A Model for Attention-Driven Judgements in Type Theory with Records

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Recently, Type Theory with Records (TTR, (Cooper, 2012; Cooper et al., 2014)) has been proposed as a formal representational framework and a semantic model for embodied agents participating in situated dialogues (Dobnik et al., 2014). Although TTR has many potential advantages as a semantic model for embodied agents, one problem it faces is the combinatorial explosion of types that is implicit in the framework and is due the fact that new types can be created or learned by an agent dynamically. Types are *intensional* which means that a given situation in the world may be assigned more than one record type. A sensory reading of a particular situation in the world involving spatial arrangement of objects may be assigned several record types of spatial relations simultaneously, for example *Left*, *Near*, *At*, *Behind*, etc. TTR also incorporates the notion of *sub-typing* which allows comparison of types. A situation judged as being of a particular record type may also be judged of potentially infinite number of its sub-types: a situation of type *Table-Left-Chair* is also of type *Table* and *Left*, etc.

The rich type system of TTR gives us a lot of flexibility in modelling natural language semantics. However, unfortunately, the flexibility with which types are assigned to records of situations and which is also required by modelling natural language and human cognition comes with a computational cost. Since each type assignment involves a binary judgement (something is of a type T or not) for each record of situation an agent having an inventory of n types can make n assignments with 2^n possible outcomes, hence for $n = 3$, $2^3 = 8$: $\{\}$, $\{T_1\}$, $\{T_2\}$, $\{T_3\}$, $\{T_1, T_2\}$, $\{T_1, T_3\}$, $\{T_2, T_3\}$ and $\{T_1, T_2, T_3\}$. Such combinatorial explosions of possible outcomes of type assignments or judgements present a great difficulty for an agent that is trying to learn what types to assign to a situation from the linguistic behaviour of another agent.

In this presentation we argue that agents need (i) a judgement control mechanism and (ii) a method for organising their type inventory. For (i) we propose the Load Theory of selective attention and cognitive control (Lavie et al., 2004) to be a suitable candidate. This model of attention distinguishes between two mechanisms of selective attention: *perceptual selection* and *cognitive control*. Perceptual selection is a mechanism that excludes the perception of task irrelevant distractors under situations of high perceptual load; however, in situations of low perceptual load any spare capacity will spill over to the perception of distractor objects. The cognitive control mechanism is an active process that reduces the interference from perceived distractors on task response. It does so by actively maintaining the processing prioritisation of task relevant stimuli within the set of perceived stimuli. It follows, that agents make judgements of several different kinds which we call (i) pre-attentive, (ii) task induced, and (iii) context induced judgements. Pre-attentive judgements (the segmentation of a visual scene into entities and background) are controlled by the perceptual selection mechanism of Load Theory. Task induced and context induced judgements require conscious attention. As such, they are controlled by the cognitive control mechanisms of Load Theory. These judgements are applied to types that are in working memory and result in new types being introduced to working memory. Task induced and context induced judgements are primed by the types associated (via memory) with the current activities that the agent is currently engaged in (making a cup of tea) and their physical location (the plate beside the kettle is very hot).

For the requirement (ii) above we propose that agents organise their type inventory into subsets or bundles of types that are represented as cognitive states. These can be thought of as sensitivities towards certain objects, events, and situations where the mapping between states and entities has been learned from experience. More than one cognitive state may be active at any moment. We propose that a (probabilistic) POMDP framework (Partially Observable Markov Decision Processes, (Kaelbling et al., 1998)) provides a useful mathematical model for implementations of a control structure for judgements in an embodied agent/robot using TTR that has learned or been given by its designer a number of cognitive states. We map the problem of controlling judgements within TTR to a POMDP control problem as follows: (i) the cognitive states of the agent are mapped to the states in the belief state of the POMDP, (ii) the priming of an agent to observe certain types is mapped to the action specified for the current belief state by the policy driven by the attention mechanisms, (iii) the types an agent actually perceives and processes are mapped to the observations the agent receives from its sensors, (iv) the benefits to the agent of being primed to comprehend the world are mapped to the reward function.

Overall, we hope that the account presented here provides a move towards linking the formal semantic representation of TTR with cognitive attentional mechanisms.

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