operate in relation to practically *any* potential momentary instance of κ and ρ inputs and ϕ output.

[33] For example, some things, such as an apple falling upwards, simply never happen. Here the boundedness being considered is due to the operation of physical laws, which point to a set of relatively simple underlying rules that nature seems never to break and that provide for predictability in the natural world. Another less absolute form of boundedness would arise where high and increasingly negative ρ input is encountered driving $\kappa\phi\rho$ coordination away and 'inward' from such a 'boundary'. This translates into animals remaining within 'comfortable' environments.

(2) Once the capacity of the neurology used to record association complexes is developed past a certain stage – enabling higher and higher capacity in relation to scope, proximity, volume and susceptibility – and given that sensory input will always be recorded as sets of values in κ global variables – it is then proposed that the association complexes that are accumulated as the infant gains experience can *merge* with each other to form a single *association matrix*. This process of merging would be made possible once the neurological capacity referred to above has passed a certain threshold relative to the extent to which variability in sensory input is bounded.[34,35]

The diagrams used in the Essay to illustrate *coalescence* of association complexes to form a single association matrix are reproduced from **a**, **b**, **c** through to **d** in Figure 2. It is proposed that an association matrix is made up of a κ submatrix, a ϕ submatrix and a ρ submatrix, each being the coalescence product of respective forks of the underlying association complexes.

These visual representations are intended to aid understanding. They are intended to be illustrative only. To keep the diagrams simple, ρ forks are not shown, but these would be present. Similarly, the parallel κ and ϕ submatrices shown as two-dimensional at **d** would be massively high-dimensional.

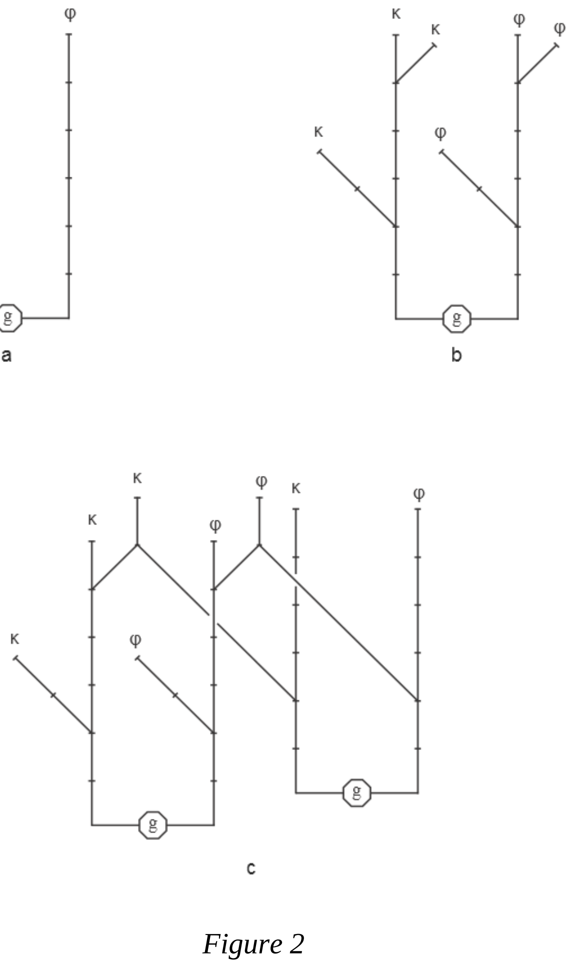

Figure 2

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[34] It may be useful to consider the formation of an association matrix as akin to a massive formation of associative arrangements between points – κ ticks, ϕ ticks and ρ ticks – with each of these a point within its own, discrete configuration space – one in κ generalised coordinates (i.e. in κ global variables), one in ϕ generalised coordinates and one in ρ generalised coordinates. In the same vein, the bounded variability in sensory inputs described at (1) would define something akin to a manifold in the configuration space of κ generalised coordinates.

[35] Consistent with the points made in footnote 32, the idea of merger of association complexes to form an association matrix could be couched in terms of a broadening out into increasingly significant overlap of the probability distributions for all recorded κ ticks, ϕ ticks and ρ ticks respectively. Thus the formation of the κ submatrix could be seen as formation of a continuum across all possible κ ticks corresponding to the capability of that submatrix to be able to provide a most likely κ locus as derived from processing the momentary set of values of κ input. Likewise for the ϕ submatrix based on κ input – particularly its proprioceptive component, p – as well the subset of s corresponding to the person's visual, tactile and other senses of their own body disposition.

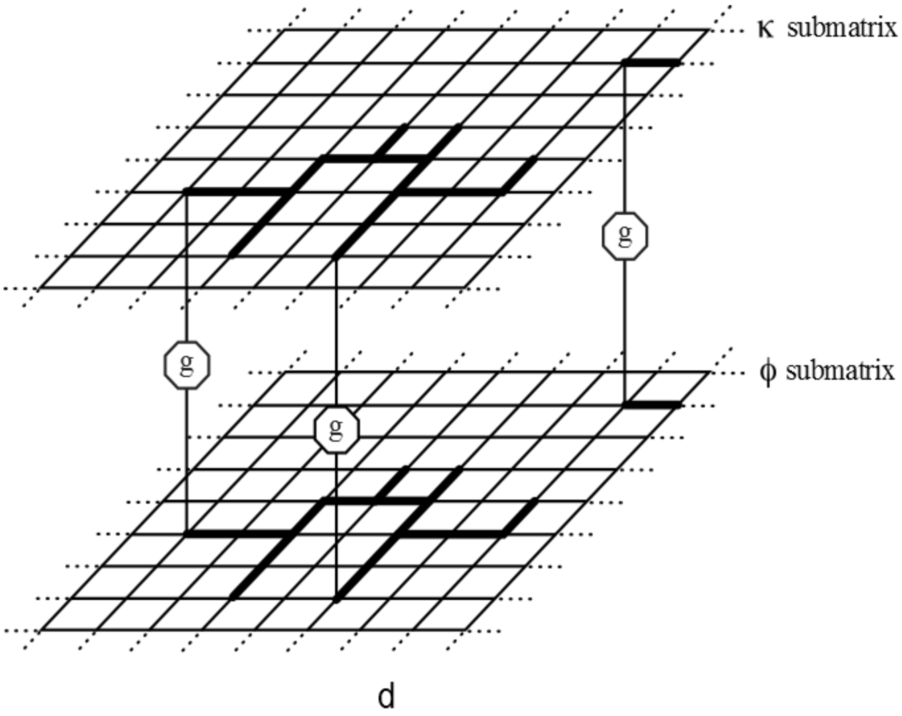

Figure 2 (cont.)

Sections 7.15 to 7.20 describe how an association matrix could operate to allow κϕρ coordination. Essentially, they describe how an emergent association matrix should be able to process virtually *any* future sensory input for the purposes of formulating motor output sequences designed to achieve as positive a visceral input as possible. This process, as described, is a relatively straight forward extension of the way association complexes have already been proposed to operate (page 5 above), but with introduction of a new idea.

This new idea is described in relatively technical terms in the Essay, but derives from the fact that κ submatrix, in order to be global – that is, in order now to be able to 'recognise' *all* of the potential forms of sensory input the person might be confronted with – would have potentially to contain 'synthetic' regions containing *synthetic κ ticks*. These regions would correspond to places and physical situations that a person has never been in before and which would therefore not be present in the form of any previously recorded association complex. Thus, they would be regions interpolated or extrapolated from previous experience, as encoded in the association complexes made previously to their coalescence into an association matrix.[36]

8. Sections 7.21

The essential assertion in these sections is that there must be ongoing error correction and learning processes that keep updating the association matrix so that it continues to reflect the history of actual sensory and proprioceptive input – κ input – being encountered, including in terms of the impacts on κ input of associated motor output, ϕ. This process of correction and learning will be inherent in the process of κϕρ coordination, which is described in Section 7.21 of the Essay, and which – with respect to operation of the association matrix – is called *the action cycle*.[37] Section 7.21 provides detail on the proposed workings of an action cycle.[38]

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[36] Such *synthetic κ ticks* would correspond to all the potential points in the 'configuration space' of κ global variables that are not close to those already experienced by the infant. In the Essay those κ ticks already experienced are called *real κ ticks* (Section 7.15). From a PPP perspective the reliability (probable accuracy) of – and therefore the weighting placed upon – the 'synthetic' priors available for a synthetic κ tick will be relatively low the further the synthetic tick is from anything already more closely experienced by the infant.

[37] An action cycle-like process could also be applied as an augmented version of the operation of association complexes which is described as *κρϕ coordination* in Section 6 above.

[38] The recommended pre-reading note *How is Free Will Possible?* – at http://teledyne.com/free_will.pdf – also provides a detailed account of operation of the proposed action cycle. That note does not, however, focus on the specifics of the association matrix, and refers – for the sake of its own stand-alone clarity – only to sensory input and motor output, ***s*** and ***m***, without the refinement of defining and using κ and ϕ – which derive from both exteroceptive, s, and proprioceptive, p, inputs – and it does not refer at all to v and its derivative ρ and β inputs to the association matrix. As such that note's description of the action cycle omits a depth of description relevant here, and which is provided in Section 7.21 - particularly at pp58 – of the Essay.

9. Relationship to the Predictive Processing Paradigm

The illustrative conceptual framework of an association matrix and its interaction with an action cycle can largely be superseded and improved by drawing on a ground up description of neurological architecture and information processing situated within the predictive processing paradigm (PPP).

9.1 Information processing in the brain

First consider the neuronal information processing architecture described by Marsel Mesulam,[39] who identifies a series of more or less concentric neurological layers each hosting an increasing level of associative sophistication as information is passed inward and upward in an information processing hierarchy in the brain. In humans the processing of incoming sensory information involves a hierarchy of several – sometimes six – layers. Figure 3 depicts this hierarchical information processing architecture and extends it to illustrate architecture for proprioceptive, interoceptive and motor processing.

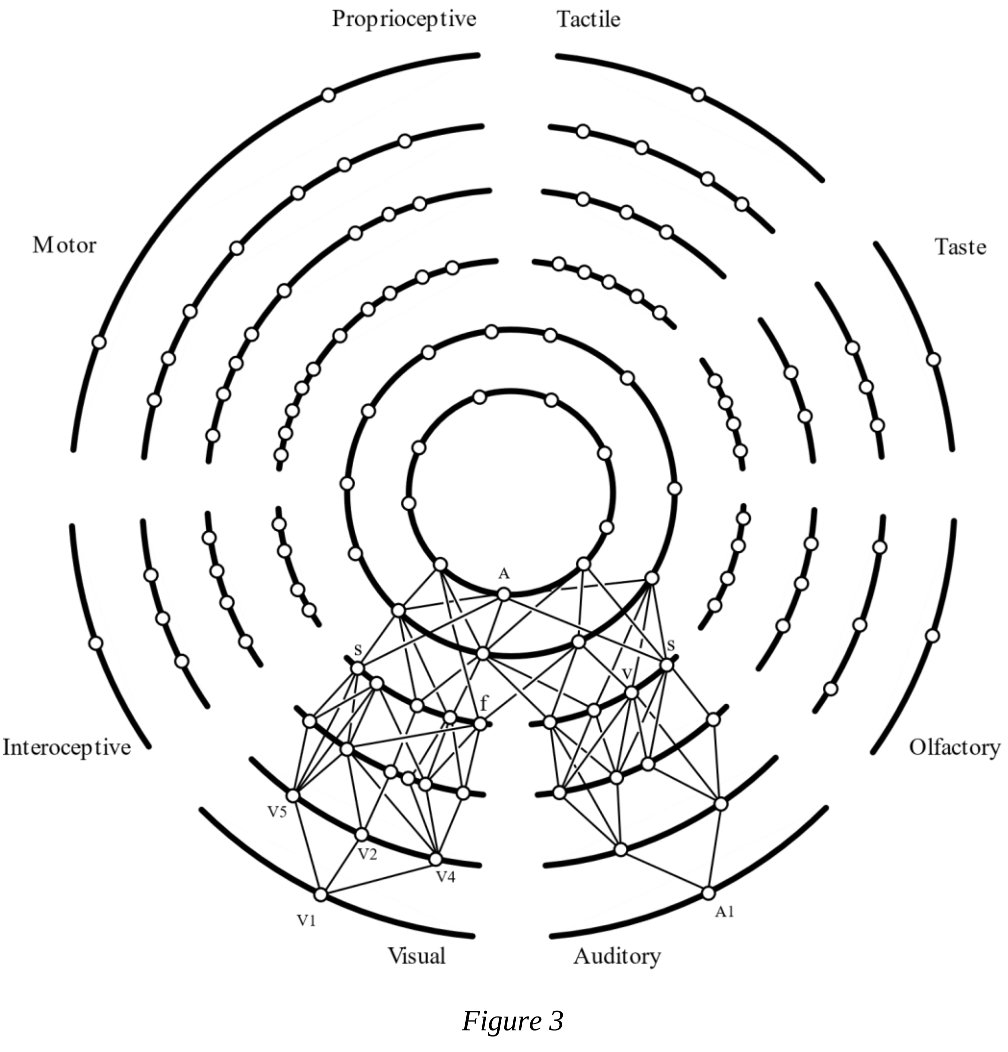

Figure 3

Figure 3 illustrates the hierarchical neurological structure found in primate brains.[40] Its key features are: (1) onion-like layers (shown as dark arcs) containing a high density of internodal synaptic connections; (2) small circles which represent 'nodes' associated with each layer, corresponding to cortical areas one to several centimeters in diameter; and (3) internodal connections that run relatively sparsely back and forth between layers, with more numerous and divergent connections running from inner to outer layers. The outermost layer represents the lowest, most *upstream* synaptic level in a neural processing hierarchy. Thus, V1 represents the primary visual cortex and A1 the primary auditory cortex. V1 is essentially retinotopic and provides all the raw data needed for higher order visual processing such as extraction, differentiation, location and 'recognition' of features in the environment – for example, objects, faces and their patterns of relative motion – that takes place as information travels inward and is re-encoded at nodes in deeper layers. This hierarchical process of feature extraction, synthesis and 'recognition' is enhanced through feedforward and feedback error minimization as described in the PPP. This layered hierarchical processing arrangement is likely to be replicated for the other exteroceptive modalities, such as tactile and auditory, as well as for proprioceptive, interoceptive and motor modalities. [40(2), 41, 42]

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[39] Mesulam, M. M. (1998) From Sensation to Cognition. *Brain 121* 1013-1052.

[40] This figure is adapted from those at (1) ibid. pp1019 and (2) Friston, K. (2003) Learning and Inference in the Brain *Neural Networks 16* pp1329.

[41] Quadt L., Critchley H.D., Garfinkel S.N. (2018) The neurobiology of interoception in health and disease. *Ann N Y Acad Sci. 1428(1)* 112-128.

[42] Motor and proprioceptive hierarchies are shown as a single modality consistent with active inference as a mechanism for motor output as proposed within the predictive processing paradigm (PPP) (see below).

The visual system can be used to elaborate the ideas illustrated in Figure 3.

Mesulam identifies six layers through which the modality of vision is processed to the point of full assimilation in the conscious brain. Nodes in the outer four layers – i.e. in the lower four levels of the processing hierarchy – including those labelled V1, V4, V5, f and s in Fig. 3 – have no direct synaptic paths to nodes in the first four layers for other modalities such as auditory. This seems designed to protect information being processed inwards for one modality until it can be sufficiently re-encoded into data structures specifically configured to enable higher-level integration with data structures being generated in parallel through other modalities.

Such higher-level integration then takes place in the inner two layers, which Mesulam describes as 'transmodal' layers. Thus nodes sitting within the outer four layers can be described as 'unimodal', while nodes sitting within in the inner two layers can be identified as 'heteromodal' or 'multimodal'.

