Deliverable D1.2:
Cognitive behaviour for self-awareness

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Abstract: This deliverable defines the models and methodologies required to study and characterise the selected cognitive behaviours needed for self-awareness, including preliminary simulation results.

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Executive summary

This deliverable can be summarised into two main parts. The first concerns the study and analysis of relevant literature and identification of a small pool of prominent cognitive areas able to synthetize the fundamental attributes of humans' cognition which could be harnessed for self-awareness. Sections 2 to 6 provide a background literature of five main broad areas form psychology that have been identified as having some potential for application to ICT environments. The following Section 7 investigate this further by extracting from them a number of cognitive behaviours and functionalities for self-awareness that could be directly implemented on specific ICT components.

Based on these findings, the last part of the document (Section 8) introduces a basic model for human cognition that identifies three key cognitive modules representing the main cognitive activities of representing knowledge. This analysis will then constitute the basis for the technical definition of a preliminary architecture for self-awareness that is object of the second work-package of the project.
1 Introduction

This deliverable contributes to the first two objectives of work package WP1:

- To determine a justified basis for self-aware behaviour from cognitive and psychological sciences.
- To map primary aspects of self-awareness to common control issues seen in diverse content centric ICT systems.

In particular deliverable addresses the following tasks of work-package WP1: Task T1.1 defining a baseline modelling about the analysis of the cognitive science literature and identification of a small pool of cognitive theories able to describe those fundamental attributes of humans' cognition which could be harnessed for self-awareness; and Task T1.2 identifying key cognitive behaviours needed for self-awareness through the modelling of basic functions of human cognitive processes.

1.1 Baseline Modelling

The following sections address the definition of the baseline model described in Task T1.1 to develop an artificial self-awareness. This involves the composition of a unitary coherent structuring of the previous models from the literature, in order to obtain a complete and efficient cognitive-based definition for the different tasks required for the project.

We have proceeded by identifying and analysing a large number of papers whose findings can be related to the concept of self-awareness. These belong to broader areas of psychology with particular focus on cognitive psychology. From these we provide key relevant papers, showing where these map within an overall tri-partite model that we propose for modelling cognition in the context of the RECOGNITION project.
Among the areas related to cognitive psychology we have systematically investigated a range of literature. The findings have been consolidated in the following five areas and are broadly based as follows:

- Modelling human reasoning
  - Belief, desire and intention
  - Mental models, heuristics and decision making
- The Influence of others
  - Social cognition
- Internal embedded disposition
  - Personality traits and information behaviour
- Spatial perception and surrounding context
  - Spatial cognition
- Related concepts
  - Concepts from neurophysiology
  - Group dynamics
  - Cognitive aspects of HCI and information relevance

We summarize our findings in the following section and provide supporting appendices where appropriate.
2 Modelling human reasoning

2.1 Belief, desire and intention

Inspired by human behaviour, the vision of intelligent agents is that pieces of software, (the “agents”), can act autonomously, communicate with their environment or other agents, and linger around in the network to pursue a specific goal. A software agent can be understood as an isolated entity comprising a state and some activities. The rationale behind the Believe-Desire-Intention (BDI) model (see Michael Bratman 1987, A.S. Rao and M.P. Georgeff 1995) for intelligent agents is the formalization and simplification of an intelligent reasoning process.

In BDI, an autonomous agent features a state containing all the agent’s knowledge about the environment. As the agent cannot be sure whether his knowledge actually reflects the genuine truth about the environment, this state is called the agent’s beliefs. These beliefs can change dynamically over time, as the agent gets updated information from its environment. A second dynamic state, the agent’s desires, reflects a set of “goals” the agents wants eventually to reach. As the agent succeeds in some desires or discovers that some desires become impossible, he modifies his set of desires. Finally, BDI specifies a set of activities an agent might take, these are called plans. Plans typically comprise a set of atomic actions or sub-plans to eventually achieve a specific desire. Based on the beliefs and desires, an agent selects a plan and commits to it. That is, the agent chooses a single plan out of all plans, and this plan becomes his intention to eventually achieve one of his desires.

The agent selects a single plan out of all possible plans by using a selection function. One way of implementing such a selection function is by “decision trees” as originally suggested by A.S. Rao and M.P. Georgeff, 1995. A decision tree is made up of decision nodes and terminal nodes, i.e., leaves. Starting from the root, the branches of a decision node in BDI reflect the possible plans an agent can chose and the different beliefs he might have. Edges in this tree are annotated with “costs” that are implied by choosing this path. While computing the decision tree, the agent can automatically remove paths that become too expensive or that will lead to a situation not complying with the agent’s desires. The leaves of the decision tree represent the
desires of the agent that can be reached by following a specific path of plans and
given certain beliefs – starting from the root of the decision tree.

