Chapter 6. Conclusion

We have shown that by using ART (EFT) we have discovered a minimal neural network anatomy that can generate equivalence relation. The model incorporates determined proxy functions for PIT and TRJ. Based on MMA, the build process led to the identification of ten postulates which were sufficient for the minimal anatomy to generate equivalence relations. The property set therefore contains these postulates:

- Comparation network exhibits reflexive and symmetric relations,
- The act of comparation involves a minimum of two inputs,
- The act compares dynamically generated axiomatic features,
- The act is judged expedient if it is not contrary to the categorical imperative,
- Comparation process comprises interacting sub-process for respective comparands,
- TRJ judges the process,
- Comparands are determined to show relationship if it is not contrary to the categorical imperative,
- The comparation process does not recall past actions,
- PIT determines the content for comparation, and
- Non-expediency of the comparation process results in PIT short-circuiting the contents.

The dynamics of this particular neural network shows that if a relationship between patterns is found, then the relationship is both reflexive and symmetric. The patterns constitute a candidate set. It is further shown that if a candidate set of patterns satisfies transitivity, then that set forms elements of an equivalence class. Therefore the neural network developed here performs comparation. It also demonstrated capability of experiencing absence of transitivity. For instance, pattern-combos {A, C} and {C, D} show relationship but not for {A, D}. In other words, the difference (in M-outputs) for {A, C} and {C, D} is smaller than Weber and Fechner's 'just noticeable difference'. But difference for {A, D} is larger and hence noticeably different.

The network also makes the prediction that, all pattern-combos will demonstrate relationship if the patterns are placed on a larger retinal-map size. This prediction of loss of sharpness of discriminating patterns with increasing retinal-map size is functionally similar to fonts 'a' and 'e' appearing indistinguishable at a distance. Thus, the difference (in M-outputs) is always smaller than the 'just noticeable difference'.

Therefore, the provided demonstrations show that generation of equivalence relation by means of minimal network (Fig.5.24) is possible. For the realization of complete synthesis of objective equivalence, the overall synthesis of judgmentation is involved.

The demonstrated results are behaviors that are emergent network properties. Nothing in the design of the network explicitly inserted the relationship vs. no relationship characteristics. In other words, no a priori objective criterion for defining features was introduced. Thus, the reported experiments are the first-ever demonstration that ART is capable of self-determining feature sets.

The model therefore does not violate epistemological law of mental physics, which holds that human beings are born with no objective knowledge a priori whatsoever. The results of this project is the first time any neural network system has demonstrated this capacity, and this is an original contribution to knowledge.

Topics for future research

Following each simulation (in chapter 5), the determined outcome (relationship or no) was analyzed for identifying the 'feature' based on the possible metric, diff-pc (difference-percentage). This metric was introduced on the premise that, the number of non-zero pixels plays an important role on the network's self-determining feature sets. Thus, diff-pc = diff-fact • ppx where, diff-fact • U = U – L (upper, U and lower, L CPV magnitudes of the two patterns) and ppx is the parameter corresponding to the difference of number of non-zero pixels. The ppx value is empirically determined. Thus, diff-pc as a metric for possible explanation of what the network considers as 'features' is based on empirical observations. In other words, diff-pc does not guarantee to explain features because it may not hold as a metric for other test-cases (not performed here). Hence, identifying the metric that would be applicable for all variants of input patterns is a topic for future research.

The input patterns (pre-normalized) for all test-cases employed in this project is binary. Binary inputs were chosen for its simplicity and convenience. Thus, implementing input with noise and real-numbered value is a topic for future research. It should however be noted that ART networks demonstrate NICE or noise-induced contrast enhancement with noisy inputs [Wells, 2010]. This NICE behavior is undesirable and can be avoided by changing the quenching threshold. This can be done by making the distance between the lower ($u^{(1)}$) and upper ($u^{(2)}$) parameters of the activation shape function smaller.

Recall that the weights (instars, W and outstars, Z) of the neural network are adaptive. The weights adapt from their respective initial values. For the next pattern-combo the weights begin adapting again from re-initialized values (not from their respective adapted weight values). This is because comparation does not have memory since the OB has no conscious experience of acts in synthesis of sensibility. This property may be incorporated (but without re-initialization for every succeeding pattern-combo) in elastic weights. The elastic weights are so called because the adapted weights decay after the input (stimulus) to the network is removed, and hence has a short-term memory like effect. This elastic function was studied by Grossberg in a simple dipole-network [Grossberg, 1972b] and has also been applied in other network [Sharma, 2011]. The incorporation of elastic weight is hence another research question.

The aim for the current project was to discover an EFT based minimal neural network to generate equivalence relations for the function of comparation. Thus, the main-body of the discovered minimal anatomy (Fig. 5.24) employs ART based neural network for comparation and proxy functions for noetic processes; TRJ and PIT. Thus, another topic for future research is to design EFT based neural network for the proxy functions.

Piaget's study of intellectual development of the study discovered that the earliest cognitive operation grows out of handling things. The operations can be divided precisely into three categories which correspond to Bourbaki's 'mother structures'; algebraic, order and topological structures. Piaget says,

> "these facts (that the earliest cognitive operations in intellectual development of the child can be precisely divided into categories; of "reversibility", of "reciprocity" or of "continuity" and of "separation") suggests that the mother (Bourbaki's) structures correspond to coordinations that are necessary to all intellectual activity, though they are very elementary, even rudimentary, and quite

> lacking in generality in the earliest stages of intellectual development. It would, in fact, not be difficult to show that in these very early stages intellectual operations grow directly out of sensory-motor coordinations and that intentional sensory-motor acts *cannot* be understood apart from structures" [Piaget, 1970].

The psycho-functional abilities at the sensory-motor stage begin with mathematical sensibility. This is the ability of making parástase structured in spatio-temporal form by re-presentations of data of senses to form intuitions and affective perceptions. This is done by Verstandes-Actus (acts of understanding).

Comparation is the first in the three-step process for logical synthesis of the Verstandes-Actus. Reflexion is the second process. Mathematically, just as the act of comparation correspond to generating equivalence relations, the act of reflexion is to generating congruence relations. Thus, with respect to the research aim to develop EFT neural networks based on mental physics, minimal neural network anatomy for reflexion is the next topic for future research.

This project provides a theoretical foundation for the noetic model and hence building on this we can continue our journey in understanding "how brain-mind works" Though the current modelling scale is more towards the psychological end, the findings from such research must correspond to empirical findings from both psychological and biological studies. Thus the collaborative interdisciplinary activities play a critical role in developing such models.