More specifically, for the first four layers in the visual modality Mesulam states[39] [with my additions in square brackets]:

> "The primary dimension of visual mapping is retinotopic and is achieved by finely tuned neurons which provide an exquisitely ordered spatial representation of the visual fields in V1. Other dimensions of visual experience, such as color and motion are mapped in V1 and V2 by coarsely tuned neurons and become more fully encoded at further synaptic stages such as V4 [for colour] and V5 [for motion].[43] Nodes at upstream levels tend to contain neuronal groups specialized for encoding relatively elementary attributes of visual experience whereas nodes at more downstream levels are organized into neuronal groups specialized for encoding more composite features."
>
> "The elementary sensory features encoded at the first two synaptic levels are used by more downstream areas…for the discrimination of form and more complex patterns… [for example] the 'face' area in the human brain [f in Fig. 3] is more strongly activated by faces than by other objects. It is also more strongly activated by upright and intact faces than by inverted or scrambled ones, but does not show a differential response to familiar versus novel faces. This area therefore appears to encode faces at a categorical or generic level, prior to the stage of individual recognition. The fourth synaptic level of the human brain contains additional regions specialized for the [generic but not individual] identification of other common objects such as chairs and houses."
>
> "The fourth synaptic level also contains components [s in Fig. 3] where relatively more elementary retinotopic and visuomotor information [such as eye position information] leads to the selective identification of extra personal targets…Some of the [relevant] neurons display tuning for locations in head-centered coordinate space."

Mesulam describes a similar hierarchy for auditory processing, where:

> "…it appears that upstream auditory areas tend to encode more elementary features such as frequency and pitch, whereas downstream areas may contain neuronal groups [nodes] that encode more composite features such as [spatial] localization of sound sources [s in Fig. 3] the characterization of object-specific sounds, and perhaps also the characterization of individual voice patterns [v in Fig. 3]."

Mesulam observes that synaptic plasticity in the unimodal areas of the four lowest layers of the hierarchical information processing system described – i.e. the four outermost, upstream layers – is low, probably in order to preserve high consistency over time in the data structure of the input these areas make to transmodal areas in the inner two layers. The inner transmodal areas of the system do, however, exhibit high plasticity which Mesulam attributes to a higher capability for associative learning.

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[43] The designations of V4 in relation to colour and V5 in relation to motion are Mesulam's (ref. footnote 39).

Mesulam goes on to observe (my italics) [and my additions in square brackets] that:

> "…the [unimodal] neural nodes in [the first four visual and auditory layers] can [separately to each other] identify *and record* visual and auditory events. Furthermore, evanescent cross-modal coherence of the visual and auditory features encoded by these nodes could arise through temporal synchrony of the two [separate] sensory channels during the actual unfolding of an event. [But] a brain that contained only those components…would face serious challenges if an associative synthesis or retrospective reconstruction of the relevant experience became necessary. It would be impossible, for example, to encode the relationships between the visual and auditory components of the experience, since the two sets of unimodal cortices [layers] have no interconnections. Experience for such a brain would therefore tend to be incoherent across multiple channels of sensory processing [since it would be unable to transform] sensory events into coherent experiences. Such transformations of sensation into cognition necessitate the participation of a different class of cortical areas that can be classified as transmodal".
>
> "Everyday experiences unfold in multiple modalities. *The establishment of a durable record of experience and its associative incorporation into the existing base of knowledge necessitate multimodal integration*."

The transmodal areas encompass the two inner layers of the system shown in Fig. 3. Their common feature is an *absence* of specificity for any single modality of input. They receive inputs from inner layer unimodal areas and from other transmodal areas. The synaptic connections to transmodal areas are reciprocal enabling them to provide a site for multimodal convergence and also to exert top-down feedback into lower level transmodal and unimodal areas.

Rounding the picture out, Mesulam says (my italics) [and my additions in square brackets]:

> "…the role of transmodal nodes [such as A in Fig. 3] is not only to support convergent multimodal synthesis but also, predominantly, to create *directories* (or address codes, maps, look-up tables) for *binding* distributed modality-specific fragments into coherent experiences, memories and thoughts. This…process can be likened to obtaining green by superimposing a blue and a yellow lens, which can then be separated from each other to yield back the original uncontaminated colours. Transmodal areas [thereby] allow multidimensional integration through two interactive processes: (i) the establishment, by local neuronal groups, of convergent cross-modal associations related to a target event; and (2) the formation of a directory pointing to the distributed sources of the related information. Transmodal areas can thus enable the binding of modality-specific information into *multimodal representations* that have distributed as well as convergent components."

And:

> "Transmodal areas in different parts of the brain share similar principles of organization, each in relation to a specific cognitive domain."

Taking this approach to its limit, it is possible to envisage an evolving 'activation' of networks of transmodal nodes carrying momentary states that correspond to an ongoing, *fully integrated* 'representation'[44] evolving in time through integrated processing of all of the inputs being received by the waking brain and taking account of all of its motor and other outputs. The components of this moment-by-moment, fully integrated representation will be maintained/updated through use of the cues provided in the information travelling inward to multimodal areas from beyond the brain via unimodal areas, through best-fit activation of the appropriate directory addresses for records of the best-fit components from previously experienced input.

In the PPP consistent account provided below a crucial feature of this arrangement will be that in normal circumstances, at any given moment the cues provided in the form of information travelling inward will not be used to 'build' the representation described from scratch, but will be used to adjust/correct an already largely complete, *predictively* generated, representation that has been established and is evolving in the activation of networks of transmodal nodes described above, and where evolution of this predictive representation will entail the generation of outward travelling *predictions* of what those incoming cues are expected to be.

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[44] Where this will be a representation of the evolving environment within which the system described by Mesulam is immersed. In terms of this note, this will be the world, W[r], within which the brain[r] is immersed (as illustrated below in Figure 8).

9.2 Hierarchical processing, predictive processing, generative models, recognition models

The neurologically-based information processing arrangements described above can be re-expressed in terms of the PPP in the form of a hierarchical information processing system as follows.[45]

To aid in describing how such a system is likely to work it is helpful to begin by considering a slightly abnormal circumstance where a person has been taken from one location to a different location while they are unconscious and without prior advice as to where that new location is.[46] It is useful to consider a circumstance of this type because it allows for a description of what will happen in the system just after the person regains consciousness – unclear as to where they are – and attends to their senses.

As they awaken, raw input will travel inwards via the system's outermost unimodal layers to be progressively parsed and formed into higher-level data structures in its inner unimodal layers. For example, in the visual modality, patterns of surfaces, edges, colours, spatial positions and how these are changing will be assembled in the inner unimodal layers into patterns then 'recognized' as similar to one or another earlier encountered generic patterns for objects and their potential movements, such as for say an 'every-bird', 'every-face', 'every-chair' or 'every-walking-human'.

In the heteromodal areas, signals then travelling inwards from those inner unimodal layers that encode such generic patterns, will then evoke in directories – and be integrated with – all available potentially relevant records of past experienced *specific* sounds, landscapes, faces, personal gaits, and other things – such as ducks and the face and gait of Uncle Bill – to then give an overall pattern that places a specific bird or face or chair at a specific static or moving location in a unified, head-centred, eye-and-head-movement independent, spatial field.

Generalized across all modalities feeding inwards, moment-by-moment, to the top of the hierarchy – to there stimulate a momentary state of activation across its innermost multimodal areas – a whole-of-world synthesis or model will thereby be built in the person's brain informed by of all of the records momentarily activated by the totality of signals travelling inward and upward through the hierarchical processor.

For example, a child awakens after having been moved between houses while asleep, to hear the voices of Mum and Dad, and to look around and suddenly realise – with a rush of reorientation – that she is now lying on one of those faded canvas chairs under the old green umbrella in Uncle Bill's garden, with its ducks and Uncle Bill himself walking along just over by the pond.

The utility of using an example of such an awakening is that it allows a straightforward description – consistent with the ideas provided in the previous section – of how first the outer unimodal areas, and then the inner multimodal areas, of the hierarchical processing system under consideration can become 'loaded' with a state of 'record activation' that constitutes a whole-of-world estimate – a form of prediction – of where it currently sits within its environment.

Once loading of this type has reached a point where such a whole-of-world estimate has been achieved – corresponding in the above example to the child's recognition of where she is[47] – the hierarchical processing system will then operate to *sustain* that whole-of-world estimate in the form of an ongoing, evolving state of record activation that is *predictive* but whose accuracy is maintained through adjustments/corrections made a posteriori through use of the incoming signals, from all sensory sources, that continue to enter the system and propagate inwards. This type of information processing is an example of *predictive processing*.

Overwhelming evidence now exists to show that some form of predictive processing is being implemented in the conscious human brain by data handling systems like that described above, to allow people to maintain and update an evolving predictive model of how they are situated in the world.[48, 49]

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[45] Consistent with the approach applied in Friston, K. (2003) Learning and Inference in the Brain. *Neural Networks 16* 1325-1352.

[46] Simple examples of this would be where a sleeping child is carried from one place to another, or where a person has had surgery under a general anaesthetic and has been moved to a recovery area.

[47] Which essentially is her *brain* recognising where *it* is.

[48] For example see Clark, A. *Surfing Uncertainty: Prediction, Action and the Embodied Mind* Oxford University Press, New York, USA 2016.

[49] In terms used in this note this will be a predictive model of B[r] in W[r], subjectively experienced in the form of B[i] in W[i] (see Appendix 1 for definition of these terms: https://teledodyne.com/working_note_A_appendix_1.pdf).

Consistent with this, but in more detail, the optimum way for the system described above to sustain an ongoing *predictive best estimate* of how it 'believes' itself to be situated and to be moving forward with and within its overall environment will be for any given node at any given level in its hierarchical processor to:

A. progressively measure any *difference* between:

   (1) the cueing signal it is receiving from nodes in layers upstream to it

   (2) together with signals it is receiving laterally from nodes within its own layer

   (3) and those cueing and lateral signals that it *expects* to be receiving based on the *predictive* state of record activation that it is already carrying

B. and to then:

   (1) refine-modify that state of record activation in response to the difference measured at A, and in that process

   (2) send as feedback, modified intra-layer signals that will contribute to a modulation of the incoming intra-layer signals it is receiving, and

   (3) send as feedback to those upstream nodes that it is receiving cueing signals from, a modified signal derived from the newly refined-modified state of record activation it has formed at B(1):

      a. that is an estimate of what those cueing signals should become if that refined-modified record is correct, and

      b. that is then subtracted by those respective upstream nodes from the cueing signals they are sending downstream

C. until the *difference* referred to at A above approaches zero and, through step B(3), the momentary queuing signals the node is receiving are *offset* – i.e. *'balanced'* – to zero.

Unless it is in the innermost multimodal layer of the hierarchical processor, the node referred to above will also be generating and sending its own cueing signals inwards to nodes in layers downstream to it,[50] and receiving feedback from such nodes, where the cueing signals it is generating will progressively be offset to zero as those downstream nodes make refinements-modifications to their own states of record activation according to the process described from A to C above. Lateral, intra-layer signals will provide for a similar – but in their case 'contextualizing' – modulation process (as per Section 4.2 of ref. cited at footnote 45).

Ultimately, at a moment when all of the cueing signals across the full ensemble of nodes in the hierarchical processor reach offset to a minimum – ideally zero – through such feedback modulation, the *whole network* of momentarily activated nodes in the system – call these *Ξ nodes* – will carry a permutation of activation – an overall activation state – comprised of all of those refined-modified records that form a best fit estimate of the momentary state and *state trajectory* (motion) of the system-in-its-environment – as it operates within and on that environment – based on all of the inputs available to it and all of the records those inputs have activated based on their expected relevance.[51]

This momentary state of activation will not however be a moment of stasis but will be a moment through which the system passes as its estimate of its own trajectory leads it into a further *predictive* state of record activation, and where these record activations will themselves – in encoding not just expected (familiar) things like objects but also expected (familiar) *trajectories* for such things – contain the information required to generate ever further forward estimates of the situation in which the system *expects* it will find itself within its overall environment.

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[50] If it is situated in the innermost multimodal layer there can nodes lateral to it but no nodes further downstream to it.

[51] Accordingly, *Ξ nodes* – pronounce these 'Xi nodes' – are defined here as that set of nodes in the processing hierarchy that each carry a residual, optimised activation state in just that moment where the cueing signals (inward travelling prediction errors) have been modulated to zero. (This definition is taken further at footnote 58 and in Section 9.3 below.)

For later reference call the full set of nodes in the hierarchical processing system that can carry activation as described above, the *node set*, Σ. Also, call the momentarily activated network of Ξ nodes a *Ξ network*, and call the momentary state of activation across all of that network a *Ξ state*, which can also simply be denoted, Ξ.[52]

In the PPP, the overall set of records held in a more-or-less enduring form and available for activation within the hierarchical processing system are viewed in terms of the architecture and operation of a *recognition model* entailing a *generative model*. Together these encode the 'learned' ensemble of records and connections available for activation and expression in the hierarchical processor as it works to maintain its integrated prediction of the state and state trajectory of the system-in-its-environment[53] including through working to 'make sense' of new, incoming, inward flowing cueing signals.

If such activated records do not, at some given moment, provide a predictive match to the incoming cueing signals of that moment, those incoming signals can be considered to carry information encoding the momentary *error* in 'the picture' being reflected in the records that the system has under activation.[54] This error will be encoded in the difference referred to at A above.

Viewing cueing signals as *error signals* is meaningful insofar as once these error signals are balanced to zero through the processes described at A to C above the modulation being momentarily achieved across all of the activated records in the processor will have led to a best-fit, or 'lowest error', estimate – in the form of a state estimate encoded as Ξ – of what the momentary situation and trajectory of the system is as it operates within and on its environment, based on all of the inputs and records available to it.

To play their role in this, the feedback signals identified at B(3) will have undergone progressive modification until all incoming cueing (error) signals and incoming lateral signals have been balanced to zero. These outward propagating, progressively modified feedback signals will be generated as an integral part of the process by which the system operates to evolve and adjust the predictive state of record activation that it is carrying. Because these signals essentially will be expressions of dynamic *adjustments* the system is making to what it is carrying as a best-fit *prediction* of its momentary situation and trajectory in its environment, they are known in the PPP as *predictive* signals – or simply as *predictions*.

More specifically, at the functional level, these signals will reflect what the system predicts will, in that moment, best balance all error signals to a minimum and with this deliver the best-fit activation state permutation – in the form of the state estimate encoded as Ξ – across all of the system's Ξ nodes.

As flagged above, in the PPP the dynamic adjustments made by the system to its prediction of its own state-in-the-world require that it 'learns' and applies both a recognition model and a generative model.[55] Broadly put, the role of the recognition model is to augment implementation of the generative model such that the evolution and dynamic adjustment of the predictive record activation that the system is carrying will always be convergent onto unified, highest probability state estimates – in the form labelled above as Ξ states – in conjunction with delivering outward propagating predictions that converge down into signals that can maximally balance/offset inward propagating, error signals. Because the resultant highest probability state estimates will, through application of the recognition model, constitute best fit Ξ states, these will be called *recognition states*, where Ξ can be used to denote any given *recognition state*.[56]

Over time, as the system encounters and navigates its way through situations of varying degrees of novelty both the recognition model and the generative model will undergo a continuous and interlinked adjustment and refinement so that into the future the system, by engaging both models, can optimize – based on its past experience of inputs – its generation of moment-by-moment best-fit predictions of its situation within its environment.

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[52] N.B: The concept of a momentary Ξ state, Ξ – designated below as a *recognition state* – is foundational for most of the ideas to be developed later in this note where, as stated above, the permutation of activation of Ξ nodes – i.e. the Ξ state – will be an activation state composed of all of the refined-modified records that form a best fit estimate of the momentary state and state trajectory (motion) of the system-in-its-environment. Note also that the Ξ nodes and Ξ network carrying Ξ will not be fixed but will vary from one moment to the next as Ξ evolves along its predictive trajectory with adjustment in response to new input into the hierarchical processor. So here, at any given moment, Ξ nodes can be seen as elements in that subset of the node set Σ – where Σ is the set of all *potentially* activatable nodes in the hierarchical processor – whose members are *only* those nodes that are activated at that given moment.

[53] Where, notably, this system will include the hierarchical processor itself.

[54] Where to be clear, this will be a dynamic, predictive 'picture' that the system will be carrying of its own situation within its environment.

[55] The need for a recognition model and its proposed co-development and interaction with a generative model to provide the system with an effective estimate of the causes of sensory and other inputs is described in detail in the ref. at footnote 45, and see also Ramstead, M.J.D. et al. (2020) A Tale of Two Densities: Active Inference is Enactive Inference *Adaptive Behaviour 28* pp225-239. See also Appendix 1. The relationship between generative models and recognition models is given further definition in Section 9.3 below.