The selection function consequently selects the “cheapest” path in a dynamic manner.
This path becomes the agent’s intention. It is notable that BDI models led themselves
very well to manifestation in software artefacts or agent based models. Before
presenting an example of the BDI software model, we will briefly overview the main
algorithm executed by a BDI agent. This algorithm is a simplified version along the

**BDI algorithm**

```
repeat
    externalEvents := getExternalEvents();
    beliefs := updateBeliefs(externalEvents);
    tree := updateTree(beliefs);
    newPlan := selectCheapestPath(tree);
    addToQueue(newPlan);
    execute();
end repeat
```

In each “cycle”, the agent receives first a set of external “events”, i.e., observations
from the environment. Therewith, he can update his set of beliefs. Based on the set of
local beliefs, the agent can modify and update the decision tree and select the most
appropriate plan to add to the execution queue. As part of the tree update mechanism,
the agent can remove paths that would lead to already satisfied desires or desire that
become impossible to reach. The agent also modifies the tree based on internal events,
i.e., changes to his belief based on his own actions. Note that updating beliefs and
removing satisfied intentions could be interpreted as the “learning” process of the
agent. Therewith, the agent learns and dynamically adopts its future activities. An
agent’s future decision making is based on learning.

The BDI model is widespread in software agent theory, and there exist many
implementations of BDI frameworks. These frameworks allow the specification or
formalization of beliefs, desires, and plans along with reasoning mechanisms that realize the core BDI algorithm.

**Example**
One of the first real-world applications of BDI agents was as part of an air traffic control scenario, cf., A.S. Rao and M.P. Georgeff 1995. In each airplane, a BDI agent has the desire to fly the airplane along a set of given waypoints and to finally land the plane before a specific estimated time or arrival (ETA). To satisfy this desire, the agent can choose between a set of possible plans, e.g., to make the plane fly for some time at a specific speed, in a specific direction or at a specific altitude. Typically, a set of uncertainties, for example, wind direction and win speed, influences the agent.

In the agent’s decision tree, nodes and outgoing branches represent the possible plans the agent might execute, e.g., fly at a specific height, fly with a specific speed, and the beliefs he has, e.g., headwind with a wind speed. The leaves stand for the time of arrival at the destination following the paths of actions chosen by the agent. In each cycle, the BDI agent receives external information (events) such as wind direction and wind speed. Therewith, the agent can update his decision tree, e.g., the costs to reach the destination. One example for a path’s cost is its fuel consumption. Also in each cycle, the agent automatically prunes the tree such that leaves with an ETA later than the desired ETA are removed. Finally, the agent selects the cheapest plan leading to a leaf node.

### 2.2 Mental models, heuristics and decision making

The human mind has long been regarded as tailored to register and to exploit frequencies of occurrence. In particular, numerous treatments of human cognition and memory centre on the effects of environmental frequencies and repetition on memory and judgment.

**Attention and perception**
*Attention, consciousness, perception* and different *memory models* are of potential relevance to the mission of the project. Attention concerns the active processing of a limited amount of information among the vast amount available (Sterneberg 1999,
Fulcher, 2003. This has also implications in terms of memory theories and decision making, see for example (Pleskac et al., 2009), in which divided attention has been found having significant effect on the ability to discriminate between random error in judgment during encoding and retrieval processes.

Of particular interest is the Broadbent's filter model (Broadbent, 1958) that relates to concepts such as selective attention and short-term memory (which also relates to the how we organize and store received information) and the classifications of autonomic and conscious processing. Here “self-relevant” stimuli are favouring status of automatic processing rather than a conscious control process, in which all available information is analysed (Bargh, 1984). Concepts related to attention and perception are explored in a recent article about ‘wandering minds’ (A. Killingsworth and Daniel T. Gilbert, 2010) and in works related to the recognition of intentions that has significant applications in ambient intelligence, for example in assisted living and care of the elderly, in games and in intrusion and other crime detection (Sadri, 2010).

**Cognition and memory**

Cognition and memory involve more than encoding and retrieving facts; they also infer cue values and even update missing cue values. The problem of finding the optimal (best) cue order turns out to be NP-hard, that is, when the number of cues vastly increases, determining the optimal order quickly becomes too time-consuming for minds and computers. As a consequence decision-making processes often follow heuristic procedures. Heuristics are strategies that guide information search and modify problem representations to facilitate solutions. In research on reasoning, judgment, and decision-making, heuristics have come to denote strategies that prevent one from finding out or discovering correct answers to problems that are assumed to be in the domain of probability theory.

Humans and animals make inferences about the world under limited time and knowledge. In contrast, many models of rational inference treat the mind as equipped with unlimited time, knowledge, and computational might. A number of works have proposed a family of algorithms based on a simple psychological mechanism: one reason decision-making. These fast and frugal algorithms violate fundamental tenets of classical rationality: they neither look up nor integrate all information (Goldstein
and G. Gigerenzer, 1996). This result is an existence proof that cognitive mechanisms capable of successful performance in the real world do not need to satisfy the classical norms of rational inference.

For decades, human rationality was studied in psychology by proposing a logical or statistical rule as normative in all situations, and then constructing an artificial problem in which this rule could be followed. In contrast, the question of ecological rationality asks in which environment a given strategy (heuristic or otherwise) excels and in which it fails. No rule is known that is rational per se, or best in all tasks. Parts of the psychological research community have resisted the asking of questions about ecological as opposed to logical rationality (Goldstein and G. Gigerenzer, 2002).

