

# Testing the Attention Capacities of a Complex Auto-Adaptive System: A Stroop Task Simulation

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## Abstract

The Stroop task is a commonly used psychological test to study interferences that occur in cognitive control when two processes are in competition, and where a non habitual response needed to reach a defined goal competes with the habitual response. Many computer simulations already exist for this task, in neural networks and production systems. This paper presents a new simulation approach. It presents the first attempt to simulate the Stroop task using the properties of complexity and auto adaptivity of a massive multi agent system. Our approach allows us to simulate the time effects of cognitive impairment on the task. Results of the simulation are compared to an existing study on effects of fatigue on cognitive control impairment.

## Introduction

When a human subject is confronted to a task that involves two different stimuli, where one brings a response associated to a goal in a task, the habitual response tends to interfere with the goal response: this is known as the Stroop effect (Stroop 1935). In this paper the two competitive processes are color naming and word naming (the latter being the habitual response). In human subjects, a higher latency is observed in incongruent trial (e.g. the word "RED" written in green) than in congruent trial (e.g. the word "RED" written in red). The Stroop task is commonly used to test the cognitive control that involves attention and working memory. Many neural networks have been developed to implement cognition theories of Shallice's supervisor attentional system (Shallice 1980) and Baddeley's Central executive (Baddeley 1986).

The goal of this paper is to present a preliminary study on a new approach: the use of a complex auto adaptive system to simulate the Stroop task. Our main contribution is the implementation of this cognitive task in a complex auto adaptive system with goal oriented features, and the use of a specific type of control: an adaptation of Thom's

morphology (Thom 1989). Morphology controls the real time parallel processing of the system which allows implementation of competitive processes (Camus 2007). Coupled with the use of an ontology, this allows an emergence of knowledge related to the environment. Whereas the neural network implementations work with static threshold values and a unique response, the system works with dynamic knowledge emergence based on an open global ontology. Moreover the neural network works with hidden processing, making it difficult to precisely understand how knowledge is implicated in action, whereas the system's implementation allows a real time "readable" knowledge emergence. If this study is effective, further development could be made thanks to the ontology. We could work with the colors and the knowledge units linked to them (Havas *et al.* 2008). We might then see alterations of links between knowledge units defined in the ontology in real time.

## Related Work

### The Stroop task

The Stroop Task is frequently used to test a subject's ability to maintain a goal in mind, suppressing a familiar response in favor of one that is less familiar. The Stroop task used here is one that illustrates the "Color Word Interference effect" (Strauss *et al.* 2006). The set of trials used is a compound of congruent trials (the word "GREEN" in green) and incongruent trials (word "RED" in green). Often measured in those tests is "the Stroop interference effect": the performance of a subject on a normal task is compared to his performances on a similar task which involves the suppression of a habitual response mechanism. Interference occurs when the subject is confronted with an incongruent trial and tends to increase with a set having a larger proportion of congruent trials: congruent trials tend to impair the cognitive control (Ionescu & Blanchet 2007).

Access to written words is a highly automated process in human adults. In children, the interference is smaller when they are beginning to learn to read and gets bigger as their

reading ability increases (Strauss *et al.* 2006). In adults, interference comes from the need to override competing pathways at the stage of the response selection: the ability to respond to a stimulus when a more compelling one (the written word) is available. The roles of selective attention and context processing are fundamental for this task. The task instruction emphasizes the context which will lead the subject to produce the right answer (Ionescu & Blanchet 2007). It has also been shown that working memory capacity plays an important role on performance in the Stroop task. The failure to maintain the goal may not be the only phenomena involved. The time consuming process that selects among the competitive responses to one that is appropriate to the goal at hand seems to have its importance too. Stroop interference may then be decomposed into attentional and memorial components (Engle *et al.* 2003).

Research that has focused on identification of the supposed components of executive processes and their neural substrates has revealed a new model of what may be going on (Botvinick *et al.* 2001). This model consists of a response conflict monitoring system, executed in the anterior cingulate cortex (ACC) and the cognitive control system located in the dorsolateral prefrontal cortices (DLPFC). The response conflict monitoring parses information from the system looking for response conflicts due to interference between processes. The cognitive control system modifies information processing in the posterior brain regions in order to reduce those conflicts (Schmidt *et al.* 2009).

### Computer simulations

Several simulations of this specific task have been realized over the years, using neural networks and production systems.