[56] Underpinnings for describing Ξ as a recognition state, and for the idea that such momentary state estimates may manifest serially in the course of ongoing active inference, are provided in Ramstead, M.J.D et al. at ibid.

Figure 4 provides an illustration of the type of hierarchical processing envisaged.[57]

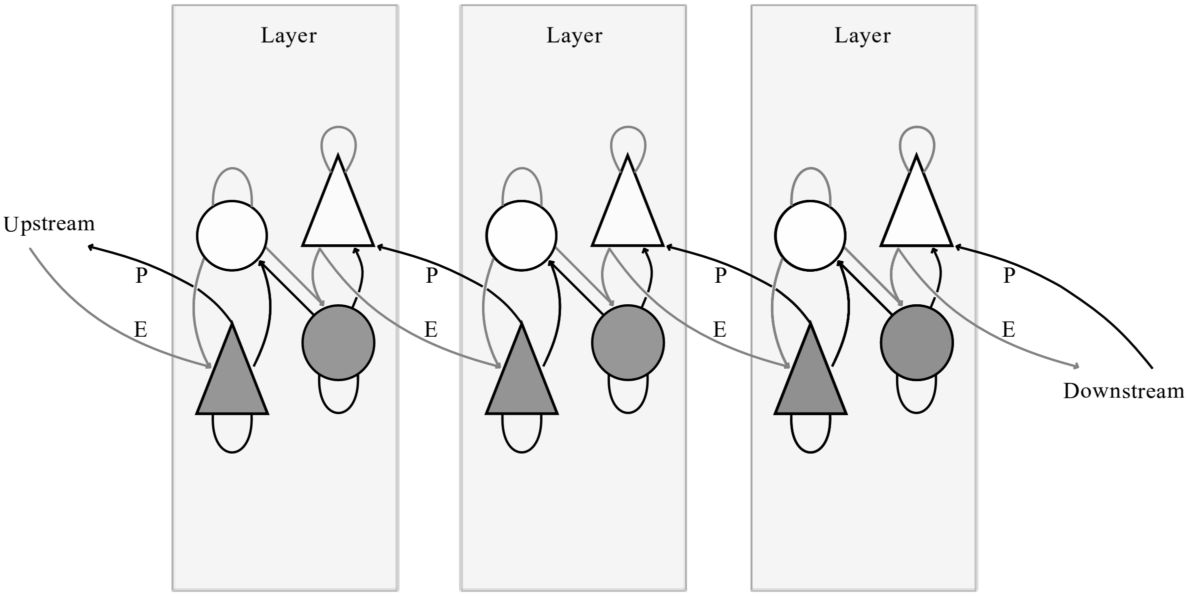

Figure 4

Figure 4 shows an inter- and intra-layer information processing hierarchy as generally envisaged within the predictive processing paradigm.[57] The greyed rectangles represent the cortical layers that are shown as concentric rings in Fig. 3. The ultimate sources of upstream inputs are the exteroceptive, proprioceptive and interoceptive signals entering the brain. Inter-layer cueing signals – described at A(1) in the text and known in the PPP as *error signals* or simply as 'errors' – are shown as long grey arrows (E). The long black arrows (P) show inter-layer feedback signals running from downstream to upstream. These are described at B(3) in the text and are known in the PPP as *predictive signals* or simply as 'predictions'. Intra-layer error signals – described at A(2) in the text – are shown as shorter grey arrows and intra-layer predictive signals – described at B(2) in the text – are shown as shorter black arrows. Two kinds of neuronal populations are envisaged for each layer; state units (dark) and error units (light). Inter-layer cueing (error) signals only travel downstream or intra-layer and only travel from error units to state units. Inter-layer feedback (predictive) signals only travel upstream or intra-layer and only travel from state units to error units. Further detail on what the illustration shows at a neurological and computational level is provided in the references at footnote 57. In the broad, this proposed architecture is considered within the PPP to be sufficient both to (1) encode and implement the hierarchical processing steps, and the recognition and generative models inherent to these, as have been described so far in this note, and (2) broadly relate this implementation to neurological systems observed in the brain.[58]

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[57] This diagram is adapted from Friston, K. (2008) Hierarchical Models in the Brain *PLoS Computational Biology 4 Issue 11* e1000211 with reference to Box 2, Friston, K. (2010) The Free Energy Principle: A Unified Brain Theory? *Nature Reviews, Neuroscience 11* pp127-138 and Box 3, Friston, K. (2009) The Free Energy Principle: A Rough Guide to the Brain? *Trends in Cognitive Sciences 13* pp293-301.

[58] In connection with this architecture it is envisaged, for the purposes of this note, that a Ξ state – as described in the text – will at some given moment, reflect the pattern of activation across *all* brain[r] hierarchical processor state units in that given moment, where all such given moments will be those moments at which all error signals within relevant brain[r] hierarchical processors in are maximally balanced (i.e. balanced out to as close to zero as possible). Hence, for the purposes of this note, it is envisaged that the network of Ξ nodes described in the text will carry an overall activation state, where the state units of the hierarchical processors involved will serve as the networked *material substrate* that constitutes the nodes carrying those states. However, to backstop this, an encompassing assumption will be made that at least some form of networked material substrate[r] affiliated with and linked across all relevant brain[r] hierarchical processors – whether or not it is made up of, or involves, state units – will carry an activation state across its network such that this activation state will be achieved at those moments when all bottom up errors and top down predictions are balanced to zero across all of those hierarchical processors and that this state is equivalent to a Ξ state, as defined. A simplifying assumption clearly is also being made that this balancing will happen synchronously and coherently across the entire Ξ network. A more detailed proposal in relation to this process – where it is envisaged to be rhythmic – is described in Section 9.4.

A sense of how the overall architecture according to Mesulam can be rendered in hierarchical processing terms is illustrated in the Figure 5.[59]

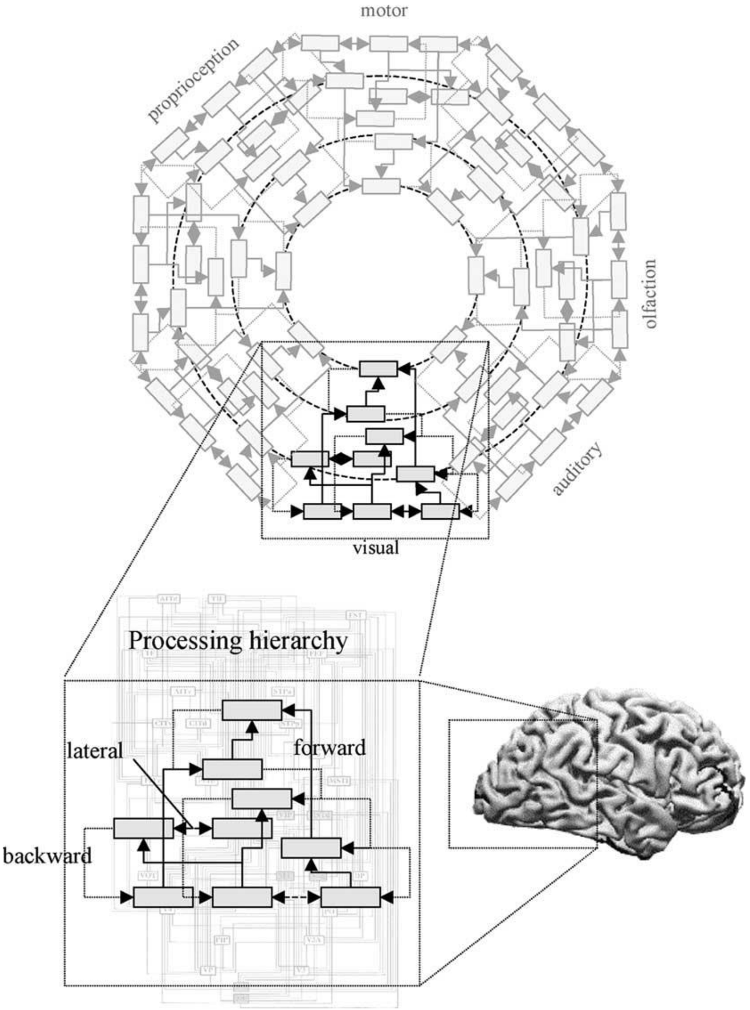

Figure 5

Figure 5 illustrates hierarchical structures in the brain and the distinction between forward, backward, and lateral connections where the element of the schematic shown in the box is intended to illustrate ensembles of the same inter- and intra-layer connections illustrated in Fig. 4. The overall schematic relates such elements to the overall architecture proposed by Mesulam as illustrated in Fig. 3.

Using the above account of brain neurology, hierarchical processing and the general thrust of the PPP, these ideas can now be related to the illustrative conceptual frameworks described in the Essay.

9.3 Recasting W[i], B[i], N[i] and the association matrix

9.3.1 Recognition states and recognition space

The Essay used the device of association complexes to describe functional records that could be built up to form a single association matrix. It also developed the idea of κρϕ coordination, to describe how association complexes could operate in real time, and this idea was then developed into the concept of an action cycle: a real-time information processing mechanism that could draw upon and improve the capabilities of the association matrix whilst also forming the core of how a person could successfully interact with their environment on a moment-by-moment basis to attain goal states.[60]

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[59] Fig. 5 reproduces a schematic developed by Karl Friston; see specifically Figure 1 in Friston, K. (2005) A Theory of Cortical Responses. *Phil. Trans. R. Soc. B 360* 815-836, and Figure 1 in Friston, K. (2003) Learning and Inference in the Brain. *Neural Networks 16* 1325-1352.

[60] The term 'goal state', as applied in the Essay, is explained at footnote 23 above. (And in due course see Section 10.5.1 in Part 2 of this note).

Drawing on sections 9.1 and 9.2 above, it is possible to recast the association matrix and action cycle in terms of the PPP. As will be shown, this will allow development of PPP-concordant ideas of how a moment-by-moment subjective sense of being a physical person interacting with a physical world can emerge, and can be used to rebase the ideas expressed in the notes *How is Free Will Possible?* and *The Construction of Phenomenal Time* without creating a need for any substantial change to the central concepts proposed in those notes.[61]

Figure 6 shows as a schematic the totality of systems proposed as illustrative concepts in the Essay.

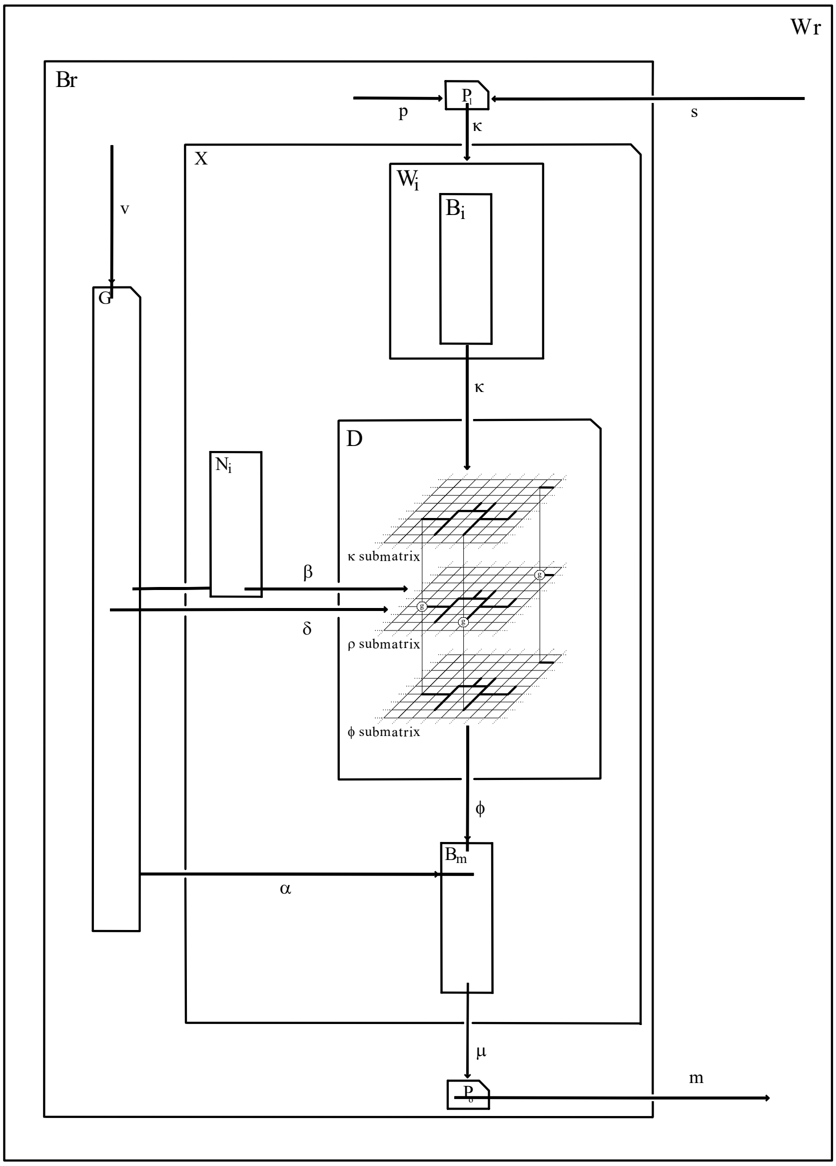

Figure 6

Figure 6 is adapted from Fig. 20 in the Essay, where the plain rectangles are called *fields* and the cut-corner rectangles are called *processors*.[62] The figure shows a person's absolute (noumenal) body, B_r, situated within the absolute (noumenal) world, W_r. The Essay proposes that exteroceptive, sensory input, s, travels from W_r into B_r to a nominal processor P_1. Proprioceptive input from within B_r also travels into P_1, where s and p are processed into κ. P_1 inputs κ into a processor X. Interoceptive, visceral input, v, travels from within B_r into G, which measures it against set points that define the targets for B_r internal homeostasis and then processes the results into inputs β, δ and α, that then travel into X. Processor X outputs μ, which is then converted into B_r motor output, m, by a nominal processor P_0. In the Essay a processor within X – called the *sensory-motor processing centre*, D – is posited. It is proposed that D contains an association matrix – shown here with all three of its proposed submatrices – along with input and output processes for that matrix. Note that the illustrative conceptual arrangement of inputs and operations affiliated with the scheme shown in Fig. 6 can be translated into, and very largely superseded by, concepts within the PPP, as shown below.

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[61] As provided at https://teledyne.com/free_will.pdf and https://teledyne.com/time.pdf.

[62] N.B: the illustrative ideas and notation of fields and processors *are rendered obsolete* once the ideas provided in Fig. 6, and more broadly in the Essay, are recast in terms of the PPP. More precise definitions for these can be found in the Essay if any reader is sufficiently interested.

The Essay proposes that the information travelling as κ could be processed in D in a way enabling systems in D to identify and differentiate on a moment-by-moment basis a person's *phenomenal body* B[i] as it operates within the larger field of their *phenomenal world*, W[i]. This is illustrated in Fig. 6 by the field B[i] – the *body image* – sitting within W[i] – the *world image*.[63] The relevant discussion is in Essay Section 7.22 which – within the broader context of Essay Section 7.2 – describes how this capacity to identify and differentiate B[i] from the broader whole of W[i] could only emerge through its intimate coevolution with emergence of an ability to express and coordinate *voluntary* motor output.

Such emergence would be attained as the infant B[r] repeatedly acts on the wider world, W[r] – through processes in D that 'observe' and 'learn' from the consequences of that action – to steadily grow out of highly incompetent levels of sensory-motor coordination into ever more competent levels eventually into a maximum, adult capability. Essentially the voluntary motor output, m – which the Essay proposes would emerge in tandem with capacity in D to differentiate B[i] from wider W[i] – is reflected in the *voluntary motor field* B_m.

The reason for parsing information travelling from G into X into three components[64] – β, δ and α – was to ensure that an infant is always forced to move and act – even if in an uncoordinated and unconscious way – whenever G detects that visceral input, v, is significantly deviating from the set point targets held in G for B[r] internal biological homeostasis. Such deviation would generate α. Essentially, α input was devised as a 'carrier' signal which could then progressively and increasingly be modulated by ϕ input from D as processes within D learned ever more effective sensory-motor coordination – and with this ever better differentiation between B[i] and wider W[i].