**What are heuristics?**

To define Cognitive Heuristics rigorously is very hard, and the problem is complicated by the large and authoritative literature about it. This chapter would draw a little history of this concept and of the opened theoretical methods seeded after its introduction. A good definition of Cognitive Heuristics should first be distinguished from the most general definition of Heuristic, used very frequently and with different meanings from a multitude of scientific disciplines. While the Greek definition of the word is literally “serving to find out or discovering” the most accepted one in the modern sciences would be “One (efficient?) list of rules (algorithm!), sometimes inspired from human behaviour, that can be used to solve a problem”. The concept of Cognitive Heuristics was born at the beginning of the 20th century as those rules from cognition that seemed to be followed to solve elementary and mainly perceptive problems, while computing heuristics are also interpreted as non-exhaustive, non-exact algorithms for quick calculation or actions.

The most general and insightful formalisation of the concept of cognitive heuristics has been probably given only 50 years later from Social Cognition (Simon, 1955), as: *Cognitive Heuristics are those strategies that guide information search and modify problem representations to facilitate (ndr. and reach) solutions*. Examples of heuristics are given in the following, for a more exhaustive survey spanning from their introduction until the most recent developments see Appendix A.
Response time data from experiments indicates that recognition judgments are made before other knowledge can be recalled (Bergert and Nosofsky, 2007). Consistent with this hypothesis, many authors show that response times were considerably faster when participants’ inferences accorded with the recognition heuristic than when they did not. Similarly, participants’ inferences accorded with the recognition heuristic more often when they were put under time pressure. These findings are consistent with the recognition memory literature, indicating that a sense of recognition (often called familiarity) arrives in consciousness earlier than recollection (Guazzini et al., 2011).

**The recognition heuristic**

The *take the best* algorithm is to “take the best, ignore the rest” and it is the basic algorithm that assumes a subjective rank order of cues according to their validities. The object with the highest “discriminating cue” (one object is positive whereas the others are negative or undefined) is chosen. However, this notion is combined with the *recognition principle*, which is invoked when the mere recognition of an object is a predictor of the target variable. The *recognition principle* states the following: If only one of the two objects is recognized, then choose the recognized object. If neither of the two objects is recognized, then choose randomly between them. If both of the objects are recognized, then proceed to next step. Thus, it differs from standard linear tools for inference such as multiple regression, as well as from nonlinear neural networks that are compensatory in nature (Pachur et al., 2008).

The *recognition heuristic* exploits the basic psychological capacity for recognition in order to make inferences about unknown quantities in the world (Goldstein and G. Gigerenzer, 2002). It is important to note that the recognition heuristic makes inferences about criteria that are not directly accessible to the decision maker. When the criterion is known or can be logically deduced, inferential heuristics like the recognition heuristic do not apply.

**The less-is-more effect**

The recognition heuristic has been also associated with the so-called the *less is more* effect (Goldstein and Gigerenzer, 2008). In psychology’s quest for general laws, the “effort-accuracy” trade-off is a top candidate: The claim is that a person cannot put
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less effort in a task and increase accuracy. Because it is widely accepted, the trade-off provides an opportunity for theory development. In inductive inference, a strong prediction is the less-is-more effect: less information can lead to more accuracy. For the task of inferring which one of two objects has a higher value on a numerical criterion, there exist necessary and sufficient conditions under which the effect is predicted, assuming that recognition memory is perfect. Based on a simple model of imperfect recognition memory, (Katsikopoulos, 2010) derives a more general characterization of the less-is-more effect, which shows the important role of the probabilities of hits and false alarms for predicting the effect.

The less is more effect has also been shown to be related to size of the samples that we take (Fiedler and Kareev, 2006). The authors have claimed that taking a small sample of information (as opposed to a large one) can, in certain specific situations, lead to greater accuracy (beyond that gained by avoiding fatigue or overload). Specifically, they argue that the propensity of small samples to provide more extreme evidence is sufficient to create an accuracy advantage in situations of high caution and uncertainty. The sample size determines how good our choices will be. Studies of decisions from experience have observed that people tend to rely on relatively small samples from payoff distributions, and small samples are at times rendered even smaller because of recency. (Hertwig, and Pleskac, 2010) suggest one contributing and previously unnoticed reason for reliance on frugal search: small samples amplify the difference between the expected earnings associated with the payoff distributions, thus making the options more distinct and choice easier. The authors describe the magnitude of this amplification effect, and the potential costs that it exacts.

However, the real validity of the findings above has caused some controversy within psychologists. In (Evans, and Buehner, 2011) a close examination of Fiedler and Kareev’s experimental results does not reveal any strong reason to conclude that small samples can cause greater accuracy. The authors argue that the negative correlation between sample size and accuracy that they reported is also consistent with mental fatigue and that their data in general are consistent with the causal structure opposite to the one they suggest: rather than small samples causing clear data, early clear data may cause participants to stop sampling. More importantly, a
specifically conducted experiment provides unequivocal evidence that large samples result instead in greater accuracy.

