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A computational model simulating human performance in the Traveling Salesperson Task

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Background

Planning depicts the skill of producing mental representations of the future behavior prior to action and sequential reasoning about the consequences of acting, in order to properly choose among the possible courses of action. The Traveling Salesperson Problem (TSP) is a useful paradigm in order to investigate planning, because participants are required to generate a strategy in order to optimize the pathway (MacGregor et al., 2000). In the TSP, given a set of n interconnected towns represented by nodes on a graph, subjects have to find an itinerary while visiting each town exactly once and then returning to the starting town, covering the shortest distance. TSP essentially involves visuo-spatial planning: participants try to optimize the performance while moving into a spatially constrained environment. In comparison with other planning tasks, the TSP requires a stronger interaction between central and peripheral processes: visual, attentive and motor factors play a fundamental role, in addition to reasoning, in determining the final behavior.

This research uses the open version of the TSP task (Hirtle and Gärling 1992), in which the start and end points are fixed. Among the other, three distinct spatially-based heuristics were considered in the solution of the open TSP. The first heuristic (Barr and Feigenbaum 1981) is the Nearest Neighbour (NNH): each location is chosen on the basis of the local minimum distance from the actual location. The other two Direction heuristics (DH: Basso 2005) come from an evolution of the Zig-Zag heuristic described in the open TSP (Hirtle and Gärling 1992): starting from a location placed on a border, the subject reaches the next locations following one of the main spatial axes (horizontal or vertical) and a direction (respectively: up/down, or left/right). In our study the starting point was always located in the upper left corner; accordingly, the heuristics have been labeled as Direction Right (for horizontal heuristic) and Direction Down (for vertical heuristic).

An interesting finding concerns the interaction between heuristics: participants often show to change heuristic during the execution of the task (Basso et al. 2001). These results confirm that subjects operate a continuous monitoring and flexibly adapt their behavior to the requirements of the task/environment, as pointed out by Hayes-Roth and Hayes-Roth (1979).

From a neuroanatomical point of view, the substrates of planning skills are located in frontal areas: frontal traumatic brain injured patients (fTBI, Basso et al. 2001) and healthy subjects under repetitive transcranial magnetic stimulation (rTMS: Basso et al. 2006) over the frontal lobes showed a significant reduction in the number of heuristic changes which are usually performed during the execution of the task.

The model

This research is aimed to develop a computational model simulating the perceptual and cognitive human processing involved in the solution of the TSP.

The computational model is composed by three interconnected modules (fig. 1: Cutini et al. 2005), with a broad hierarchical organization and feedback connections, that loosely simulate the occipito-parieto-

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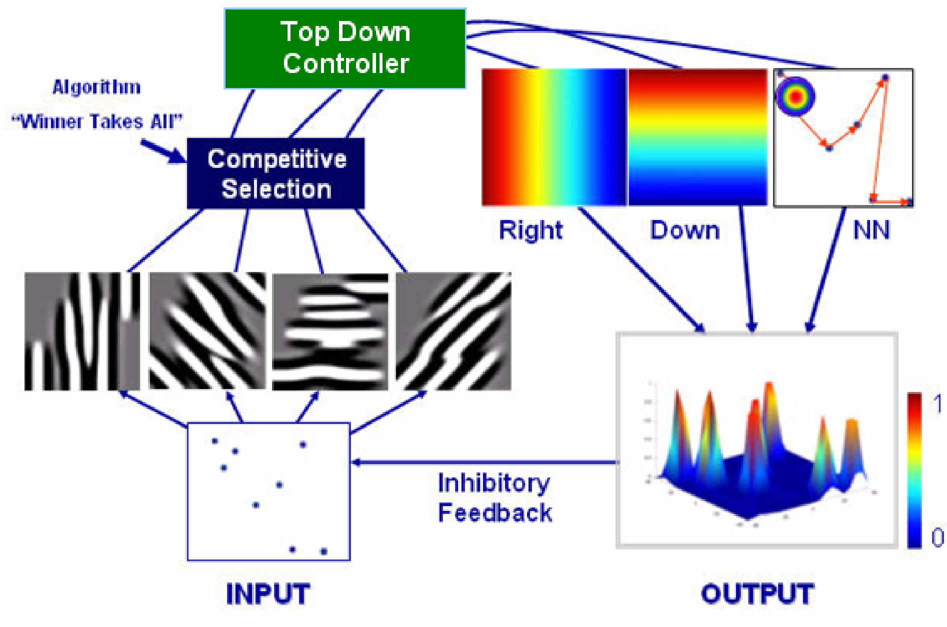

Fig. 1. The architecture of the model.

frontal circuit involved in the TSP task. These components comprise: 1) a visual module, in which the input pattern is processed by Gabor filters to simulate the processes responsible of perceptual grouping; 2) a competitive selection module that simulates the internal dynamics for the choice of the heuristic; 3) a motor map, based on population codes, that executes the pathway at the spatial level. At the end of each step, the units in the motor map corresponding to the visited city are inhibited and the activation of the same city in the input pattern is reduced via inhibitory feedback loops. This reduction allows a change of heuristic: indeed, the visual input is processed again in the visual module and, whenever a different heuristic emerges from the competitive selection, the Top Down Controller (TDC) inhibits the previously selected heuristic to foster the new heuristic. This process takes place at every single step, therefore heuristics can be changed several times during the execution of a single path.