It was also proposed that G derive β and δ from v, and send these to D, where:

- β mirrors α and encodes the exact momentary specific need or set of needs B[r] is experiencing as deviations against one or another specific set point; say for blood hydration or blood sugar or blood carbon dioxide.[65] The input β to D is reflected in Figure 7 as N_i, the *need image* (denoted N[i] in future). β can also encode specific kinds of pleasure or reward.

- δ encodes the magnitude of each momentary need or reward, with need magnitudes reflecting the degree of deviation from one or more set point targets for B[r] homeostasis.

These illustrative conceptual arrangements can be recast and extended to integrate them with the PPP as it has been described in Sections 9.1 and 9.2 above.[66] To begin with, transposition onto the PPP framework allows the schematic shown in Fig. 6 to be simplified to that shown in Fig. 7.

Although Fig. 7 retains a number of the features of Fig. 6, much has been removed. Some of these features will be recovered in recast form later, particularly in relation to the illustrative concept of an association matrix, and of B[i] in W[i], while much else will be fully subsumed into terms of the PPP.

Note that in Fig. 7, X is denoted X[r] and D is denoted D[r]. This provides for notational consistency since, as parts of B[r], X and D are at the noumenal level.[67]

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[63] In work finalised following the Essay the *absolute* body, B_r, is referred to as the *noumenal* body, B[r], and the *absolute* world, W_r is referred to as the *noumenal* world, W[r]. Likewise a person's body image, B_i, is referred to as their phenomenal body, B[i], and their world image, W_i, is referred to as their phenomenal world, W[i]. These respective terms are entirely synonymous. (See also footnote 10 and Appendix 1.)

[64] Explained in detail in Essay Sections 7.4 to 7.7.

[65] For example, for blood carbon dioxide levels above the set point tolerance, the input to B_m of α would – in the absence of any balancing or overriding ϕ input – drive breathing. Holding one's breath would correspond to offsetting momentary α input with the right ϕ input.

[66] A crucial part of this will be to incorporate hierarchical predictive processing into how what have been described as sensory, proprioceptive and visceral inputs into D – as well as motor outputs from D – are processed.

[67] The notation X[r] and D[r] will be adopted from hereon in within this note.

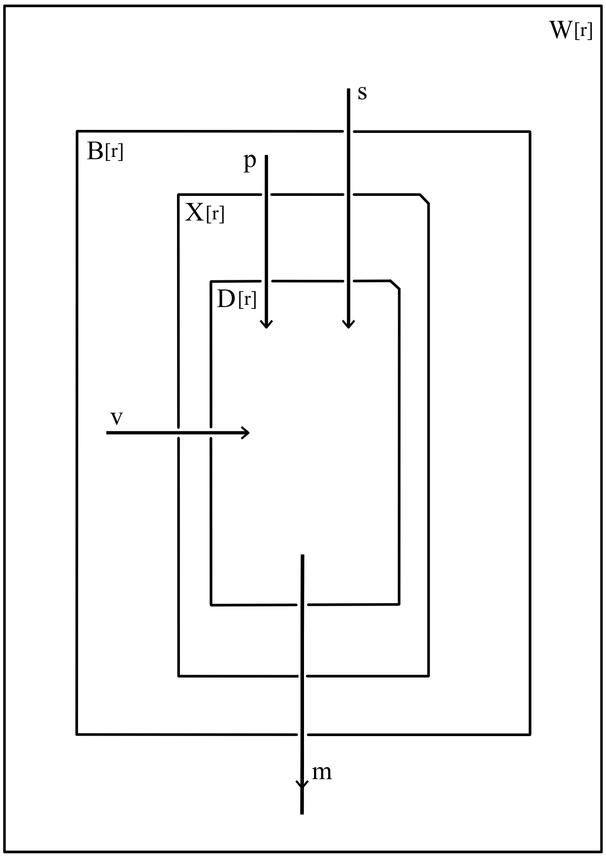

Figure 7

Figure 7 parallels Fig. 6. It retains the idea of a noumenal world, W[r] and, within that, a noumenal body, B[r]. In PPP terms these form an environment of 'hidden states' – which inter alia will constitute the 'hidden causes' of sensory input – and which can be moved by motor output. The boundary of the processor X[r] onto B[r] can be considered the interface between the nervous system[r] and the rest of B[r]. Sensory/exteroceptive input, s, proprioceptive input, p, and visceral/interoceptive input, v, will pass into X[r] and on into the processor D[r].[68] One output expressed from D[r] is motor output, m.[69] The boundary between D[r] and X[r] can be considered a Markov blanket[70] partitioning this neurological processing system[r] from the rest of the nervous system[r], where the latter can then also be considered part of D[r]'s environment of hidden states. Thus, this scheme envisages that it is D[r] that houses the hierarchical information processing machinery, along with its generative and recognition models, that are described in Figs 3, 5 and related text, with reference to the PPP.

Figure 8 shows the same architecture as that outlined in Fig. 7, but details the interior of D[r]. Specifically, it is now proposed that D[r] inter alia contains those parts of brain[r] described by Mesulam, as illustrated in Fig. 3, and discussed at length in Section 9.1 above.

In Fig. 8 Mesulam's nodes – equivalent to the nodes referred to in Section 9.2 – are shown both as hollow and filled circles embedded in both the multimodal areas of the two innermost cortical layers and in the monomodal areas of the four outermost layers. Together define all of these nodes as elements of the *node set*, Σ.[71] Now call the subset of Σ made up of all nodes activated at some given moment in time the *activated node set*, Θ. At that moment in time, and consistent with the notation introduced in Section 9.2, the members of Θ will be Ξ nodes and will form a Ξ network. In Fig. 8, Ξ nodes are represented by filled circles. Some of these Ξ nodes are labelled $a^1, a^2, a^3, a^4, \ldots, a^n$ to allow illustration of the set $\Theta = \{a^1, a^2, a^3, a^4, \ldots, a^n\}$.[72]

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[68] There may be inputs/outputs into/from D[r] that predominantly or solely originate in/operate on that part of X[r] which is not D[r] but which have little or no inception or impact beyond X[r]. Such inputs/outputs are not consequential to the purposes of this note.

[69] Other kinds of output could, for example, lead to expression of hormones or other biochemicals into B[r] systems. Similarly, there may be other inputs to D[r] beyond those shown. As per footnote 68, while such additional inputs and outputs may exist, the ideas to be presented in this note can be well enough expressed without need for further exploration of this area.

[70] Markov blankets are well described for the present purpose in Friston, K.J. et al. (2020) Sentience and the Origins of Consciousness: From Cartesian to Markovian Monism *Entropy 22* 516.

[71] Consistent with the notation and concepts introduced in Section 9.2 (and listed in Appendix 1: https://teleodyne.com/working_note_A_appendix_1.pdf.).

[72] Note that it is envisaged that if some node – say a^3 in Θ above – is activated, it may be activated to a greater or lesser degree and in one of many possible different ways. It is also not ruled out that all nodes in Σ may be activated, each to some degree and in some way, at all times. These considerations can be accommodated within, and do not affect the thrust of, the proposals to be made. In these proposals it is the way and degree to which a node is activated that is of importance, with non-activation simply being one of many logical possibilities for any given node.

Since the inputs and outputs of D[r] will normally change from moment to moment, the members of Θ, which are those nodes that momentarily form a Ξ network and carry that network's overall activation state – the Ξ state (recognition state) – will normally also change from moment to moment.

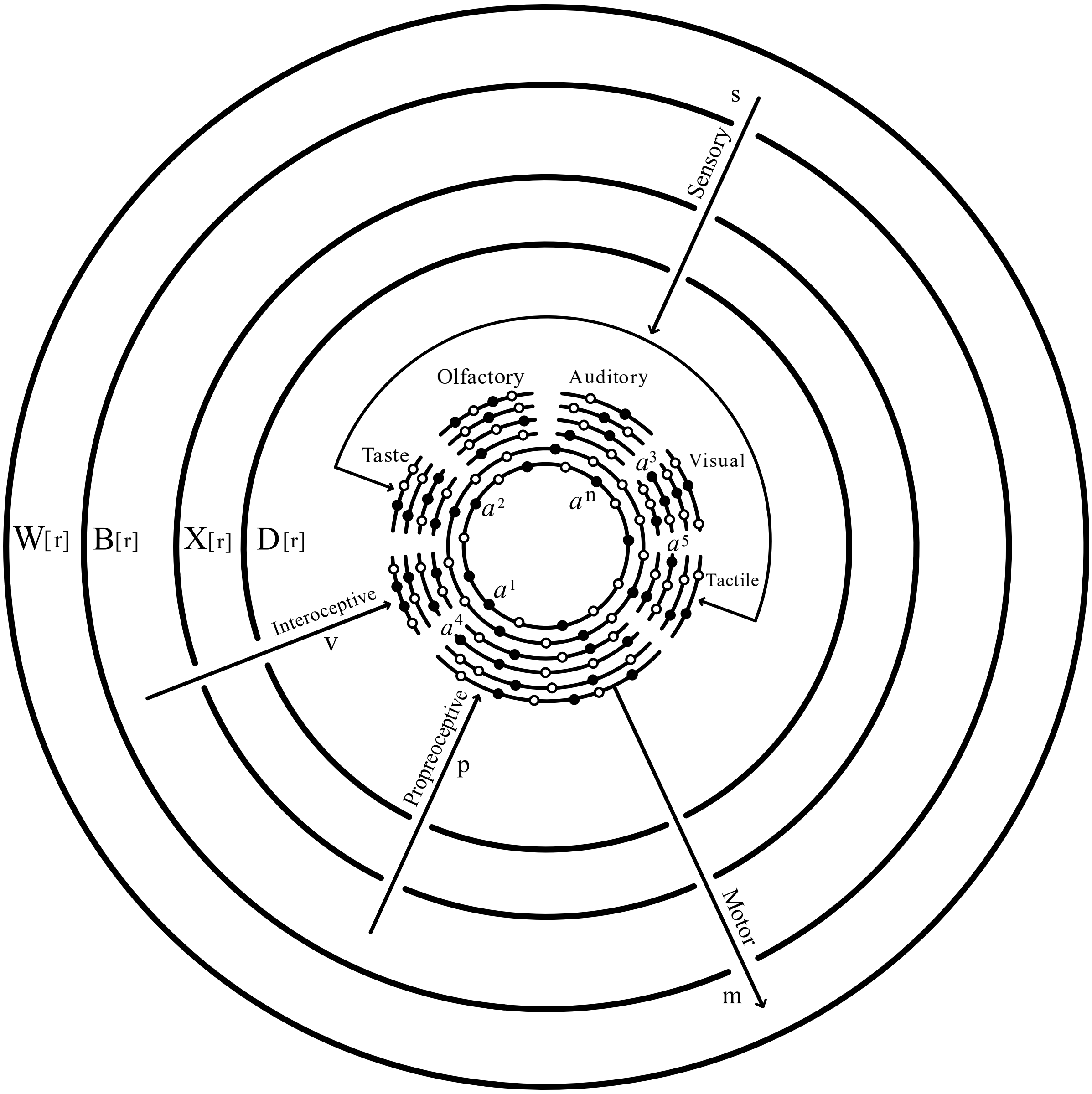

Figure 8

Figure 8 extends Fig. 7 by illustrating the proposed interior of the processor D[r], which reflects the contents of Fig. 3. In D[r] the two innermost cortical layers – again shown as rings – contain heteromodal nodes in multimodal areas while the four outer layers contain unimodal nodes in monomodal areas.[73] Nodes are shown as either hollow or filled circles embedded in these layers. All nodes in the hierarchical processor, hollow or filled, are members of the node set, Σ. The filled nodes illustrate the subset of Σ identified in the text as the set Θ, whose members are those members of Σ that, at the moment in time depicted in the figure,[74] are activated by – and carry an activation state due to – the result at that moment of a balancing to as close to zero as possible across the whole hierarchical processor of outward propagating predictions against inward propagating cueing signals (errors). Some nodes have been labelled to allow illustration of the *activated node set*, $\Theta = \{a^1, a^2, a^3, a^4, \ldots, a^n\}$. The network of all such momentarily activated nodes – which will be made up of all of the members of Θ – is defined as a Ξ network, and the specific overall momentary activation state of that network is defined as a recognition state, also called a Ξ state or simply denoted Ξ.[75]

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[73] See Section 9.1 for details on heteromodal and unimodal nodes, and on multimodal and monomodal areas.

[74] This is a moment *i* as defined in Section 9.4.2 below.

[75] Note that in Fig. 8 the sensory input, s, as shown represents only exteroceptive input, and that for this figure, and from hereon in this note, exteroceptive, proprioceptive and interoceptive inputs are defined in accordance with Chapter 12 of Patestas, M.A. and Gartner, L.P. *A Textbook of Neuroanatomy Ed.2* Wiley & Sons, Hoboken New Jersey USA 2016.

Define *recognition space* – or Ξ space – as that space defined by the number of degrees of freedom required to express, as a position[76] in that space, any possible momentarily activated recognition state, Ξ. Thus, any Ξ will define a unique position in Ξ space. Call such a position a Ξ *locus*.[77]

The idea of an association matrix can be subsumed by the idea of Ξ space as follows.

Recall the set of activated nodes, Θ, where $\Theta = \{a^1, a^2, a^3, a^4, \ldots, a^n\}$. It is proposed that Θ exists at the neurological level of a momentarily activated network of nodes across the hierarchical processor in D[r].

If a node a^x is carrying an activation state at some given time, label that specific activation state, $\underline{a}^x$. Using this notation the recognition state, Ξ, can be expressed as a set where $\Xi = \{\underline{a}^1, \underline{a}^2, \underline{a}^3, \underline{a}^4, \ldots, \underline{a}^n\}$.

Now assume that the individual activation state of any node in Θ will have had properties conferred on it by incoming cueing signals such that it will either be part of a specific type of *sub-network* of activation among members of Θ or it will not. Such a sub-network can be described as a subset of $\Theta = \{a^1, a^2, \{a^3, a^4, \ldots\}, \ldots, a^n\}$ where $\{a^3, a^4, \ldots\}$ is such a subset. As a concrete example, consider that such a sub-network might have as its members *only* those nodes in Θ carrying some component of their momentary activation state that is, or has been, driven by cueing signals arising from retinal[r] input. Such nodes would be found in monomodal areas responsible for visual processing, but many other nodes in heteromodal areas may also be activated by such input.

Then say that at the level of activation states, there will be corresponding subsets; $\Xi = \{\underline{a}^1, \underline{a}^2, \{\underline{a}^3, \underline{a}^4, \ldots\}, \ldots, \underline{a}^n\}$, where $\{\underline{a}^3, \underline{a}^4, \ldots\}$ is such a subset. Call these subsets *substates* of Ξ.

The overall picture proposed then is that, *over time*, the series of recognition states arising in the D[r] hierarchical processor can be seen as an evolving overall state composed of an evolving pattern of networked activation, 'morphing' over time across the node set Σ, where at any given moment the overall set of activated nodes, Θ, can be seen as comprised of variously intersecting – and perhaps some non-intersecting – subsets, where each such subset is defined by a specific characteristic that must be present in at least some of the cueing signals that have activated each of its member nodes. In the example used above, such a specific characteristic would be that some of these cueing signals carry information arising from retinal[r] input.

Over time, the corresponding substates in the evolving recognition state, Ξ, will correspond to evolving positions in subspaces of Ξ space where such subspaces will be comprised of the subset of those degrees of freedom in overall Ξ space required to define, as a distinct position in that subspace, any possible momentarily activated substate of Ξ made up of the subset of Ξ whose members are states that have components activated by cueing signals arising from some specific type of input into D[r].

There could then – in the abstract – be many ways of carving recognition space up into various kinds of subspaces. For current purposes however, only four recognition subspaces will be defined. Two of these will be subspaces that respectively can be used to supersede the κ submatrix and the ρ submatrix.[78]

With this, it is now proposed – and will be shown below – that the illustrative concept of an association matrix as a whole – as described in Section 7 of this note, in the current section, and in the Essay – can for all practical and conceptual purposes be superseded and improved upon by using the concept of a recognition model operating in conjunction with a generative model.