*Decision making under competition*

The context within which human action takes place plays a crucial role in the prioritization of the employed cues/heuristics. In general, human rationality dictates actions that pursue the highest possible scores with respect to specific decision tasks. When human response efficiency relies exclusively on their action, their skills or motivational strength determines their level of satisfaction. In the opposite vein lie cooperative or competitive environments where the intertwining of individual decisions derives the ultimate individual utility ranking. Indeed, any nugget of competitive or cooperative feelings amongst humans can justify even full-scale changes in their behaviour towards decisional operations, compared to their solo activity.

The social-comparison theory investigates human reaction within competitive frameworks. In particular, it provides insight into factors, either subjective or objective, that influence the motivation to – compare to others and thus to – compete. The former category includes the *relevance* of the performance dimension as well as the *commensurability* and *closeness* between rivals (Goethals and Darley, 1977). Among the objective factors the competitor *proximity to a meaningful standard* (Garcia and Tor, 2007) and the mere knowledge of the *number of competitors* (Garcia and Tor, 2009) stand out. Concerning the latter objective factor, the relevant theory introduces the “*N-effect*”, stating that increasing the number of competitors *N* can decrease the motivation to compare to others. However, according to social – facilitation notion, the presence of others triggers social comparison interests and therefore competition feelings. Consequently, it seems that an upper bound of the number of co-actors signals the decrease of competing motivation. Thus, when humans draw on this numerical cue, resign from effort (i.e. saving resources) once they become aware of the presence of a specific (case-sensitive) number of other competitors, sharing the same objective.
3 The influence of others

3.1 Social cognition

Important efforts to bridge the psychological and the social levels are emerging in the literature. These cross discipline efforts will generate new insights based on linking the behaviour of individuals and cognitive processes to social phenomena. In particular, social networks can be investigated to analyse the psychology of weighting information and how the distribution of information within a group affect that group's behaviour. It would be then possible to impute computational processes onto cognitive functions, and thereby to generate runnable computational models.

Tomasello et al. (2005) state that the difference between human cognition and that of other species is the ability to participate with others in collaborative activities with shared goals and intentions: shared intentionality. Participation in such activities requires not only especially powerful forms of intention reading and different models for cultural learning and reasoning (Tenenbaum et al., 2006), but also a unique motivation to share psychological states with others and unique forms of cognitive representation. This analysis borders up to another related area of psychology known as social cognition. This refers to an approach to social psychology in which cognitive processes such as representation, encoding, storage, retrieval, and processing were studied according to the methods of cognitive psychology and information processing theory (Augoustinos and Walker, 1995, Wyer and Srull, 1984, C. Heyes, 2009).

Social cognition also relates to concepts as attributions and attitudes (social evaluations); social schemas; social identity; social representations; and social learning by observation and imitation. This sub-discipline of psychology involves concepts such as the cognitive dissonance theory that is based on the fact that in order to mediate conflicts between behaviours and ideas (dissonances), individuals tend to attribute the origin of their decisions to potential contrasting behaviours rather than recognizing the existence of (internal) constraints. Another theory of interest here is that of self perception, that states that to evaluate their own actions individuals partially relies on the same cues that others use when they infer their own internal states (D. Bem, 1967)
However, the principal aspect of this branch of psychology focuses on social schemas as cognitive structures containing knowledge of the social world. This is an information processing model of perception and cognition which attempts to identify the mechanisms by which people come to understand the complex social world in which they are immerse. Each individuals has its own social identity (social-self) that, differently form the physical self, locates them into a social structure, identifying the self with a particular social position and role.

This also links to the fundamental concept of social representations that, in a broad sense, can be defined as the set of concepts, statements and explanations originating in daily life in the course of inter-individual communications (S Moscovici, 1981). This affects individual actions and decisions to different extents. Applications of a social structure as an input for opinions and suggestions that will influence people behaviour can be found in several fields.

Risk perception

(S. Kitchovitch and P. Lio, 2011) applies the use of community structure in social networks, in terms of community behaviour and feedback, to epidemiological modelling. This work reveals a better understanding of the effects that community-structured networks and variations in awareness, or risk perception have on disease dynamics and to promote more community-resolved modelling in epidemiology.

An individual’s risk perception can be defined as awareness of the disease based on which he acts to reduce the probability of becoming infected. The modelling of this perception takes into account fundamental parameters representing individual’s awareness. For example, (F. Bagnoli et al., 2007) identifies them as individual perceptions, that determine how strongly the individual reacts to observing infection among his close contacts, and community awareness, that determines the awareness that an individual has gained from external factors: media broadcasts, knowledge of adequate precautions, etc. Here the authors apply the risk perception approach as a simple framework to represent variations in behaviour between communities.

Studies on risk perception in the social sciences, regarding various hazards, have shown that individuals estimate risk differently depending on the target that is at risk from the hazard. According to empirical observations an individual’s perceived estimate of risk tends to be lower when the target is themselves or their families,
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compared to when the risk target is the rest of the population (L. Sjoberg, 2000). The estimates of perceived personal or family risk are likely to increase if the hazard is proximate to the individual. Additionally, the authors note that individuals aware of cases of infection in their neighbourhood (representing their social community) had a higher level of perceived personal or family risk, a phenomenon that could be modelled using to account for such cases in the individual’s vicinity, and that different levels of risk perception can coexist between communities.