In all neural network simulations stronger connections are made in the "word to name" pathway than in the "color to name" pathway. A fixed threshold indicates that the trial is terminated. The number of cycles needed to reach threshold is generally considered as an equivalent of the reaction time of human subjects (Servan Schreiber *et al.* 1998).

Dehaene's neural network (Dehaene *et al.* 1998) illustrates the hypothesis of two computational spaces, where the processes underlying effortful tasks take place: the Global Workspace and a space composed of a set of specialized perceptual and motor neurons.

In Gilbert and Shallice's model (Gibert & Shallice 2002) built around the notion of supervisor of attentional system (SAS) (Norman *et al.* 1980), the SAS has access to a representation of the environment and of the organism's intention and cognitive disorders. The "task demand" units regulate the activation to their corresponding pathways (color naming and word reading) assuming the regulation role of an SAS. More recent work (Buyukaksoy *et al.* 2007), makes a component of the neural network correspond to a particular neuroanatomic component of the prefrontal circuit taking part in the execution of the Stroop

task. Also built with the notion of an SAS named "the attention directing module," this module and a habitual response module are in turn inhibited depending on the task. The response time is the same as for human subjects, thanks to a specific use of processor properties in the implementation of the network. An analogy can be made between the architecture of the above simulations and ours: a control unit and specialized units processing the inputs.

The ACT R cognitive architecture (Anderson & Lebiere 1998) is often used for cognitive simulations with production rules. "NJAMOS" (Lovett 2002) is one of them using parallel processing. A set of production rules specifies the knowledge required to perform a Stroop task. Fixed mechanisms in ACT R help the system choose production rules during the goal retrieving process. The simulation presented in this paper is a whole different approach. Parallel processing is used to perform the internal organization of the system. The internal organization performs the goal directed behavior of the system.

## Method

### Complex Auto-Adaptive System

The system used in the paper is a Complex Auto Adaptive System (AAS) (Camus 2007). In the AAS, the decision making level proceeds with parallel information, real time processing and communication. The properties of the system are compatible with the notion of consciousness as defined here (Changeux 1985 p158):

The different groups of neurons in the reticular formation inform each other of their mutual activity. They form a system of hierarchical, parallel pathways in permanent reciprocal contact with the other structures of the brain. A holistic integration between various centers results. From the interplay of these linked regulatory systems, consciousness is born.

Here are the main defining properties of the system: morphology, auto adaptivity, complexity which are interrelated.

**Morphology.** In the AAS, it is morphological organization that allows the control of the system: Thom's morphology has been applied to a multi agent system in a synchronous adaptation (Campagne 2005), whereas in the present AAS adaptation is asynchronous adaptation in a massive multi agent system (Camus 2008). In Thom's morphology, geometric shapes represent information and phenomenon (Thom 1989 p7):

The space of observables  $M$  contains a closed subsets  $K$  called the catastrophe set, and as long as the representative point  $m$  of the system does not meet  $K$ , the local nature of the system does not change [...]. The evolution of the system will be defined by a vector field  $X$  on  $M$ , which will define the macroscopic dynamic. Whenever the point  $m$  meets  $K$ , there will be a discontinuity in the nature of the

system which we will interpret as a change in the previous form, a morphogenesis [...]. From a macroscopic examination of the morphogenesis of a process and a local and global study of its singularities, we can try to reconstruct the dynamic that generates it.

In AAS, morphology is the geometrical shape taken by an organization of agents. Depending on the situation, the morphology will increase or decrease the prominence of agents. The agents in charge of morphology compute statistics regarding the activity of structuring agents. There is constant communication between the morphological agents and the structuring agents (see below). Morphology's goal in the system is to turn the system towards a specific shape in order to match its goals.

**Auto-adaptativity and complexity.** The system is built around a systemic loop (defined below). Parallel processing allows the system to adapt its behavior to its environmental situation, repeating the same steps in cycle. This behavior is possible because of a large number of low level agents acting as in Holland's definition of a Complex Adaptive System (Waldrop 1993 p194):

A Complex Adaptive System (CAS) is a dynamic network of many agents [...] acting in parallel, constantly acting and reacting to what the other agents are doing. The control of a CAS tends to be highly dispersed and decentralized. If there is to be any coherent behavior in the system, it has to arise from competition and cooperation among the agents themselves. The overall behavior of the system is the result of a huge number of decisions made every moment by many individual agents.

AAS is complex because of its auto adaptive organization (Pinker 2000 p160):

Organisms are not just cohesive blobs [...]. They are machines, and their "complexity" is functional adaptive design: complexity in the service of accomplishing some interesting outcome.