It is also proposed – and will be shown below – that two of the submatrices described as integrated together to form the association matrix – namely the κ submatrix and the ρ submatrix[78] – can similarly each be shown to have superseding counterparts in terms of a recognition model operating in conjunction with a generative model.

Most importantly, it is now further proposed that at any given moment the recognition state, Ξ, will provide for the overall contents of a person's phenomenal experience of reality – i.e. what they are subjectively experiencing, physically, emotionally, and in all other ways to be real – in that moment.[79, 80]

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[76] Here a position need not strictly be a point but could be some form of narrow distribution around a central, highest-amplitude point (mode).

[77] Here – as in the Essay – the term *locus* is used simply to denote a *location,* which is a position (ibid.) in the space described.

[78] Because the ϕ submatrix, as proposed, has to do with a D[r] system *output* – i.e. motor output – not an *input*, it will be treated differently.

[79] This is a large claim, but it can reasonably be made since so many studies of phenomenal experience in test subjects show that a range of predictable deficits arise in such experience should one or more of the nodes/areas described by Mesulam be damaged. Indeed, the emergence of such deficits has provided a major evidentiary basis for the edifice of hierarchical neurological architecture and processing referenced in Section 9.1, and on which much of the material provided in Section 9.2 rests. Further, the literature supporting the PPP provides strong evidence of that paradigm's ability to explain various types of perceptual illusion. Because of its importance, this claim is revisited in greater depth in Sections 10.1 and 10.2 of Working Note A – Part 2.

[80] Also note that this claim does not preclude the possibility that certain substates of Ξ could arise that are phenomenally silent. Call the set of such phenomenally silent substates, S. For example, this could be the case among substates of Ξ whose members exclusively are activation states of nodes in the outermost monomodal areas of the processor, noting that we usually perceive an object as an object, not as its components, suggesting the possibly that it may only be activations in the inner say four of Mesulam's six layers that provide for the run of everyday phenomenal experience.

9.3.2 Recasting the κ submatrix

It has been proposed that application of the recognition model will give rise to serial recognition states, Ξ, as hierarchical processing proceeds,[81] where these can be written:

$$\Xi = \{\underline{a}^1, \underline{a}^2, \{\underline{a}^3, \underline{a}^4, \dots\}, \dots, \underline{a}^n\} \qquad \text{E1}$$

Now define a subset of Ξ whose members are *only* those states that have *at least one component* that is, or has been, activated by cueing signals that carry information that contributes to inference of spatial location.[82] If it is accepted that Ξ will at any given moment provide for the overall contents of a person's phenomenal experience, then this substate can be used to supersede what has been described in the Essay and elsewhere as W[i].

It can be written $\quad \Xi = \{\underline{a}^1, \underline{a}^2, \underline{a}^3, \dots, \underline{a}^x, W[i], \underline{a}^{(x+y+1)}, \dots, \underline{a}^n\} \qquad$ E2

where: $\quad W[i] = \{\underline{a}^{(x+1)}, \underline{a}^{(x+2)}, \dots, B[i], \dots \underline{a}^{(x+y)}\} \qquad$ E3

Which can all also be written: $\quad \Xi = \{\underline{a}^1, \underline{a}^2, \underline{a}^3, \dots, \{B[i] \text{ in } W[i]\}, \dots, \underline{a}^n\} \qquad$ E4

or: $\quad \Xi = \{\underline{a}^1, \underline{a}^2, \underline{a}^3, \dots, \{B[i] + W[i]\backslash B[i]\}, \dots, \underline{a}^n\} \qquad$ E5[83, 84]

It is now proposed that what has been referred as W[i] across all the work presented on this website and elsewhere, including the Essay, can be redefined as a substate in the overall recognition state Ξ, and that this can be done without loss of any essential aspect of its meaning in that work.

This proposal is consistent with the fact that the *world image*, W[i] – the physical world as a person phenomenally experiences it moment-by-moment – *always* presents itself, moment-by-moment, as distributed in space. Also, those parts of the physical world a person perceives to be 'outside themselves' are experienced as phenomena in that part of space that they perceive to be outside their B[i]. This is the part of W[i] – annotated $W_i\backslash B_i$ in the Essay and W[i]\B[i] here and elsewhere – that can be called a person's *environment image* – which will inhere across substates within the subset $\{\underline{a}^{(x+1)}, \underline{a}^{(x+2)} \dots \underline{a}^{(x+y)}\}\backslash B[i]$ in E3, where these are members of W[i] but not members of B[i]. For example, what a person phenomenally experiences as chairs[i], tables[i] etc. will be encoded across such W[i]\B[i] substates.[85]

Another way of defining the environment image, W[i]\B[i], is to say that it is the subset of Ξ whose members are *only* those states that have at least one component activated by cueing signals that carry information indicative of spatial location and that arise from input that originates in W[r]\B[r].[86]

Because a person's moment-by-moment phenomenal experience of their physical body, their *body image*, B[i], also subjectively presents itself to them as existing in physical space, B[i] can be identified as a substate of W[i].

B[i] can then be differentiated from W[i]\B[i] by requiring that it be the subset of W[i] whose members are *only* those states that have at least one component activated by cueing signals that carry information derived from inputs to D[r] which arise from *within* B[r], including from:

- exteroceptors that are *not* teloreceptors;
- proprioceptors, including in the vestibular system; and
- interoceptors, such as stretch receptors.[87, 88]

Note that, taken as a whole, the above are intended as working definitions of W[i], B[i] and W[i]\B[i] – sufficient for the purposes of the overall thesis under development here – and are not an attempt to be utterly precise or exhaustive in terms of the assignment of the specific sources of their defining cueing signals.

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[81] By means described at pp13-14 in Section 9.2.

[82] These will typically include such cueing signals as those driven by exteroceptive, proprioceptive and vestibular inputs to D[r].

[83] N.B: Set theory notation '\' is applied in this note to the effect that A\B is used to denote that part, subset or substate of A which is not B.

[84] Note that {B[i] in W[i]} is equivalent to {B[i] + W[i]\B[i]}. The distinction is drawn purely for purposes of context in that the formulation {B[i] in W[i]} is useful where discussion places emphasis on a person's phenomenal experience of themselves as a physical body, B[i], being considered as *integral to and embedded in* a physical world, W[i], whereas the formulation {B[i] + W[i]\B[i]} is useful where discussion places emphasis on a person's phenomenal experience of themselves as a physical body being considered as *distinct and separable from* its physical environment, W[i]\B[i].

[85] Noting that this is not to say there need be any one-to-one correspondence between the activation state of any specific node, e.g. $\underline{a}^{(x+1)}$ or $\underline{a}^{(x+4)}$ and say a chair[i] or a table[i], but that perceptions of objects such as a chair[i] or a table[i] could by some means be encoded across some, or conceivably even all, of the network of such node states in the substate $\{\underline{a}^{(x+1)}, \underline{a}^{(x+2)}, \dots, \underline{a}^{(x+y)}\} = W[i]\backslash B[i]$.

[86] That is, from the outermost realm of 'hidden states', as per the caption to Fig.7, and shown in Fig.8 as the realm from which s input into D[r] arises.

[87] In full then, B[i] will be the subset of Ξ whose members are *only* those states that have at least one component activated by cueing signals that carry information able to contribute to inference of spatial location and at least one component activated by cueing signals that carry information derived from inputs to D[r] arising from *within* B[r] as described above, where the terms, definitions (and spelling) used above are taken from Chapter 12 of Patestas, M.A. and Gartner, L.P. *A Textbook of Neuroanatomy Ed.2* Wiley & Sons, Hoboken New Jersey USA 2016; esp. pp189. Note that teloreceptors respond to distant stimuli such as light or sound and do not require direct physical contact with the source.

[88] Note then that a further way of defining W[i]\B[i] is as the subset of Ξ whose members are only those members of W[i] that do *not* have a component activated by the B[i] specific cueing signals described above. It is not difficult to see how this latter definition of W[i]\B[i] could be useful as a starting point to explain various malfunctions in the sense of 'body ownership' (as per Braun, N. et al. (2018) The Senses of Agency and Ownership: A Review. *Frontiers in Psychology 9:535*) where, in the PPP, loss or undue attenuation of some or all cueing signals from, say, within a limb, might lead to its subjective perception as part of W[i]\B[i] and therefore as physically present but "not mine".

Under these definitions the illustrative concept of a κ submatrix can be superseded/recast as follows:

- Substitute for the κ submatrix a subspace, within Ξ space, comprised of the subset of those degrees of freedom in overall Ξ space required to define, as a distinct position in that subspace, any possible momentarily activated substate of Ξ made up of that subset of Ξ whose members are states that have a component activated by cueing signals carrying information on spatial location.

Call this the *κ subspace* (or *κ space* or *kappa space*). Kappa space will be the space within which any state of W[i] will define a distinct position. This will be the same as the position defined by {B[i] in W[i]} since B[i] is a subset of W[i]. Call this position a *κ locus*, given that the idea of such a locus will serve a similar purpose here as the idea of a κ locus served when described in the Essay as a position in the κ submatrix.

Define another subspace of Ξ space – call it the *σ subspace* (or *σ space* or *sigma space*) – which will be the space within which any state of B[i] will define a distinct position. Call this position a *σ locus*. Clearly, σ space will be a subspace of κ space (from E3).

Define a further subspace of Ξ space – call it the ω subspace (or *ω space* or *omega space*) – which will be the space within which any state of W[i]\B[i] will define a distinct position. Called this position an ω locus. Omega space will be all of the subspace of κ space that excludes σ space, and σ space will be all of the subspace of κ space that excludes ω space. So σ space + ω space = κ space, corresponding to {B[i] + W[i]\B[i]} = {B[i] in W[i]} = W[i] noting (E3), (E4) and (E5) above.

9.3.3 Recasting the ρ submatrix

A similar approach can be used with respect to the ρ submatrix.

Define a subset of Ξ whose members are *only* those states that have *no* component activated by cueing signals that carry information able to contribute to inference of spatial location. This substate can be used to supersede what has been described in the Essay as the *need image*, N[i].

It can be written: $\Xi = \{\underline{a}^1, \underline{a}^2, \underline{a}^3, \ldots, N[i], \ldots, \underline{a}^n\}$ E6

where under this definition: $N[i] = \Xi \backslash W[i] = \Xi \backslash \{B[i] + W[i] \backslash B[i]\}$ E7

The proposal here then is that what has been referred as N[i] in the Essay, can be redefined as a substate in the overall recognition state Ξ, such that:

$\Xi = N[i] + W[i]$ E8

where from E3 $\Xi = N[i] + \{B[i] + W[i] \backslash B[i]\}$ E9

and from E4 $\Xi = N[i] + \{B[i] \text{ in } W[i]\}$ E10

At a subjective level N[i] will manifest as a person's moment-by-moment perception of such phenomena as desires and appetites – including for water, food or air – and of *emotions* and of all other *non-spatial* percepts.[89]

The illustrative concept of a ρ submatrix can now be superseded/recast as follows:

- Substitute for the ρ submatrix a subspace, within Ξ space, comprised of the subset of those degrees of freedom in overall Ξ space required to define, as a distinct position in that subspace, any possible momentarily activated substate of Ξ made up of that subset of Ξ whose members are states that have *no* component activated by cueing signals carrying information on spatial location.[90]

Call this the *ρ subspace* (or *ρ space* or *rho space*). Rho space will be the space within which any state of N[i] will define a distinct position. Call this position a *ρ locus*, given that the idea of such a locus will serve a similar purpose here as the idea of a ρ locus did when it was described in the Essay as a position in the ρ submatrix.

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[89] Proposals as to how appetites – and a crucial range of other emotions related to decision-making – are generated and expressed as substates of N[i], and thence perceived, are described at length in Working Note A – Part 3.

[90] It stands to reason that the cueing signals leading to such states will mainly be driven by certain interoceptive inputs to D[r] considering that many such inputs – for example inputs providing information on blood chemistry[r] – seem most unlikely to contain information able to contribute to any inferences of spatial location. Reciprocally, there is strong evidence that certain interoceptive inputs play a major role in the production of non-spatial perceptions, including perceptions of emotions and, beyond this, that they play a major role in inducing behaviours that seek to maintain B[r] biochemical and biophysical homeostasis (a finding in accord with claims made in the Essay for the role of the ρ submatrix). For example see Seth, A.K. and Friston K.J. (2016) Active Interoceptive Inference and the Emotional Brain *Phil. Trans. R. Soc. B 371*: 20160007 and most comprehensively, Feldman Barrett, L. *How Emotions Are Made* Horton Mifflin Harcourt, New York 2017.

9.3.4 Recasting the ϕ submatrix

In the Essay the overall idea of an association matrix – and of its predecessor association complexes – was developed to illustrate how sensory input from W[r], proprioceptive input from within B[r], and interoceptive input from within B[r], might cotemporally and associatively be recorded in D[r] together with motor output expressed by B[r], to provide a knowledge base able to support ongoing and optimisable sensory-motor processes designed to get B[r] to goal states.

In this respect the idea of a ϕ submatrix was designed to help describe a tight associative linkage between the κ and ρ submatrices – realms defined by the range of recorded and possible exteroceptive, proprioceptive and interoceptive *inputs* to D[r] – and, in the form of the ϕ submatrix, a realm of recorded and possible motor *outputs* from D[r].[91]

In the PPP, this realm of recorded and possible motor outputs inheres in the generative and recognition models held in D[r]'s hierarchical processor, where such motor outputs are evoked and expressed through the process of active inference (see Section 9.4 below). So while it is possible to recast the ideas of κ and ρ submatrices as κ and ρ subspaces in Ξ space – based on the operation of recognition model held in D[r] – the ϕ submatrix must here be recast not as a space but as a facet of the generative and recognition models held in D[r] and accorded no presence in recognition space.

Consistent with this – in relation to the proposal that at any given time the recognition state might provide for the overall contents of a person's phenomenal experience – it has not been envisaged in the Essay or elsewhere[92] that there should be any form of conscious phenomenal experience of motor *output* per se.

It has, of course, been envisaged that motor output can be *indirectly* perceived at the phenomenal level through the processing of those components of exteroceptive and proprioceptive *input* caused by it, and that emergence of such perception goes hand in hand with systems in brain[r] drawing an inferential distinction between B[i] and W[i]\B[i] – i.e. between what is consciously identified to be one's physical body as distinct from what is identified to be the body's external physical environment.

9.4 Recasting the action cycle

9.4.1 The recognition cycle

The discussion and proposals advanced in Section 9.3 show how the illustrative concept of an association matrix can be recast as encompassing a recognition model and generative model enabling the ongoing production and resolution of recognition states, as described above, and enabling the expression of motor and other[93] outputs through active inference.[94]

In the Essay, updating of the association matrix based on error correction, as well as real-time updating of the phenomenal model of the physical self-in-the-world, {B[i] in W[i]}, was described as being carried out along lines of the illustrative concept of an *action cycle*. Under the PPP updating of the recognition and generative models is carried out in the course of active inference.

The idea of an action cycle was developed to perform a similar function with respect to an association matrix as active inference performs in relation to recognition and generative models. However, a crucial difference between these two processes is that while the action cycle has been laid out serially, as a repeating sequence of steps that process information inputs (sensory) and outputs (motor) as 'quanta', ongoing active inference seems likely to proceed through repeating rhythms or 'pulses' of hierarchical processing.

The essential features of the illustrative idea of an action cycle are described in Section 7.1 of the Essay and, with some bowdlerization, in the note *How is Free Will Possible?*[95] Those descriptions show that the hypothetical operation of the action cycle has strong functional parallels with the operation of hierarchical processing in the PPP.

In the following recasting of the action cycle in terms of the PPP, the idea of an overall cycle is preserved. It is proposed that this updated version – call it a *recognition cycle* – will unfold over the time interval it will take for the hierarchical processing system in D[r] to get from one state estimate to

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[91] That is, envisaged as realms of 'real' (i.e. recorded) or 'synthetic' (i.e. possible) κ, ρ and ϕ ticks, where synthetic ticks were to have been extrapolated or interpolated on the basis of 'real' ticks.