Methods

The performance of the computational model has been compared with the behavioral data of the experiments based on the TSP variant. We evaluated the heuristics considering the relationships among the cities: the heuristic used to move from a city to another one was judged on the basis of the distance between that city and the other cities not yet visited. At each step, we determined the horizontally closest city, the vertically closest city and the absolute closest city, with respect to the last visited city, thus obtaining a precise description of the heuristics used by the model.
Ten different performances of the normal model were obtained by introducing a gaussian noise (mean=0, variance=0.05) at every step of the competitive dynamic in the TDC, while ten lesions to the TDC have been simulated by decreasing (10% up to 70%) its capacity to reset the competitive selection module.
When a switch between heuristics was present, the resulting strategy was labeled as "flexible"; conversely, the strategy was labeled as "rigid". Each pathway executed by the model has been compared for the frequencies of errand-lists and types of strategy with the pathways produced by the human participants in each corresponding pattern (data provided by Basso et al. 2001).

Results

In the skilled performance, the results demonstrated that the pathways chosen by the model were often among the most frequently produced ones by healthy adults. In particular, in 50% of patterns, the pathway chosen by the model was the most frequently executed by the human participants.
A Chi-square analysis of the skilled performance showed no difference between the healthy participants and the model ($X^2(1)=1.571$, n.s.). Similarly, the comparison between the frontal injured patients and the ten damaged models did not showed significant differences ($X^2(1)=2.343$ n.s.).
In the damaged model, the lesions produced a conspicuous decrease of flexible strategies.
A comparison of the type of strategy (flexible vs. rigid) employed by the healthy and the damaged model revealed a significant difference [$X^2(1)=13{,}976$, $p<0.001$]. Rigid strategies were more frequent than flexible strategies in the damaged model, whereas the unimpaired model showed the opposite result. This pattern mirrored the results obtained by Basso et al.

(2001) employing healthy participants and traumatic frontal injured patients.

Performance of the model was still adequate because the bottom-up mechanism was preserved, however, the damage of the TDC caused a loss of flexibility and responsiveness in the behavior, resulting in a greater difficult in the switch between heuristics.

The distance covered to achieve the solution is a fundamental measure in the evaluation of the performance in the TSP task. The Ratio of the Tour Length (RTL) variable was computed by assessing the percentage of distance in excess to the most efficient solution. An analysis of variance with Subject Type (humans vs. model) and Lesion (absent vs. present) as factors was run on the RTL values: the Lesion factor achieved a significant value [$F(1,117) = 16.986$ $p<0.001$].

These results showed that path lengths of both healthy participants and model were shorter than those of the fTBI patients and of the damaged model. Therefore, both strategy and performance data obtained by the evaluation of the model clearly mirrored the differences found between healthy subjects and frontal injured patients.

Discussion

From a cognitive point of view, the key of our model's ability to perform plausible pathways resides in two main features: the selection of the most appropriate heuristic given the contextual information and the incremental monitoring process, which allows a change of heuristic when the ongoing one fails to fit to the sensorial information. Indeed, the most intriguing characteristic of the model dwell upon its capacity to switch between heuristics. This is a fundamental characteristic in order to give psychological plausibility to the model. The flexibility of the model, highlighted by the heuristic switching during the execution of the pathway, reflects the similarity of its computational mechanisms with the human cognitive processes involved in the solution of TSP. Subjects execute TSP in an iterative manner; the incremental process is less resource demanding than a global planning because subjects do not need to generate a comprehensive plan resolving the entire situation but only the following appropriate action(s). The model is thought to execute the pathway operating the same incremental process observed in human subjects by making hypotheses about, and eventually selecting, the appropriate heuristic at every point of the pathway. The interaction of bottom-up (Gabor filters and competitive selection module) and top-down influences (TDC) implemented in our model have been successfully demonstrated to mimic the incremental process.

This model shares several conceptual properties with the Attention to Action (ATA) model proposed by Shallice (1988). The competitive selection module operates in a way similar to the contention-scheduling mechanism, whereas the top-down controller could be meant as a sort of Supervisor Attentional System (SAS). The model showed a good match to human performance when tested on the same patterns administered to the healthy participants. Moreover, after an artificial lesion to its "frontal lobe" component, the model accounts for the behavior exhibited by fTBI patients.

This suggests that our model may be able to capture the basic cognitive processes involved in the human solution of the TSP. Moreover, the model may be tested also in other spatially-based domains, when properly modified in order to make the executive processes able to compute also other kind of spatial tasks.

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