## Components of the system

**The Ontology.** Describing the knowledge level (Newell 1982), the ontology contains the knowledge that is translated into agents in the system. The ontology is distributed: the knowledge is a group of words which are linked, the links between the words help define their topography in the morphologic organization. Knowledge is shared and interpreted at the same time in numerous agents. Each stimulus is understood thanks to the knowledge. There are knowledge units representing "physical capacities," which are linked to other units. The words classification forms various conceptual plans. For the purpose of this paper, we only used the "Object" conceptual plan. When aggregated to a robot, the system is able to send robot commands based on the decision the system takes. Decisions made are based on the system's representation of its environment.

**Links.** The ontology also contains the links between the knowledge units. New links can be created during experiments and the system can thus capture an amount of new information. In this paper, we established links between the knowledge units representing the colors, and with the frontal agents first described in (Havas *et al.* 2008): the agents (see below) in charge of processing information from environmental stimuli.

**The agents.** Each agent has a communication module, a role and a state (defined by a level of activation). Depending on its role, it will be associated to a specific organization. The system's basic agent is the aspectual agent (Cardon 2005). All agents have the same structure as that of the aspectual agents. Every aspectual agent has communications channel to others, and the ability to create new agents and is able to structure the system using his communication feature. Agents differ by their implication in a specific organization depending on their role:

- **Structuring:** Representing the knowledge inserted in the ontology, they produce the internal activity of the system. Their state depends on the information sent by the inputs and the links of the agent in the ontology.
- **Morphological:** Morphological representation depends on the organization of the structuring agents. Observation of the structuring agents will lead to assignment of a geometrical shape, which then enables the interpretation.
- **Analyze:** Geometrical shapes are generated thanks to the morphology. These shapes are interpreted as graph of histograms which are used by the Pattern of specific events agents.
- **Pattern of specific events (PSE):** These are aspectual agents using the graph sent by the "analyze" agents. Their role is set to "goal". The goal is sent by the user. In the present paper, the goal is "RecognizeColor". When the system is working, a shape is associated to "RecognizeColor". When "RecognizeColor" is activated, the knowledge units to which it is linked are activated too, causing this shape to incorporate their topology. This is then this shape the system will try to conform to, in order to reach a goal. The distance between the targeted shape and current shape is used to control activations in order to reach the targeted shape. It focuses the system on specific elements and enables them to act according to its current objectives, and is therefore part of the decision making process. The PSE is a kind of "limited" capacity (imposed by the system) attention administrator, controlling activities in the system. In this sense, it is similar to a Central Executive (evolution of Shallice's notion of SAS), in Baddeley's working memory model which posits a limited control role of the working memory on cognitive activities. The PSE will allow the activation of a part of the agents, according to the situation: they help produce the mechanism of working memory in the system: the limitation of a number of activated agents in the system at a time. The structuring agents with the correct corresponding role and shape will be activated to match the shape associated to the system's goal(s).

**Systemic Loop.** The system repeats the same steps in a cycle:

sensors >representation >interpretation >action plan > effectors > sensors

Every action is made in parallel. When the system is processing information from its sensors, it can also be acting on its environment according to previous stimuli it received.

## Experiment

### Procedure

For the purpose of our experiment, whose object is to simulate a full Stroop task experiment, we added a new

Front agent, the OCR (optical character recognition) front agent, and established an experimental scenario.

**The OCR Front Agent.** A "Color front agent" developed (Havas et al. 2008) in order to enable AAS to recognize colors was used in our experiment to fulfill the same function. A new frontal agent was however developed to enable the agent to read words. The OCR frontal agent (subsequently referred to as ColorOCR) was implemented on the same model than the Color frontal agent (subsequently referred to as ColorHisto) using an OCR program instead of the Color histogram program of the Color front agent. The OCR Library is a part of the OCRopus library: tesseract (Tesseract 1995). All implementations were made in Oz/Mozart (Van Roy et al. 2004), the language/compiler with which the AAS is built.

To represent the predominance of the "word to name" pathway over the "color to name" pathway, a higher number of agents were assigned to this knowledge set in the ontology.