[92] Elsewhere in https://teleodyne.com/.

[93] Other outputs as per footnote 69.

[94] See below, and for example, the extensive account of how active inference can work provided in Chapter 4 of Clark, A. *Surfing Uncertainty: Prediction, Action and the Embodied Mind* Oxford University Press, New York, USA 2016.

[95] See pp56-59 Essay and pp4-6 in *How is Free Will Possible?* at http://teleodyne.com/. Note that in *How is Free Will Possible?* motor output is denoted ***m***. There is no difference between what is denoted there as ***m*** and what is denoted throughout this note as m. Both simply mean motor output.

the next – i.e. from one recognition state, Ξ, to the next – where such state estimates will arise at a specific moment within the period of the cycle, say at a time $t = a$, which will be the moment at which predictions are maximally balanced (to ~zero) against prediction errors.[96]

Call a single iteration of the recognition cycle one *beat* of the recognition cycle. So if time is counted in units of one beat of the recognition cycle a series of state estimates will then arise at times, t, where $t = a, (a+1), (a+2), (a+3), \dots (a+n)$ as the recognition cycle proceeds.

Further to this it is proposed that the momentary recognition state, Ξ, be considered a composite that can be described using two terms, Ξ^{a} and $\Xi^{(a+1)*}$ and expressed in the form $\{\Xi^{a} + \Xi^{(a+1)*}\} = \Xi$ for any time $t = a$. These terms are intended to capture an inescapable property of the phenomenology of human perceptual experience; namely, that we always experience ourselves and our physical environment as being situated at a 'now' in A-series time.[97] We experience this 'now' as 'moving forward' into an 'open' future that we expect we can shape through our actions, and as 'leaving behind' a fixed or 'closed' past that we expect we can 'no longer' shape or change.[98]

If the proposal made at the conclusion of Section 9.1.3 is accepted – which is that at any given moment the recognition state, Ξ, will provide for the overall contents of a person's phenomenal experience of reality, i.e. what they are subjectively experiencing, physically, emotionally, and in all other ways to be real, at that moment – then, in order to take a person's subjective experience of time into account, Ξ must somehow encode a perspectival past together with a perspectival future.

Logically and specifically if, at $t = a$, the momentary recognition state Ξ encodes a past as well as a future, then a time series of recognition states Ξ as they arise at each successive beat of the recognition cycle can be described for $t = a, (a+1), (a+2), (a+3), \dots (a+n)$ as follows:

$$\Xi = \{\Xi^{a} + \Xi^{(a+1)*}\}, \{\Xi^{(a+1)} + \Xi^{(a+2)*}\}, \{\Xi^{(a+2)} + \Xi^{(a+3)*}\}, \dots, \{\Xi^{(a+n)} + \Xi^{(a+n+1)*}\} \qquad \text{E11}$$

where, at $t = a$:

- Ξ^{a} is defined as the *a posteriori* 'aspect' of Ξ which, at $t = a$, will encode what the hierarchical processor estimates to have been the past – including most predominantly from a subjective perspective, an estimate of what *has*, most immediately, just happened; and
- $\Xi^{(a+1)*}$ is defined as the *a priori* 'aspect' of Ξ which, at $t = a$, will encode what the hierarchical processor estimates to be the future – including most predominantly from a subjective perspective, an estimate of what *is*, most immediately, just about to happen.

In this scheme, with each beat of the recognition cycle, as the D[r] hierarchical processor arrives at each successive state estimate – with Ξ evolving from, for example $\{\Xi^{a} + \Xi^{(a+1)*}\}$ to $\{\Xi^{(a+1)} + \Xi^{(a+2)*}\}$ – the processor's prediction at $t = a$ of what is most immediately about to happen will, with the operation of active inference, move from $\Xi^{(a+1)*}$ to $\Xi^{(a+1)}$ to become at $t = (a+1)$ – with adjustment for a degree of error – an encoding of what most immediately has just happened. In the same period, and as part of the same process (see below), the D[r] hierarchical processor will, with taking such error into account, have generated a new prediction, $\Xi^{(a+2)*}$, of what is to happen next, including a prediction of what is most immediately about to happen at $t = (a+2)$.[99]

Taking these ideas into account, Figure 9 illustrates a proposal as to how the idea of an action cycle can be recast in terms of hierarchical processing and active inference as these apply in the PPP.

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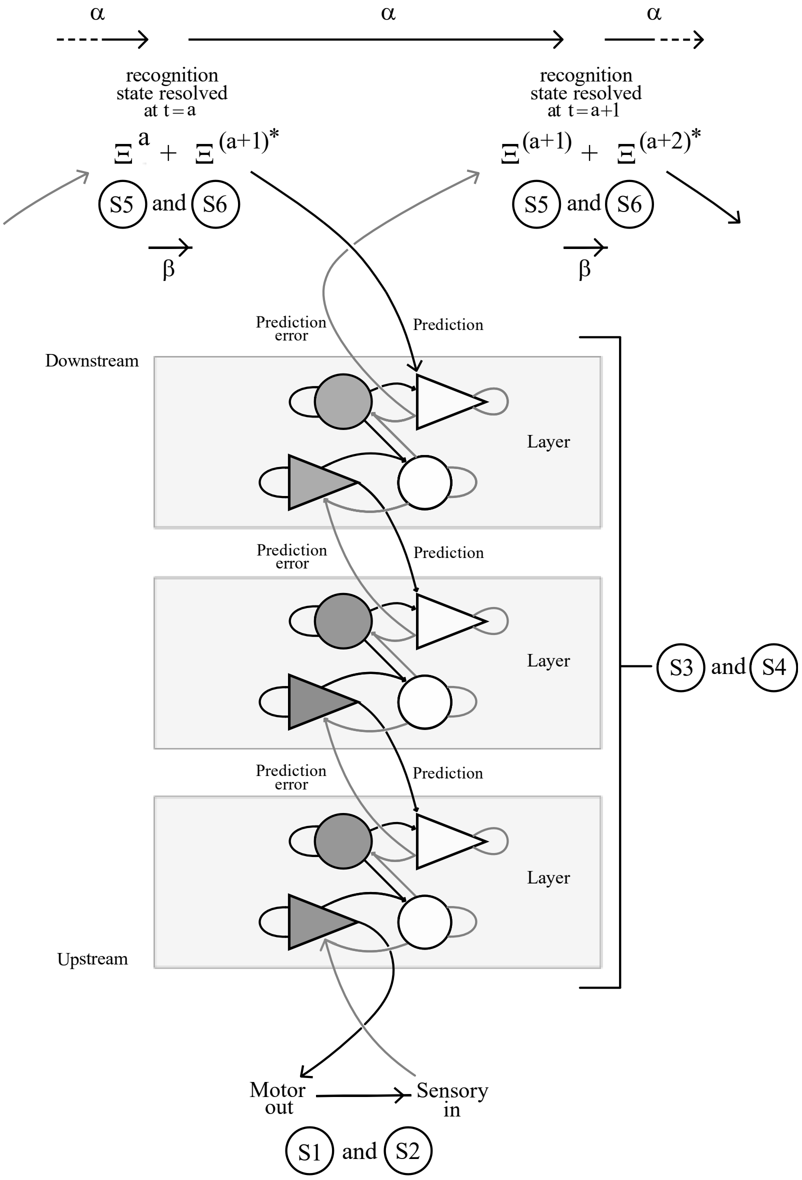
[96] It is proposed here for working purposes that the overall hierarchical processor in D[r] will cyclically attain single, coherent states of maximal balance between downward propagating predictions and upward propagating errors to give single, momentary Ξ states. In reality the situation may be more complex. In particular, it seems possible outer regions of the processor may run higher frequency subcycles, able to attain faster, lower level balances that – at times when complete balances are attained – yield no further inward propagation of errors from those regions.

[97] The designations A-series and B-series follow McTaggart, J.M.E. (1908) The Unreality of Time. *Mind 17*: 457–73.

[98] A more complete description of this situation is provided in *The Construction of Phenomenal Time* at https://teleodyne.com/time.pdf .

[99] It is germane to these proposals to draw a distinction here between 'phenomenal time' and 'noumenal time'. (For definitions see ibid. noting that the ideas of phenomenal and noumenal time correspond closely and respectively to the ideas of A-series and B-series time, and to what might be called 'subjective time' or time as each of us subjectively experience it, and 'objective time' or time as measured by shared external clocks, as for physics). Essentially, it is empirically clear that we are unable perceive how events unfold over very short periods of noumenal time, e.g. a bullet flying by. This is because brain[r] processes delivering subjective states will only be able to operate at a certain rate, such that the evolution of such subjective states will be unable to capture with sufficiently fine a temporal grain the structure of events taking place within noumenal time intervals below a certain threshold. The neurology[r] will simply be unable to operate fast enough in noumenal time. If this is the case then there is a question of how a moment of phenomenal time – i.e. time as it is subjectively experienced – can be described in terms of neurological[r] processing. Consistent with this, and in terms of the proposals being made in this note, the approach adopted here is to assume that a subjective 'now' will have a duration of ca. the length of the threshold just described, and that this duration will be ca. the interval between one state estimate and the next in the recognition cycle. If it is then accepted that a subjective 'now' must sit at the interface between an *inference* of the future and an *inference* of the past, consistent with the idea of predictive processing, and that these must somehow be encoded in the momentary recognition state Ξ, then this supports the proposal that for any time $t = a$, Ξ can be expressed as $\{\Xi^{a} + \Xi^{(a+1)*}\}$ where Ξ^{a} can be considered an encoding of the past as perceived from the 'now' of $t = a$, while $\Xi^{(a+1)*}$ can be considered an encoding of the future as perceived from that same 'now' at $t = a$.



Where:

$$\Xi^{a} = N_{[i]}^{a} + \{B_{[i]} \text{ in } W_{[i]}\}^{a}$$

$$\Xi^{(a+1)*} = N_{[i]}^{(a+1)*} + \{B_{[i]} \text{ in } W_{[i]}\}^{(a+1)*}$$

Figure 9

Figure 9 shows where each step (numbered circles) of the illustrative idea of an action cycle can be transposed onto a PPP consistent hierarchical processing system. Ξ^{a} denotes an *a posteriori* aspect of the momentary recognition state, Ξ, resolved through application of the system's hierarchical processor at time, t = a, where Ξ^{a} encodes the system's best estimate of its past situation in its environment including its *most immediate past situation*. $\Xi^{(a+1)*}$ denotes an *a priori* aspect of the momentary recognition state, Ξ, resolved through application of the system's hierarchical processor at time, t = a, which inter alia will encode the system's best estimate (prediction) of its future situation in its environment including its *most immediate future situation*. In this scheme the system's prediction of its immediate future, encoded as part of $\Xi^{(a+1)*}$, will evolve through the application of active inference as the system moves through one beat of the recognition cycle to form the system's best estimate of its immediate past, encoded as part of $\Xi^{(a+1)}$, with both recognition and generative models 'learning' from any differences between $\Xi^{(a+1)*}$ and $\Xi^{(a+1)}$. In this process, as the system moves through one beat of the recognition cycle, it will refine a further prediction of its immediate future situation in its environment encoded as part of $\Xi^{(a+2)*}$ (see the text for further detail). The central three layers in the diagram are taken from, and explained at, Fig. 4. Here these layers are intended to illustrate the totality of the hierarchical processing system in D[r], which is envisaged as encompassing – and fully integrating – the hierarchical processing of all information – including exteroceptive, proprioceptive, interoceptive and motor information – flowing into and out of D[r] over time. In reality there may often be more than three such layers, noting that Mesulam[39] points to six in the neurology he describes. The set relationships shown at the base of the figure summarize how the ideas of a phenomenally experienced need image, body image and world image can be expressed in terms of the PPP, as described in Sections 9.3.1 and 9.3.2. The arrows α and β are time intervals.[100]

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[100] The arrows α and β show time intervals consistent with proposals to do with the subjective experience of time developed in the note, *The Construction of Phenomenal Time* (TCPT) (and see below). Fig. 9 above relates to Fig. 3 in that note (see https://teledyne.com/time.pdf). Although TCPT deals only with what has here been defined as the Ξ subset {B[i] in W[i]}, it transpires that the approach the TCPT describes is sufficient to cover Ξ as a whole since the processes by which substates of N[i] are generated turn out to be largely independent of both the recognition cycle and of how TCPT proposes that the subjective experience of a 'now' is produced. The relevant proposals and ideas are described in Working Note A – Part 3.

On this basis the steps of the action cycle can be recast in terms of the PPP as follows.[101]

Step 6: In *How is Free Will Possible?*[6] S6 was described as an action cycle step where:

> "…a new ***m*** (motor) output quantum is designed and created in line for expression at the subsequent S1. Here a brain[r] process will draw on the accumulated 'knowledge' held in the association matrix to formulate an ***m*** output quantum that it inductively predicts will lead to a specific state of B[i] in W[i], namely $\{B[i] \text{ in } W[i]\}^{(a+1)}$. Say that the brain[r] processing involved in formulating the next ***m*** quantum will need to refer, as a key starting point, to $\{B[i] \text{ in } W[i]\}^{a}$ and then use the association matrix to formulate the required ***m*** output quantum and its associated *predicted* state $\{B[i] \text{ in } W[i]\}^{(a+1)*}$."

And in the Essay (page 57) S6 was described as, "Next locus projection:

> "where the recalculated association matrix is used along with the new κ locus to generate a set of possible next κ loci…The range of available next κ loci would be derived by estimating the transformation of the new locus under various known ϕ output phrases enabled by the new κ locus's parallel ϕ tick. The ρ submatrix will then be used to select the optimum next κ locus…" (where that optimum next κ locus's correlate ϕ output phrase is then expressed at Step 1).

In PPP terms S6 can be recast as a moment in the recognition cycle arising almost precisely at time, $t = a$, in the end stage of the short time interval β and immediately ahead of the long interval α (see Fig. 9), where a state estimate – i.e. a recognition state $\Xi = \{\Xi^{a} + \Xi^{(a+1)*}\}$ – has just been resolved through the balancing of predictions against prediction errors as a result of operation of the D[r] hierarchical processor during *the preceding beat* of the recognition cycle, i.e. the beat running from $t = (a-1)$ to $t = a$.

Organic to arriving at that state estimate, $\{\Xi^{a} + \Xi^{(a+1)*}\}$, the generative model inherent in the D[r] hierarchical processor will have become primed – driven by the prevailing homeostatic and allostatic imperatives of the system[102] – to express a revised but as yet unrealized set of predictions, including proprioceptive predictions, informed by

- the most contemporary *a posteriori* inference of the state of {B[r] in W[r]} available to it, and encoded at $t = a$ in the recognition state aspect Ξ^{a}

and reflected in

- a re-optimized inference of the best future *path* (sequence of predictions) available to {B[r] in W[r]} to maximize *value* for B[r], and encoded at $t = a$ in the recognition state aspect $\Xi^{(a+1)*}$. [103]

Essentially then, it is proposed that at $t = a$, at the PPP equivalent to S6 – call this ***S6E*** – the generative model inhering in the D[r] hierarchical processor will be primed to express a re-optimized set of outward propagating predictions,[104] as an expression of the $\Xi^{(a+1)*}$ aspect of the newly minted recognition state, $\{\Xi^{a} + \Xi^{(a+1)*}\}$, which itself will have just come to be carried by state units in the activated nodes of the D[r] hierarchical processor as a result of the balancing of predictions against prediction errors during the preceding beat of the recognition cycle. These nascent predictions will have been 'designed' inter alia to generate motor output shaped to move the state and state trajectory of {B[r] in W[r]} such that the next recognition state achieved will be as close as the processor can predict to $\{\Xi^{(a+1)} + \Xi^{(a+2)*}\}$.

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[101] To aid clarity some small additions and substitutions have been made in the quoted material. These are shown in round brackets, (…).

[102] Along lines described – see pp133-135 – in Friston, K. (2010) The Free Energy Principle: A Unified Brain Theory? *Nature Reviews, Neuroscience 11* pp127-138.

[103] So here $\Xi^{(a+1)*}$ can be considered to encode not only system's best estimate (prediction) of its immediate future situation, as discussed in caption to Fig.6, but also an optimized prediction of how it 'expects' its situation to unfold over some substantial period (i.e. over many beats of the recognition cycle) into the future. For elaboration on this, including on how potential future paths are decided, see Working Note A – Part 3.