Finally, a further component of social cognition is the notion of social learning as opposed to individual learning that stems solely through direct interaction with the environment, for example, through trial and error. At first sight, social learning appears advantageous because it allows individuals to avoid the costs, in terms of effort and risk, of trial-and-error learning. However, social learning can also cost time and effort, and theoretical work reveals that it can be error-prone, leading individuals to acquire inappropriate or out-of-date information in non-uniform and changing environments.

Social learning theory (Bandura, 1971) can be used to structure the evolution of cognitive processes, and the definition of data-driven and schema-driven processes (Fiske and Neuberg, 1990) can capture the great adaptability and optimization of the mind. Current theory suggests that individuals should be selective in when and how they use social learning, so as to balance its advantages against the risks inherent in its indiscriminate use. Accordingly, natural selection is expected to favour social learning strategies, psychological mechanisms that specify when individuals copy and from whom they learn. (Lopes et al, 2009) proposes a computational model that describes how observed behaviour can influence an observer’s own behaviour, including the acquisition of new task descriptions. The sources of influence on our model’s behaviour are diverse such as: beliefs about the world’s possible states and actions causing transitions between them; baseline preferences for certain actions; variable tendencies to infer and share goals in observed behaviour or to act efficiently to reach rewarding states. Acting on these premises, their model is able to replicate key empirical studies of social learning in children and chimpanzees. In particular, it is of some interest the distinction between different categories of learning such as emulation (when the subject is conscious of replicating an action in order to achieve a specific identified goal, in this case the subject can even vary the action and substitute
it with an equivalent in terms of final scope and replicate only the observed effects) and imitation (when the specific goal cannot be easily identified so that the subject have no choice of copying exactly the observed behaviour and so replicating both the observed actions and effects). In addition, young children and chimpanzees are rather prone to imitate even parts of action sequences that are not obviously necessary to achieve the goal (a phenomenon known as over-imitation).
4 Internal embedded disposition

4.1 Personality traits and information behaviour

Another related area is that of personality psychology, which is a branch of psychology that studies personality (as the set of characteristics that influence a person’s cognitions, motivations, and behaviours in different situations), individual differences, and commonalities of human behaviours. Different theories have been formulated (see R. M. Ryckman, 2004) including types and traits theories, behaviour theories (how personality relates to the effects that external stimuli have on behaviour), and social cognitive theories mentioned above. The study of personality links with other fields of social psychology involving the concepts of cognitive similarity (that concerns attitudes, values, interests and personality matches between people) and emotion cognitive theories (how judgments, evaluations, and thoughts cause emotions to occur).

The personality traits theory proposed by (Digman, 1990) is based on five broad dimensions or factors originally discovered and defined by several independent sets of researchers. Most recently, L.R. Goldberg (2003) proposed a five-dimension personality model, also known as the “Big Five” personality dimensions, which has achieved a general consensus as the current state of the art among researchers.

Brief history of the ‘big five’

Researchers have converged on the Big Five as the accepted model for personality evaluation after decades of study. Although the field of personality traits has been significant and active since the first part of the last century, it was only around the eighties that researchers increased their efforts towards a common structure. What was missing in personality psychology was a descriptive model or taxonomy defining an overarching domain in which large numbers of specific instances could be included and understood in a simplified way. The use of taxonomy allows us to study related personality characteristics rather than examining separately the hundreds and thousands of specific attributes of individual human beings. Such taxonomy does not reflect any particular theory but is instead derived from the analysis of natural-language terms that individuals use to describe themselves and others. An extensive report on the history of the development of this taxonomy is given in John et al.
The starting point of this research stems back to the thirties when researchers such as Allport and Oldberg (1936) looked at natural language as a source of possible attributes. This work began with the extraction of relevant terms from the dictionary and, subsequently, using a lexical approach, it aimed to provide an extensive but finite set of attributes that reflected the socially relevant personality characteristics of individuals.

The initial studies still returned an extremely large set of these attributes (around 1800 in the Allport experiments). However, they did manage to identify four major categories, namely personality traits, (e.g. social, aggressive), defined as ‘generalized and personalized determining tendencies, consistent and stable modes of an individual’s adjustment to his environment’; temporary states, moods and activities, (e.g. afraid, elated); judgments of personal conduct and reputation (e.g. excellent, average); and physical characteristics, capacities and talents. Subsequently (Norman 1967) these classifications were elaborated in seven categories representing, traits, internal states, physical states, activities, effects, roles, and social evaluations. However, such categories were highly overlapping and presented fuzzy boundaries, mainly because of the extremely large number of the underlying lexical attributes identified. Another pioneer of this research was Cattel (1943) who, about a decade later than the Allport studies, was able to reduce the number of attributes. He initially reduced them to 4500, then took them down to 35 variables that eventually converged into a smaller number of factors that were a part of his final 16 personality factors questionnaire published in the seventies. He also claimed that his identified attributes showed excellent results in evaluation methods such as self-reports, rating of others and objective tests. Although his work has been not free from heavy criticism, it is recognized as showing significant correspondence with the five factor models proposed later.