### Simulation Scenario.

- A specific ontology (a set of colors name)
- Gnuplot visualize (Figure 1) showing conceptual plans
- Blocks of cards 2 types of blocks: 25% congruent trials and 50% congruent trials. Words: "red," "green," "blue," "yellow"
- 2 frontal agents: "ColorHisto" and "ColorOCR"
- A goal: "recognize color"

### Results

**Anatomy of color naming.** Using its Frontal Agents (ColorHisto and ColorOCR), the system gets external information. The color information of the agents ColorHisto and ColorOCR (which are linked in the ontology to the structuring agents that represent colors knowledge: "blue," "green," "red," "yellow") activates the right color agent corresponding to the external stimulus. The system processes these in parallel, which adds the psychological plausibility of competitive stimuli to our

model. At first, information coming from the processes in competition (ColorHisto and ColorOCR) is represented according to the proportion information (Figure 1) entered

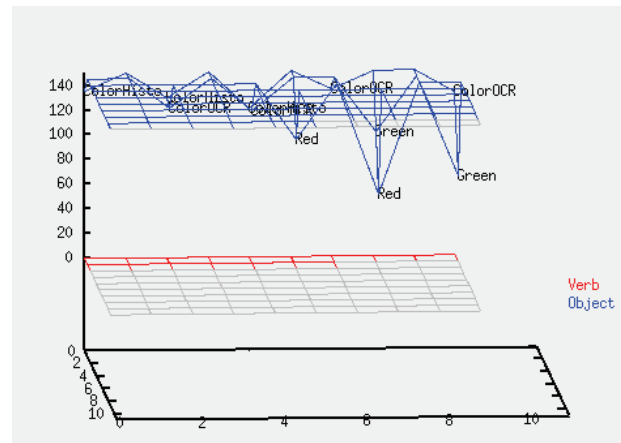


Figure 1: Emerging agents for the "RED" written in green, first the written color has the highest number. In depth, the level of activation, and on abscissa and ordinate the topology of the knowledge unit.

in the ontology (predominance of the number of ColorOCR agents to emphasize the preponderance of the reading ability). Thereafter, due to analyze agent's observation and according to the goal entered in the system, the morphological organization can modify the repartition of the information coming from the agents (by inhibiting the "reading ability" preponderance) (Figure 2).

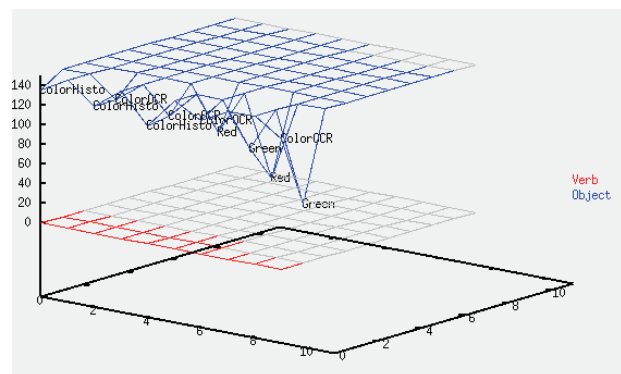


Figure 2: Emerging agents for the "RED" written in green, now that the reading ability is inhibited, the ink color has the highest number. In depth, the level of activation, and on abscissa and ordinate the topology of the knowledge unit.

### Evolution in time of the Stroop Task interference.

Blocks were constituted of 32 trials. Once the system stabilized, the highest repartition of agents was considered as the answer. When an equal activation was encountered for the two colors, the answer was counted as an error.

The following observations are compared to human results from Schmidt and collaborators (Schmidt *et al.* 2009) who studied cognitive impairment over time for a Stroop task, using the trials similar as ours (it should be noted that our trials were shorter).

Stabilization times are higher for incongruent tasks. Impairment similar to that of human subject is observed when we compare performance on mostly congruent trials and mostly incongruent trials. It is hypothesized that for the human subjects, in mostly congruent trial, congruent trials tend to impair the cognitive control. This impairment then leads to failures of goal maintenance and error monitoring processes: more errors occur in later stages. The systems results in Figure 3 reproduce the same kind of impairment, the error rate being the highest for the last quarter of the block due, firstly, to the activation of the system's primary links between the knowledge units (the past presented colors) and the OCR units and, secondly, to the already predominant representation of the "reading ability" (ColorOCR).

A performance decrease in the task is observed in human subjects as the experiment moves on. In later stages of the task the performance gets lower (the decrease is highest in mostly congruent trials but nonetheless existent in mostly incongruent trials). This type of impairment is explained by the excessive load put on the working memory at later stages of the trials, even inducing high naming errors (naming a color which is neither the word written, nor the color in which it is written). These impairments are also observed in the AAS: the last quarter of the block has the highest error rate for both congruent and incongruent blocks. In advanced stages of the block, many different color agents are activated, thus putting a heavy burden to the limited capacity PSE organization, and thus leading to errors. The proportionally increased error rate across time shows the augmented load of working memory for each quarter of blocks.