[104] In the scheme envisaged, working assumptions are made that, as the proposed recognition cycle proceeds, outward propagating predictions will be (1) generated *ahead of* the inward propagating errors that are then applied to refine/correct those predictions and with this that, (2) – unless they are reflexive – these predictions will largely arise in, then flow from, the innermost, multimodal areas of the hierarchical processor. In Fig. 9 these working assumptions are broadly illustrated by showing $\Xi^{(a+1)*}$ – along with Ξ^{a} – at the 'top' of the D[r] hierarchical processor. (Note however it is assumed here that Ξ^{a} will be attained at that moment in the recognition cycle when predictions reach a point of balance with errors *throughout* the hierarchical processor – not just at the 'top' (innermost multimodal areas) – meaning that the depiction in Fig. 9 of Ξ^{a} as being at the 'top' of the processor does not entirely accurately capture this part of the ideas being illustrated. It may be more accurate to say that Ξ^{a} is attained at the moment when predictions and errors have been balanced *all the way back to* the top, innermost multimodal areas, of the hierarchical processor.)

Consistent with the conceptual framework provided by the PPP, it is proposed that as it moves from what is described above as S6E into the next moments of the recognition cycle – i.e. into the front end of the long interval α – the system within D[r] will apply precision weighting across its hierarchical processor that places strong weighting on predictions and weak weighting on prediction errors, such that at the front end of α predictions will be the dominant driver in the hierarchical cascade, as described immediately below under Step 1 (as S1E).[105, 106]

Step 1: S1 was cast as an action cycle step where voluntary motor output, m, is expressed from D[r] into wider B[r] and, via B[r], into wider W[r].[107]

Recast in PPP terms, this output will be generated in D[r] through active inference, through the outward propagation and expression of predictions generated by the hierarchical processor – having been reflected in $\Xi^{(a+1)*}$ – as the system in D[r] passes through S6E, as described above.

At the onset of this process – at the front end of the interval α – the precision weightings applied in the hierarchical processor will place overwhelmingly dominant emphasis on those predictions, which in turn will drive motor and other output[108] as the processor literally moves B[r] until {B[r] in W[r]} attains a situation where the proprioceptive prediction errors – and all other prediction errors – coming back into the D[r] hierarchical processor as inward propagating input have been moved to a point where they once again come into a balance with outward propagating predictions.

Call this PPP equivalent to S1, ***S1E***. It is proposed that S1E will take place over the interval α.

As described, it is proposed that the hierarchical processor will set its precision weightings to place overwhelmingly dominant emphasis on outward propagating predictions in the first moments of α. It is now further proposed that leading out of those first moments, and from then on through to conclusion of α, their will be a shift in precision weightings to place an increasing and eventually – in the final moments of α – overwhelmingly dominant emphasis on inward propagating errors.

It will therefore be the temporal *front end* of S1E – at the front end of the interval α – that most closely corresponds to the idea of action cycle step S1.

Step 2: S2 was cast as an action cycle step where exteroceptive sensory input, s – arising in W[r]\B[r] – is passing into B[r] via the sensory pathways[r] and on into brain[r] and D[r].

In terms of a PPP equivalent, call this ***S2E***, this input – as well as all proprioceptive, interoceptive and other input into D[r] – will be processed through inward propagation of prediction errors into the D[r] hierarchical processor over the interval α. This is the same interval over which it is envisaged SE1 will occur.

But note again that, as described for S1E, it is proposed that the hierarchical processor will set its precision weighting to place overwhelmingly dominant emphasis on outward flowing predictions in the first moments of α, but will shift those precision weightings ultimately to place overwhelmingly dominant emphasis on inward flowing prediction errors in the final moments of α.

It will therefore be the temporal *back end* of S2E – at the back end of the interval α – that most closely corresponds to the idea of action cycle step S2.

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[105] The proposal that such a shift in precision weightings will take place is well supported in the literature; for references see Chapter 7 in Clark, A. *Surfing Uncertainty: Prediction, Action and the Embodied Mind* Oxford University Press, New York, USA 2016. See also Section 9.4.3 below for a relevant discussion of perceptual rhythms.

[106] The potential subjective side of such a shift in precision weightings is explored in ibid. and have an intuitive parallel to ideas provided in the Essay with respect to the action cycle sequentially having within it a *reflective sequence* and an *expressive sequence*; pp82-83 Essay.

[107] Put more precisely, S1 was cast as a step where voluntary motor output, m, is expressed from D[r] into B[r]\D[r] and also, via B[r]\D[r], into W[r]\B[r].

[108] An example of a form of output other than motor output will be output leading to expression of hormones or other biochemicals into B[r] systems beyond D[r] (consistent with footnote 69).

Step 3: S3 was cast as an action cycle step where the sensory input received by D[r] at S2 is used to update the momentary state of {B[i] in W[i]} to make it fully contemporary, where at time t = a+1, that state will be $\{B[i] \text{ in } W[i]\}^{(a+1)}$.

In terms of a PPP equivalent, this state estimate will not occur as a discrete step but as an organic part – call this ***SE3*** – of the process of balancing outward propagating predictions with inward propagating errors. The relevant state estimate at t = a+1 will be the encoded in the $\Xi^{(a+1)}$ aspect of the recognition state $\{\Xi^{(a+1)} + \Xi^{(a+2)*}\}$ that will momentarily be achieved when all prediction errors entering and propagating inwards in the hierarchical processor are balanced to near zero. This balance will not be achieved until the very end of the interval α, as the system travels into the interval β and into recognition cycle step S5E, as described below.

Step 4: S4 was cast as the action cycle step where the predicted a priori state estimate made through S6 at t = a for t = a+1 – namely$\{B[i] \text{ in } W[i]\}^{(a+1)*}$ – is compared to the subsequently attained a posteriori state estimate $\{B[i] \text{ in } W[i]\}^{(a+1)}$ to obtain an error, $\{B[i] \text{ in } W[i]\}^{(a+1)E}$. (It was envisaged that $\{B[i] \text{ in } W[i]\}^{(a+1)*}$ would have been generated by applying the association matrix as a forward model to select which of all *potential* $\{B[i] \text{ in } W[i]\}^{(a+1)}$ would be on the best path to restore/maintain homeostasis.) [109]

In terms of the PPP, this error estimation process will not occur as a discrete step but will, like SE3, occur as an organic part – call this ***SE4*** – of the process taking place through the interval α of balancing downward propagating predictions with upward propagating prediction errors through to the very end of the interval α, as the system travels into the interval β and into recognition cycle step S5E.

Step 5: S5 was cast as an action cycle step where it was inter alia envisaged in *How is Free Will Possible?*[6] that:

> "… brain[r] uses $\{B[i] \text{ in } W[i]\}^{aE}$ to apply an enduring correction to the 'association matrix'. So S5 will be the step where the association matrix 'learns' to further minimize error between all future $\{B[i] \text{ in } W[i]\}^{n*}$ and $\{B[i] \text{ in } W[i]\}^{n}$, where the divergence found in each $\{B[i] \text{ in } W[i]\}^{nE}$ will be between the predictive model of B[r] in W[r] held in the association matrix and the reality of B[r] in W[r] as B[r] acts at the noumenal level."

In terms of the PPP, this enduring adjustment of the recognition and generative models will occur organically – along with SE3 and SE4, as part of the overall process from S1E through the interval α through into the *onset* of what will be defined as S5E (see below) – as the hierarchical processor progressively balances downward propagating predictions with upward propagating prediction errors to the point where all prediction errors are momentarily balanced to zero.

At this point, at the onset of S5E, the system will have progressively reached a point of having been able fully to estimate, and to 'learn from', $\Xi^{(a+1)E}$, where $\Xi^{(a+1)E} = \Xi^{(a+1)} \Delta \; \Xi^{(a+1)*}$ and $\Xi^{(a+1)E}$ reflects the error in prediction made at the previous S6E in terms of an error in the recognition state estimate. This will have exposed some degree of error in both the recognition model and the generative model inhering in the D[r] hierarchical processor, both of which will have been adjusted – i.e. both of which will have 'learnt' – due to such error through the interval α in the course of balancing predictions against errors.[110]

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[109] The time here, which is from S6 t = a to S4 t = a+1, is indexed one beat further forward than it was in the description of the action cycle provided in *How is Free Will Possible?* where it was indexed from S6 t = (a – 1) to t = a. There is no conceptual difference here. The change was made simply because it makes more sense for the explanatory purposes of the current note to start with S6 in recasting the action cycle into a recognition cycle with than it did in *How is Free Will Possible?* where description of the action cycle starts with S1.

[110] Ways this can occur are described in Section 2.1 of Ramstead, M.J.D. et al. (2020) A Tale of Two Densities: Active Inference is Enactive Inference *Adaptive Behaviour 28* pp225-239.

It is now proposed that a moment in the recognition cycle that can be called ***S5E*** will arise just ahead of time, t = a, right at the end point of the long interval α and into the onset of the short interval β right at the *threshold* at which a state estimate – i.e. a recognition state $\Xi = \{\Xi^a + \Xi^{(a+1)*}\}$ – will be resolved through the balancing of predictions against prediction errors as a result of operation of the D[r] hierarchical processor during *the preceding beat* of the recognition cycle, i.e. the beat running from t = (a – 1) to t = a.

The distinction between S5E and S6E will include that in going from S5E to S6E, through the span of the short interval β, the precision weightings in the D[r] hierarchical processor will shift rapidly from placing highly dominant weighting on errors to placing highly dominant weighting on predictions. This will be a shift from placing maximum effort on resolving out the recognition state $\{\Xi^a + \Xi^{(a+1)*}\}$, by rolling through maximum resolution of its a posteriori aspect, Ξ^a, into maximum resolution of its a priori aspect, $\Xi^{(a+1)*}$, and into placing maximum emphasis and effort through shifted precision weighting into expressing $\Xi^{(a+1)*}$ via active inference. In a sense, and put more broadly, this will be a shift in emphasis for the D[r] processor from 'looking backwards' to 'looking forwards', where S5E and S6E will occur virtually co-temporally, and where each can metaphorically be viewed as opposite sides of the same coin, with one side the backwards facing Ξ^a and the other the forward facing $\Xi^{(a+1)*}$.

9.4.2 Interim summary

Sections 9.3 and 9.4.1 above provide means to recast the illustrative concepts of an association matrix and of an action cycle in terms of concepts developed in the PPP. In these sections it has been proposed that the idea of an association matrix can be replaced with that of a recognition model entailing a generative model, and that the idea of an action cycle can be replaced with the idea of a recognition cycle.

Regarding the proposed recognition cycle, it can be seen that what was laid out in time as a sequence of six steps in the action cycle has been recast above into something more like a three step process running from S6E, starting at time t = a, through to S5E, completing at time t = a+1.

These three steps correspond to: (1) S6E, occurring through the end of the short interval β; flowing into (2) S1E, S2E, S3E and S4E, all occurring in a fully integrated way over the long interval α, culminating in (3) S5E, occurring at the start of the short interval β, then flowing into the next iteration of S6E.

S$_\beta$ To further simplify, the two 'steps' S5E and S6E can be viewed as a single continuous process, call this process S$_\beta$, taking place over the short interval β.

At the centre of this interval the hierarchical processing system in D[r] will pass through a moment at t = a where maximum balance is achieved between inward propagating errors and outward propagating predictions, yielding maximum resolution in the recognition state $\{\Xi^a + \Xi^{(a+1)*}\}$. Here, as the system travels out of α into β, it will be placing highly dominant precision weighting on errors until maximum resolution of $\{\Xi^a + \Xi^{(a+1)*}\}$ has been attained at t = a. Then, as it passes through t = a, the system will rapidly shift to placing highly dominant precision weighting on predictions as it travels out of β into the next α.

Here S$_\beta$ can be seen as a process that occurs around an inflection point at t = a in the D[r] hierarchical processor's strength of application of precision weighting – where this will move from highly dominant weighting on errors to highly dominant weighting on predictions – and where, as it passes through this inflection point – call this point ***i*** – it will in that moment achieve a maximally defined recognition state, $\{\Xi^a + \Xi^{(a+1)*}\}$. With this it is proposed that *immediately* ahead of t = a, maximum resolution of the a posteriori aspect of $\{\Xi^a + \Xi^{(a+1)*}\}$ – that is, of Ξ^a – will be attained, with this then undergoing an extremely rapid (virtually instant) evolution into maximum resolution of the a priori aspect of $\{\Xi^a + \Xi^{(a+1)*}\}$ – that is, of $\Xi^{(a+1)*}$ – *immediately* following t = a.

S_α Similarly, the four ‘steps’ S1E, S2E, S3E and S4E can be viewed as a single continuous process, call this S_α, taking place over the long interval α.

As the system travels out of the short interval β and into α, the hierarchical processor will place highly dominant precision weighting on outward propagating predictions. Then, as it travels through α it is envisaged that this precision weighting will shift – to swing across – until, as the system travels out of α into the onset of the next β, it will place highly dominant precision weighting on inward propagating errors.

In the course of this process the state of B[r] in W[r] will be moved by motor and other[108] output driven by ‘uncontested’ downward propagating predictions being expressed at the front end of α.

Then, as the system moves through α, and its precision weightings swing back to place increasing emphasis, and eventual dominance, on inward propagating errors, the system will, in passing from α into β, and then at t = a through *i*, attain an estimate based on that error input to D[r] – where this estimate is $\{\Xi^a + \Xi^{(a+1)*}\}$ – of the state and state trajectory that B[r] in W[r] should have arrived at as a result of that motor and other output.

9.4.3 Evolution of the recognition state

Figure 10 illustrates how it is proposed the recognition state will evolve over successive beats of the recognition cycle, as described in Sections 9.4.1 and 9.4.2 above.

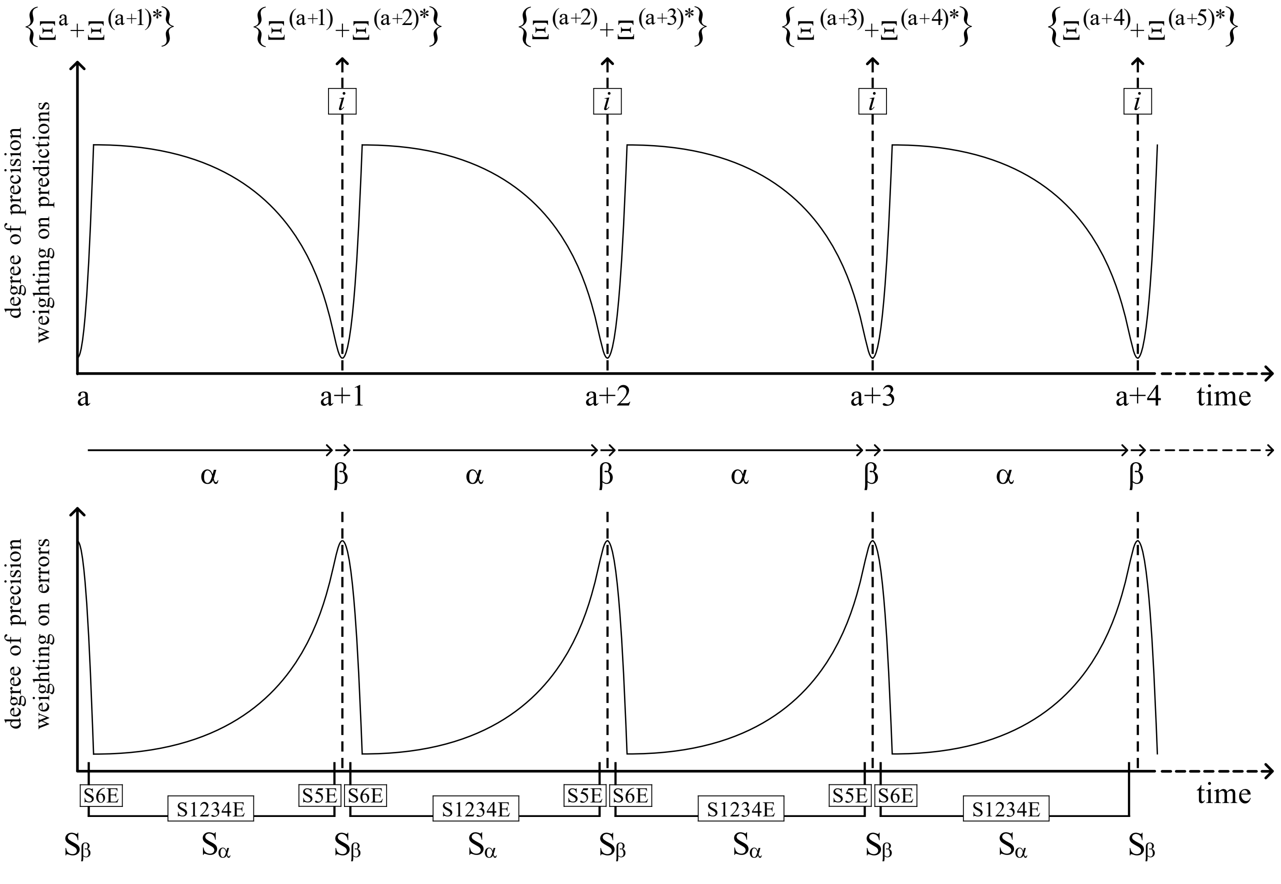

Figure 10

Figure 10 illustrates the proposed evolution of the recognition state, Ξ. The x-axis of each graph shows time in beats of the recognition cycle, starting at an arbitrary time, t = a. The arrows running between the graphs denote the time intervals α and β referred to in the text. The y-axes of each graph index the degree of precision weighting that the hierarchical processing system is placing on downward propagating predictions (top graph) and, reciprocally, on upward propagating prediction errors (bottom graph). *The shape the curves is notional*, and is intended only to give a broad sense of the shift in precision weightings expected to take place as the system moves through each beat of recognition cycle. The recognition states serially attained as the system passes through each inflexion point *i* (see text) are shown as a time ordered sequence across the top of the figure, starting with $\{\Xi^a + \Xi^{(a+1)*}\}$ at time t = a. It is proposed below that the *beat frequency* of the recognition cycle is ~4Hz.