The work of Cattel was extensively used in the following decades as a basis to propose a range of five factors, obtained by reducing his 35 variables through a number of experiments involving self-rating, rating by peers, and rating by psychologist. These factors, although initially proposed with a variety of different names, became eventually the big five structure defined by Goldberg in 1981. Note that the adjective big was used by the author to emphasize the broadness of such
factors that were intended as a high level of abstraction summarizing the large number of distinct and specific personality characteristics, without implying that personality difference could be reduced to 5 factors only.

The five dimensions of personality currently used are classified as: 
- **Openness** – the tendency to be imaginative, independent, and interested in variety vs. practical, conforming, and interested in routine; 
- **Conscientiousness** – the tendency to be organized, careful, and disciplined vs. disorganized, careless, and impulsive; 
- **Extraversion** – the tendency to be sociable, fun-loving, and affectionate vs. retiring, sombre, and reserved; 
- **Agreeableness** – the tendency to be soft-hearted, trusting, and helpful vs. ruthless, suspicious, and uncooperative; 
- **Neuroticism** – the tendency to be calm, secure, and self-satisfied vs. anxious, insecure, and self-pitying. These five factors are also known in the form of acronyms as OCEAN (or CANOE), see John et al. (2008) for the most recent description.

**Personality questionnaires and facets**

Beside the development of the five factors model, research has also been conducted into its evaluation, with the proposition of a number of questionnaires to be used to assess its validity. Several different questionnaires have been proposed since this started to gain increasing popularity among researchers, each with peculiarities and differences in the type and number of attributes and facets, (subordinate dimensions).

Among others we can mention the work of Costa and McCrae derived from the original NEO Personality inventory (NEO-PI) proposed in 1985. It was labelled NEO because it was initially designed to measure the three dimensions of Neuroticism, Extraversion, and Openness to experience. Subsequently, this has been extended to include Agreeableness and Conscientiousness and published in 1992 in the form of a 240-item inventory as NEO Personality Inventory Revised (NEO-PI-R), in which each dimension is classified into six different facets. This test was developed by testing samples of older and middle-aged adults using both factor analysis and multi-method procedures for validation. Intended to test both the five factor and their facets, NEO-PI-R is a commercial product and is considered by many psychologists as the best inventory for measuring traits as well as the NEO-FFI (NEO Five Factors Inventory), which is a shorter 60-item version that only measures the five factors.
Finally, these authors also contributed to the development of the so-called Five-Factor Theory, including a number of propositions about the nature, origins, and development of personality, as well as a biological account of traits including other related aspects such as learning and experience.

Another group of sub-classifications and questionnaires derives directly from the lexical based research of Goldberg that, in contrast to the NEO experiments, mostly relied on samples of students. The resulting *International Personality Item Pool (IPIP)*\(^1\) is currently considered as the main reference prototype by a group of experts (Goldberg, 1999, Goldberg et al, 2003). In fact, although initially given less attention than the NEO-PI, the use of items and scales from the IPIP has increased dramatically since its inception in 1996. However, some personality researchers argue that this list of major traits may not be exhaustive, see for example (Johnson, 2000) that proposes a comparative validity study of the original five traits model. The IPIP repository is in the public domain and contains several different factors, including variations of the NEO-PI scales. It also includes the set of 100 unipolar traits adjectives (TDA) commonly used for research purposes. For its development Goldberg conducted a series of factor analyses selecting those adjectives that uniquely define each of the attributes. The resulting scale is recognized as having high internal consistency and ease of replication. There is also a shorter, 50 item version that is very effective for instructional purposes.

In order to propose a shorter yet effective version for measuring the big five components, John et al (1991) proposed the 44 items Big Five Inventory (BFI) with the aim of capturing and synthetizing the core and principal elements among previous studies and inventories. Items were selected after conducting a factor analysis in large samples of junior and university students. It received more than one criticism for being specifically designed as an intermediate instrument between the NEO-PI and Goldberg’s IPIP scales, but also received praise for saving testing time and preventing subjects from excessive boredom and fatigue because of its short format and ease of use (this particular test intentionally does not include any single word adjectives within its items, being mainly constituted by short phrases). The test can be freely used for non-commercial research purposes.

\(^1\) http://ipip.ori.org.
Finally, more recently, in order to fulfil the need of very brief measures, five and ten item inventories were produced and a number of tests conducted on them showing a significant convergence with respect to self, observer and peer reports and between self and observer ratings. From the results of these tests Gosling et al. (2003) proposed a 10 item measure intended for this type of very short measure, where personality may not the principal topic of interest and when it is tolerable to deal with diminished psychometric properties during their subsequent analysis.

