Sequencing of information versus interfacing between processing levels

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1 Control and "control"

In his inspiring article, Frawley argues that a distinction should be made between representation and control in cognition. We would like to contribute to the further development of these ideas by penetrating the concept of cognitive computation from a cognitive–neuroscience perspective.

Taking this perspective, two varieties of cognitive control can be discerned in what Frawley refers to as 'unit–level control' in cognition: One involving the sequencing and coordination of linguistic output, and one constituting interface management across levels of processing. On a first blush, both of these may seem to constitute meta–level control mechanisms in cognition, and both may seem to be conceptually and computationally distinct from object–level processing of linguistic representations, such as phonemes and lexical units.

Contrary to this intuitive distinction, interfacing across processing levels in the brain is computationally inseparable from the processing of information "within" processing levels. In contrast, the sequencing and coordination of information, for example, during the production of a linguistic utterance, poses a qualitatively distinct computational problem in the cognitive system. Hence, while the first type of control outlined by Frawley would in a sense correspond to the concept of control in computers, the second type of "control", referred to heavily in Frawley's treatment of linguistic impairments, seems indistinguishable from the processing of cognitive "representation".

2 Computer versus brain

In a von Neuman–style computer, CPU–time and primary memory must be shared between processes. Processes and sub–processes are allowed access to these resources one at a time. The order in which pieces of a computer program are supposed to be loaded into memory and executed constitutes the program's control structure. Given that computer programs can only be processed piece–by–piece, it becomes important that segments of code that are optimally processed together are also located close to each other in the program code. In addition, as only one piece of code can be processed at a time, there is a need to communicate partial computational results between those parts of the code that are being processed and other, inactive pieces of code. These and other, more or less practical considerations have given rise to modularity, encapsulation and parameter passing in computer programs.

In contrast to the serial computation realized in computers, the human brain implements hybrid computation. In general, information can be processed in parallel, without resource sharing, and hence without a need for monitoring and control, according to a computational scheme that can be described as *processing in cascade* (McClelland, 1979; McClelland and Rumelhart, 1981). For reasons described below, cognitive processing which is initially parallel will have to be sequenced before final output can be produced.

2.1 Interfacing between levels of processing cannot be separated from computation in cognition

Computational resources that is, neurons and synaptic connections, are in abundance in the brain. On the other hand, synaptic connections are relatively slow: sometimes on the order of milliseconds. Cognitive computation is speeded up by parallel processing and instantaneous pipe–lining of information between lower and higher levels of processing.

Somewhat simplified, computation in the human brain is organized into massively interconnected levels of processing. Considering the simplicity of individual neurons, computation is defined by the complex arrangement of connections between neighboring levels of processing. The interdependence between levels of processing is further enhanced by the fact that connections are mostly reciprocal. As a consequence, if the interface between two levels of processing is damaged processing at these levels will be most profoundly affected.

Processing in the cognitive system is continuous, and is inherently defined by the connection structure between processing levels. Information is processed in cascade: Any change in the continuous inflow of information is registered and instantaneously passed on to neighboring levels of processing. In a reciprocally interconnected system, this gives rise to an incessant back-and-forth communication across processing levels of whatever information is available at any given moment in time. Hence, higher level processes will have access to a rudimentary flow of bottom–up information before this information has been fully processed at lower levels, and vice versa.

2.2 Control realized as sequencing in cognition

Although the human wetware can handle massively parallel processing, the human body imposes a severe limitation on the responses that can be executed: We have one pair of eyes, two hands, one mouth, and so on. For this reason, somewhere along processing from perceptual input to motor output, the parallel flow of information must be sequenced. In other words, a series of choices has to be made regarding which part of information should be used for the production of output.

The sequence of information, which on a conscious level is obtained by focusing, defocusing, and moving *selective attention* between relevant pieces of information (Kovordányi, 1999, 2000), could be seen to correspond, loosely speaking, to pieces of code that are chosen, loaded into primary memory, and executed in a computer. Sequencing of information could thus be conceived as an overarching, meta–level control mechanism in cognition.

A problem that is inherent to sequencing is how to coordinate information across separate slots in the sequence. An important point is that this problem is intrinsically lateral that is, occurs within a representational level, and may thus rely on cognitive mechanisms which can be dissociated from those involved in the vertical interfacing between representational levels.

3 Implications for language processing

In light of the above analysis, language production seems to involve two fundamentally distinct mechanisms. The first of these consists of the evoking of linguistic representations that is, selecting the *content* that will be communicated. The second mechanism comprises the *arrangement* of this content according to 'domain–specific' rules of sequencing.

Note that the distinction between these two mechanisms is computational rather than implementational, and need not be reflected in the neural substrate that underlies language processing. Moreover, these computational components need not be language specific. For example, sequencing disorders in language production could be related to a general deficit in focusing or refocusing selective attention, an inability to form higher–level intentions, or simply a difficulty to plan and follow–up a sequence of response actions.

Given a processing–in–cascade framework for cognition, parallel evoking of linguistic representations and serial sequencing can go on simultaneously, and on multiple levels of processing. Hence, for example, linguistic representations can be evoked in parallel and arranged into corresponding sequences of words, morphemes, and phonemes simultaneously at multiple levels of processing. Correspondence between super– and sub–categories of linguistic representations across these levels is established through reciprocal interaction between levels of processing. We see an important distinction between the previously described problem of lateral coordination across a sequence and this vertical establishing of correspondences across 'linguistic domains'.

On the one hand, the vertical establishing of a correspondence across linguistic domains is computationally intertwined with linguistic processing. For example, if interaction between the syntactic and morphological levels is impaired, this can profoundly affect subjects' ability to process both morphological and syntactic structures, and can show up as a fundamental inability to produce syntactically and morphologically correct expressions.

On the other hand, a deficit in lateral coordination during sequencing may be general and concern cognition as a whole. During linguistic processing, it ought to result in an inability to carry over information from one part of an expression to another. As an example, the disadvantage that Williams children have on agreement tasks in French may reflect a basic inability to coordinate information laterally between syntactic elements.

3.1 References

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