9.4.4 The frequency of the recognition cycle

Means of estimating the beat frequency of the action cycle discussed in the note *How is Free Will Possible?*[111] can also be applied to the recognition cycle. For example, reaction time experiments[112] can be expected roughly to estimate the interval between (1), the moment an incoming cueing/error signal (the prompt, perhaps a loud beep) enters the hierarchical processor in D[r] and (2), the moment a specific motor output signal (the response, perhaps a button press) exits the hierarchical processor plus (3), the time taken by B[r] systems outside D[r] to process these signals from and into W[r]\B[r].

Overall recognition cycle steps will include inward hierarchical processing of the prompt – through S_α – into resolution of a recognition state encoding the prompt – at S5E of S_β – into formulation of a response prediction – at S6E of S_β – into expression through active inference of a motor output driven by that prediction during the subsequent S_α.

In simple reaction time experiments[112] the average time for a person to express motor output in response to a visual prompt is ~225 ± 50 msec.[113] This gives an estimate of the beat frequency of the recognition cycle as ~4Hz.

Data across other relevant experiments gives a complex picture.[114] Even so, there is strong evidence to show that – at a general level – brain[r] systems process sensory inputs and integrate these with motor outputs through rhythmic processes which exhibit higher frequencies for component, e.g. unimodal processes – such as sampling/processing visual (~7–10 Hz)[115] or tactile (~8–20Hz)[115,116] inputs – but which, when integrated with expression of motor output, exhibit an overall frequency of ~4Hz.[117] These findings provide a second means of arriving at an estimate of ~4Hz for the frequency of the recognition cycle.

In the PPP it is proposed that application of attention to sensory stimuli entails strong relative weighting on incoming cueing signals by the hierarchical processor. In terms of the recognition cycle, as it has been described in immediately preceding sections, and illustrated in Fig. 10, application of attention is expected to trough at the front end of S_α – as motor output is expressed through active inference – and peak towards the back end of S_α as the system works to resolve a new state estimate Ξ. This should lead to a rhythm in attention of roughly one beat of the recognition cycle.

Consistent with this expectation there is strong experimental evidence to suggest that attention is rhythmic. For example, for visual attention several studies indicate a rhythm of ~7Hz while others indicate a rhythm of ~3–4Hz.[118] Importantly, the second rhythm seems associated with alternation between an attentional peak coupled to a motor output process that entails an attentional trough,[119] as anticipated for operation of the recognition cycle.[120] These findings provide a third means of arriving at an estimate of ~4Hz for the frequency of the recognition cycle.

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[111] See in particular Appendix 1 to *How is Free Will Possible?* at https://teledyne.com/free_will.pdf.

[112] For example, see https://humanbenchmark.com/tests/reactiontime.

[113] Seeking greater precision from this type of experiment may be futile since all manner of variables could come into play. Moreover, even for a single experimental subject, the frequency of the recognition cycle might vary with circumstances (see footnote 120 below).

[114] See VanRullen, R. (2016). Perceptual Cycles. *Trends in Cognitive Sciences 20*, 723-735 and references therein.

[115] Ibid; and Chota, S. & VanRullen, R. (2019) Visual Entrainment at 10 Hz Causes Periodic Modulation of the Flash Lag Illusion *Frontiers in Neuroscience 13* Article 232.

[116] See Baumgarten et. al (2017) Subliminal Stimuli Modulate Somatosensory Perception Rhythmically and Provide Evidence for Discrete Perception *Scientific Reports* 7:43937 DOI: 10.1038/srep43937.

[117] See Benedetto, A. et. al (2019) The Common Rhythm of Action and Perception. *Journal of Cognitive Neuroscience 32*, 187-200.

[118] See in particular Box 2 in VanRullen, R. (2016). Perceptual Cycles. *Trends in Cognitive Sciences 20*, 723-735.

[119] See in particular Fiebelkorn, I.C. & Kastner, S.A. (2019) A Rhythmic Theory of Attention *Trends in Cognitive Sciences 23* 87-101, Hogendoorn, H. (2016) Voluntary Saccadic Eye Movements Ride the Attentional Rhythm *Journal of Cognitive Neuroscience 28*, 1625-35 and analysis and references in Benedetto, A. et al. (2019) The Common Rhythm of Action and Perception. *Journal of Cognitive Neuroscience 32*, 187-200.

[120] It is tempting here to speculate that the ~7Hz rate may indicate a rate for the recognition cycle that applies in situations where maintenance of attention to a single specific unimodal sensation is not coupled to any motor output – i.e. where action is virtually suspended along with most of the load of multimodal integration. This might lead to less processing time for both the front (motor output) and back (multimodal integration of sensory input) ends of S_β. If so, this would suggest that for Fig.10 both the shape of the curve, and the duration of the recognition cycle, could vary with circumstances, leading to a recognition cycle duration moving around within the theta-band range but averaging out to a frequency of ~ 4Hz across the range of possible processing loads.

9.4.5 Consciousness in relation to the recognition cycle

Based on ideas first developed in the Essay[1] and then circulated and discussed through the moderated mailing list PSYCHE-D,[121] it was proposed in the note *How is Free Will Possible?*[6] (HFWP) that:

- "A subjective, moment-by-moment sense of self-in-the-world may be generated in the course of a process in brain[r] which at a rate of ~4Hz realigns a person's B[i] in W[i] (the physical world as they perceive it) to update it back to high fidelity with their B[r] in W[r] (the physical world as they act upon it)."

This conjecture was limited to a person's subjective sense of being a physical self – i.e. of being a physical body – existing within, interacting with, and operating on a physical world. A person's perceptions of *non-spatial* phenomena such as emotions were not addressed.

In the current note it is proposed that the time evolution of the totality of a person's phenomenal experience will, through operation of the recognition cycle, be reflected in the series:

$$\{\Xi^{a} + \Xi^{(a+1)*}\},\ \{\Xi^{(a+1)} + \Xi^{(a+2)*}\},\ \{\Xi^{(a+2)} + \Xi^{(a+3)*}\}\ , \ldots ,\ \{\Xi^{(a+n)} + \Xi^{(a+n+1)*}\} \qquad \text{R1}$$

consistent with the previously stated proposal that:

- at any given moment the recognition state, Ξ, will provide for the overall contents of a person's phenomenal experience of reality – i.e. what they are subjectively experiencing, physically, emotionally, and in all other ways to be real – in that moment.[122]

But if – as for HFWP and its sequel *The Construction of Phenomenal Time*[123] (TCPT) – only the physical – i.e. the spatially distributed – aspects of a person's phenomenal experience are taken into account, the series under consideration will be the sub-series of R1 shown below as R2:

$$\{\{B[i] \text{ in } W[i]\}^{a} + \{B[i] \text{ in } W[i]\}^{(a+1)*}\},\ \{\{B[i] \text{ in } W[i]\}^{(a+1)} + \{B[i] \text{ in } W[i]\}^{(a+2)*}\}, \ldots ,\ \{\{B[i] \text{ in } W[i]\}^{(a+n)} + \{B[i] \text{ in } W[i]\}^{(a+n+1)*}\} \qquad \text{R2}$$

consistent with the relationship between Ξ and {B[i] in W[i]} defined at E4.[124]

This way of viewing the time evolution of {B[i] in W[i]} as the time evolution of a substate of Ξ does not materially affect any of the proposals made in HFWP or TCPT, it simply places those proposals into a context, which is that of the moment-by-moment generation of a person's subjective sense of being a *physical* self in a *physical* world, while leaving any account of their emotional and other 'non-physical' experience to one side.[125]

On this basis, the key idea expressed in HFWP – then used in TCPT to develop insights into the nature of phenomenal time – can be recast to bring it into accord with the ideas proposed in this note in relation to application of the PPP, as follows:

1) Once the D[r] hierarchical processor becomes sufficiently capable, through experience-driven honing of its generative and recognition models, the degree of predictive error arising as it moves through any given beat of the recognition cycle into the next beat will – for all of the practical operational purposes of a person's physical interaction with the world – become negligible for long periods of time.[126] In other words, for the duration of such periods active inference will work with sufficient precision that for any beat of the recognition cycle, at any time t = (a+n) within such a period, the Ξ aspect $\{B[i] \text{ in } W[i]\}^{(a+n)*}$ will *with all but inconsequentially small degrees of error* predict – and will thereby 'seamlessly' evolve into – $\{B[i] \text{ in } W[i]\}^{(a+n)}$.[127]

2) This will enable information processing systems within D[r] to sustain an inference that at any given moment the evolving states of {B[i] in W[i]} can be put into identity with the evolving states of {B[r] in W[r]}, an inference that those systems will be able serially inductively to maintain each time motor output from D[r] – arising through the operation of active inference and expressed at the *noumenal level* of {B[r] in W[r]} through action of B[r] – delivers at each S_β during interval β of the recognition cycle precisely that predicted state of {B[i] in W[i]} that the D[r] hierarchical processor will have just used to drive that motor output via S_α during the *preceding* interval α of the recognition cycle.

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[121] See https://teledyne.com/Psyche_D.pdf and https://teledyne.com/free_will.pdf.
[122] See the concluding paragraph of Section 9.3.1.
[123] See https://teledyne.com/time.pdf.
[124] See Section 9.3.2, noting that there is no difference in meaning between the expressions B[i] in W[i] and {B[i] in W[i]}.
[125] Such non-physical experience – including mood and emotional experience – is explored in detail in Working Note A – Part 3.
[126] In relation to the execution of physical coordination and actions in familiar environments, these intervals may be of the order of hours and tens of thousands of iterations of the recognition cycle.
[127] Note that this is fully parallel to the idea expressed in TCPT as $\{B[i] \text{ in } W[i]\}^{(a+n)*} \equiv \{B[i] \text{ in } W[i]\}^{(a+n)}$.

3) Sustaining an inference by such means that at any given moment {B[i] in W[i]} is in identity with {B[r] in W[r]} will entail sustaining an inference that at any given moment B[i] is in identity with B[r].

4) This will in turn enable information processing systems within D[r] serially to infer that D[r] is itself – by virtue of its agency in generating the motor output referred to at (2) above – situated ‘within’ B[i].

5) In this way D[r] will be able to represent its own physical agency – or ‘physical self’ – to itself as being that entity[i] within a B[i] that drives the motions of that B[i] as it moves within, and interacts with, a W[i]\B[i]. Thus D[r] can come to represent itself to itself at a phenomenal level as being housed within a B[i] and as driving – and in that sense as ‘being’, and ‘being in’ a B[i] – as it moves within, and interacts with, a W[i]\B[i].[128]

6) On this basis, and given (2) above, it is proposed that a series of ‘subjective moments’ will arise at around four times a second at each S_β of the ongoing recognition cycle, when D[r] systems reaffirm that {B[i] in W[i]}^{n*} has, for all of their ‘intents and purposes’ been a virtually exact prediction of {B[i] in W[i]}^{n}.

    - Successive ‘subjective moments’ may then, as they arise through successive beats of the recognition cycle, merge into an experienced continuous stream of subjective self-realization – that is, an experienced continuous stream of *consciousness* – by D[r] of being a physical self-in-the-world in the form of being a {B[i] in W[i]}.

Point 6 above is a virtual paraphrasing of the concluding paragraph of the section entitled, “Consciousness in relation to the Action Cycle” in HFWP. Accordingly, for a fuller account of the key idea being described above, readers are directed to that section of HFWP while being asked fully to bear in mind that it is now being proposed that the idea of a recognition cycle – rather than that of an action cycle – will form the basis of the processes being described in HFWP and, with this, that the proposed recognition cycle process S_β must be substituted for action cycle step S5.

The ideas expressed in TCTP can also be understood in terms of the PPP concordant ideas presented in the current note. But this again requires, as for HFWP, that the idea of a recognition cycle and its underpinnings be substituted for that of an action cycle and, with this, that the proposed recognition cycle process S_β be substituted for action cycle step S5.

Interim foreword to Parts 2 and 3

The foregoing Part 1 of Working Note A is intended to recast in terms consistent with predictive processing approaches the highly speculative conceptual frameworks presented in its predecessors, the Essay, The Introductory Summary, *How is Free Will Possible?* and *The Construction of Phenomenal Time*.

To achieve this, new ideas and conceptual frameworks have been developed. These are once again highly speculative. Parts 2 and 3 of Working Note A use these new ideas and frameworks to probe and conjecture further into the nature of human subjective experience and into how, in its various forms, such experience may be generated.

More specifically, Part 2 addresses in more detail the means by which D[r] can come to represent its own physical agency – or ‘physical self’ – to itself as being an entity[i] ‘within’ B[i] and, with this, how D[r] can come subjectively to experience itself as operating from the centre of what can be called *phenomenal space*; where this is the three dimensional space we each perceive ourselves to live in and look out into, and which we each perceive to ‘contain’ phenomenal objects in relative motion and variously affected by the advent and application of physical forces.[129]

Part 3 addresses imagination, memory, decision-making and to an extent, emotion and mood.

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[128] This proposal is examined at length in Working Note A – Part 2.

[129] Notably, the ideas described above in relation to Ξ space, movement of a recognition state through Ξ space, the proposal made in Section 9.3.1 that at any given moment such a recognition state will provide for the overall contents of a person’s phenomenal experience of reality, as well as the further detailed ideas about *phenomenal space* that are developed in Working Note A – Part 2, seem closely to align with the conceptual framework proposed in Fingelkurts, A.A. et al. (2010) Natural World Physical, Brain Operational, and Mind Phenomenal Space-Time *Physics of Life Reviews 7* 195-249. This conceptual framework proposes what Fingelkurts et al. call (1) a ‘brain-operational space-time’ that serves to connect (2) ‘physical space-time reality’ to (3) ‘mind subjective space-time’. If, as proposed here, a recognition state moves through a Ξ space over time, it will form a line through a Ξ space-time, where the idea of a Ξ space-time can be aligned with the idea of a ‘brain-operational space-time’. Similarly, (2) and (3) respectively can be aligned with the ‘noumenal space-time’ of W[r] and with a person’s phenomenal space-time of W[i], where these two ‘worlds’ can be considered to be ‘connected’ through expression in the person’s brain[r] of Ξ states in Ξ space-time.