**Applications of the five factors personality model in ICT**

The application and use of personality tests in Information and Communications Technology (ICT) is growing with the introduction and progress of new technologies. For example, they have been used in personnel selection and a number of international companies have implemented systems that consider the impact of personality in assessing an employee’s qualification by selective filtering (J. Ade et al., 2010). One of the most recent application fields is within recommendation systems and filtering of information in ICT systems. Recommending is a deliberative social process performed by ordinary people when they want to describe their degree of appreciation about someone or something. Recommendation systems do not yet make extensive use of psychological aspects. Only recently have some systems introduced a variable that assesses personality traits by incorporating one of the available questionnaires (most commonly the NEO-PI) in their application and including personality variables into profiles representing the interests and characteristics of users. In this way personality can be used to reveal further similarity between users.

Booker et al. (2007) attempts an evaluation of the personality tests through an on-line student course recommendation system. It compares and contrasts the Big Five personality questionnaire against simple past behaviours as part of a learning algorithm for understanding which traits are important in the selection of courses students find appealing. Pennock et al. (2000) conducted empirical experiments on the EachMovie database of movie ratings, and on data collected from the CiteSeer digital library. The authors developed a collaborative filtering system to make recommendations about movies and scientific articles. Here user profiles have been
enhanced introducing a personality diagnosis, and then given a user’s preferences for some items, they computed the probability it is of the same personality type as other users, and finally the probability that he or she will like new items. Tkalčič et al. (2009) uses a similar approach to build a collaborative filtering recommender system based on the big five-personality model. In this system recommended items are selected directly from highly rated items from a lists of similar neighbours, being the similarity calculated according to personality. (Hu and Pu, 2010b) does not rely directly on the personality parameter but has incorporate it instead in a more complex weighting systems in which the personality factor is combined with a weight based on similarity of ratings between users (for items that they have all purchased) as more traditionally used in commercial web sites using collaborative filtering for suggesting items (e.g. Amazon). For items that have not been rated by more users, such as new items, and commonly for new users that have only done a limited number of rating then the component of the weight related to personality will assume higher impact.

Following a more direct approach (Hu and Pu, 2010a) implemented a system that uses a direct mapping between personality and music preferences. This is based on several studies that attempted to assess the relation between Personality and Music. Perkins (2008) gives an extensive survey on the psychological studies that have investigated the five-factor model in conjunction with musical preference. There is a prominent belief that music preference can provide accurate psychological information has been supported by a number of studies that have uncovered significant correlations between certain music preferences and particular personality traits. Radocy and Boyle (2003) extensively reviewed current explanations of a variety of musical behaviours concluding that ‘psychologists may use expressed musical preferences to assess personality via deviations from population trends regarding musical choices’. These foundations have been object of research by psychologists since early days studies, such as Burt that in the thirties investigated the behaviour of extroverts and introverts in relation to their music preferences (Note that the thirties is the period that when psychologies started a more structured investigation of personality aiming to the development of a proper personality factor model John et al. (2008). His original findings claimed that that ‘stable extraverts would be attracted to music that possessed dynamic equilibrium, solidity, and weight and a certain predictability, as well as balance and brightness’ whereas stable introverts are attracted to musical pieces that
“reveal a feeling of unity and are more likely to take an intellectual stance, valuing aspects of form rather than emotional expression with the listener appearing to take a cold and critical stance to pieces’. In his terminology the definition of ‘stables’ corresponds to the opposite of neurotics, also called ‘unstables’ in his work.

In particular, the model for a music recommender application proposed by (Hu and Pu, 2010a) is based directly on the landmark work of Rentfrow and Gosling (2003), and directly maps the personality of users (acquired through the Big Five on line questionnaire) with specific music genders. In their work Rentfrow and Gosling identified four musical preferences groups: reflective and complex (e.g., blues, jazz, classical and folk); intense and rebellious (e.g., rock, alternative, and heavy metal music); upbeat and conventional (e.g., country, religious, and pop music); and energetic and rhythmic (e.g., rap/hip-hop, soul/funk, and electronic/dance music). They also stressed the fact that musical preferences are not only associated with the level of complexity, emotionality and energy transmitted by musical compositions, but also individual differences in personality, ability and self-perception. More specifically they conducted a correlation analysis revealing that ‘the reflective and complex dimension is positively related to Openness to New Experience; the intense and rebellious dimension was positively related to Openness to New Experiences; the upbeat and conventional dimension has positive correlations with Extraversion, Agreeableness and Conscientiousness, and a negative correlation with Openness to New Experience; the energetic and rhythmic dimension is positively related to Extraversion and Agreeableness’. The authors then evaluated the application through a small group experiment involving an on-line questionnaire to gain user feedback and evaluate the system, further validating these results with known techniques to determine their statistical significance (ANOVA).

Nunes et al. (2010) again look at the application of personality questionnaires for decision-making problems. However, differently from the case of personnel selection, the questionnaires were not filled by the subjects under consideration but by third parties. The authors conducted experiments with a group of students with the goal of taking decisions on ‘who would be the best next French president’, based on the results of the personality questionnaire filled on behalf of the two actual candidates contending for the presidencies. Decisions were then taken from the estimate of their
personalities returned form the tests and according to the matching to some given criteria about hypothetical personality characteristics of an ideal president.