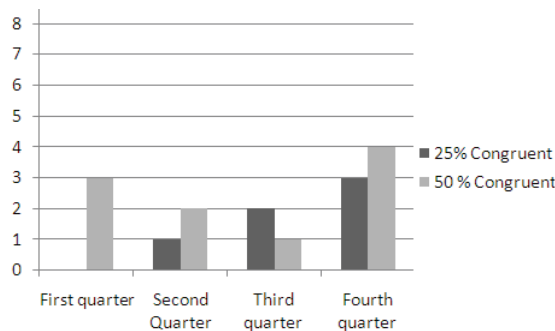


Figure 3: Error rate (ordinate) evolution by quarter of block (abscissa) for 25% congruent block and 50% congruent blocks. A quarter is compound by 8 cards.

**Discussion.** This work is a first attempt to simulate human cognitive disorders in a complex auto adaptive system. Although more comparison to actual data reported in the literature is needed, and therefore more adjustment of the system to fit human capacities, our work present positive results for the modeling of the functional capacities of the working memory and cognitive control involved in a Stroop task. A more accurate setting of the PSE could help

increase the processing capacity thereby increasing the overall system capacity, since morphology and complexity of the system are codependent. With more data to manage, morphology could thus get stronger and goal maintenance easier to observe. A modification in the experimental setup should be made in order to harvest more accurate time data and establish a ratio to compare human with AAS time.

The actual "weakness" of the system, as it is currently set actually shows interesting results for the functional understanding of cognitive disorders regarding working memory impairments and its relation to impairment in cognitive control as currently hypothesized (Engle *et al.* 2003).

The experiment supports our choice of a complex adaptive system for functional cognitive capacities, since the complex organization of the system allows us to observe the system's processing over time as current psychological hypotheses suggest. We believe that this new approach could be useful for many competitive or cooperating psychological processes simulation due to the system's flexibility.

By further testing the system's capacities on task requiring attention and decision making (even if not the most accurate decision), we can study its usefulness for the management of machines or software entities. Sometimes an approximate decision is better than none at all.

## Future Works

The present work did not use the full capacities of the system. As shown in previous work (Havas *et al.* 2008), it is possible to incorporate "emotion knowledge" to the system. This knowledge interference in the decision making is inspired by work in neurosciences (Damasio 1994). More work on the emotion ontology could allow the simulations of emotional Stroop task, thus providing a simulation of an actual theory of the role of emotion in the cognitive control.

Using the semantic possibilities offered by the system's ontology, it may be possible to upgrade the present Stroop task to other Stroop tasks designed to test working memory. These tasks involve naming words related semantically to a set of words and colors word ("red" "green"), and therefore need temporary memorization of the set of word.

The present work also provides a basis for the simulation of psychopathologies that involve a modification of the organization of internal processing (Banich *et al.* 2009). This could provide a simulation tool to observe cognitive impairments with theories resulting from the involvement of various competitive neurological, as well as the development and evolution of those pathologies. Such a tool would allow us to compare results with existing literature on those clinical subjects, and this could then provide a meaningful contribution to the field of psychopathology simulations, most of which are currently made with neural networks (Servan Schreiber *et al.* 1998).

## Conclusion

The Stroop task is a psychological test revealing the interference between competitive processes. This interference comes from the need to override competing pathways at the stage of the response selection: the ability to respond to a stimulus when a more compelling one (the written word) is available. Selective attention and context processing are fundamental for this task.

There have been many simulations of the Stroop task, on neural networks and production systems. This paper presents a new approach using a complex auto adaptive system. In this system the control is implemented thanks to the morphology: geometrical shape taken by an organization of agents. The morphology will increase or decrease the prominence of agents in order to reach a goal. Real time parallel processing of information coming from sensors allows the system to adapt itself and make decision in accord with its goal keeping data from the environment in his memory.

The simulation used a scenario similar to existing work, on a word naming/color naming task. Interesting results were observed regarding impairment in the cognitive control in advanced stages of the task for incongruent trials thereby confirming the plausibility of the AAS for further experiments on cognitive disorders in context maintenance, attention and working memory. Further adaptations must be made concerning the setting of the system to obtain numerical results comparable to larger existing studies. But the present study is an encouraging step supporting the idea of using this complex auto adaptive system for cognitive simulations.

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