Seck et al. (2005) focuses on the concept of cognitive complexity as an important factor in decision making in problem solving. In particular it examines the relation between complexity and personality traits. It concludes that openness presents a positive correlation with cognitive complexity and so dynamic updates of openness corresponding to the changes in its facets (possible in particular circumstances, for example under stress and fatigue) can increase the complexity of a problem and consequently affect the decision making abilities and performances. The application of dynamic personality filters to human performances in human behaviour, as represented in simulation studies, is found as a possible corrective element for these particular conditions.

The need for cognition

Another variable that is of fundamental importance for understanding and analysing human behaviour is the concept of need for cognition. Historically, research on cognition has focused on two main issues: study of the nature of knowledge, and that of the underlying processes enabling that use and acquisition of it. The notion of ‘need for cognition’ was introduced for the first time by Cohen in the middle fifties, (see Cohen et al. 1955), who described the need for cognition as ‘a need to structure relevant situations in meaningful, integrated ways. It is a need to understand and make reasonable the experiential world’. In other words it reflects the tendency for an individual to engage and enjoy in effortful thinking or other related cognitive activities (Cacioppo and Petty, 1982). In their article, Cacioppo and Petty realized that there was no specific test for measuring it directly and they proposed a scale of 45 items. In the same work four case studies were presented conducting a factor analysis of the proposed scale in different experimental conditions. For example they tested the scale with two groups of subjects expected to have respectively high and low-need for cognition values and, in a further study, they aimed to test the correlation between need for cognition and other significant variables such as cognitive style and anxiety.

In a later work the same authors proposed a reduced scale of 18 items (Cacioppo and Petty, 1984), that is still used as a standard to measure the need for cognition,
showing a very high correlation with the results of the longer scale produced in the early work. Other authors have subsequently investigated this topic and acknowledged the importance of the concept of need for cognition, see for example Epstein (1994) that included need for cognition in his rational against experiential construct (in his work he assumes the existence of two parallel interacting modes of information processing for the human brain: a rational system and an emotionally driven experiential system).

A further group of papers have investigated the relationship between the need for cognition and the big five-factor model of personality discussed earlier in this section. For example (Sadowsky and Cogburn, 1997) conducted a study on 85 undergraduates in which the results from the short form of the need for cognition test was compared to the NEO-FFI scale from Costa and McCrae. Looking at the original definition of Cacioppo and Petty in 1982 and their later studies on persuasion (Petty and Cacioppo, 1986), the authors were expecting a positive correlation between need for cognition and some components of the five-factor model such as openness to experience and consciousness. The results obtained confirmed the expectations. The first relationship is explained by directly referring at the definition of need for cognition as enjoying in effortful thought, which relates to the enjoyment for cognitive activity reflected by openness to experience, whereas the correlation with consciousness seems more related to the tendency of engaging in cognitive experiences. Hence need for cognition appears to be conceptualized as a multi-facet construct.

The authors also measured a negative correlation between need for cognition and neuroticism; this is consistent with other studies that found instead a positive correlation with opposite characteristics of personality, i.e. between individuals high in need for cognition and having stable self-concept and effective capacity of coping. However, this can be a consequence of the negative correlation that is recognised between consciousness and neuroticism, thus concluding that the need for cognition itself cannot be interpreted as a direct measure of instability (neuroticism).

A very recent study (Zhong et al, 2011) explored the connections between need for cognition, the predisposition in making large use of innovation in computer technology (called ICT innovativeness), and the use of social networking. Results
suggest that people high in need for cognition are less inclined to make large use of social networking whereas they seem keener on the use of more traditional media. Vice versa individuals with low score in the test for need for cognition usually are also frequent social networking users. ICT innovativeness is presented as a possible trait of personality and, as expected, results positively correlated with the use of social networking. However, the authors underline that this study cannot be interpreted as a conclusive one and some apparent inconsistencies may require further investigation, for example, the correlation between ICT innovativeness and need for cognition is less evident. In fact high need for cognition is related to low ICT innovativeness but this is not valid for individuals with medium scores in the need for cognition test that appear more ICT innovator than those with low scores (that are instead massive social networking users). Moreover, it would be interesting to investigate the relation between social networking and other personality traits (such as those of the five factors model).

**Personality and information seeking**

Hamburger and Ben-Artzi (2000), conducted a study that aims to analyse the relations between extraversion, neuroticism and the use of Internet. The study was conducted in Israel and considered gender differences among its parameters. Results were generally consistent with other studies but gender differences appear to have a different effect. For example, with men, extraversion was positively related to the use of leisure and social services and neuroticism was negatively related to information services. Different results were obtained with women, for whom extraversion was instead negatively related to social services whereas neuroticism related positively. The authors attempted to partially explain these results by noticing that, for example in the case of neuroticism women can found a feeling of safety in the anonymity that social networks can offer whereas the negative connection between men and information can be directly related to the known negative correlation between neurotic subjects and need for cognition. The study also implicitly reveals how services of the same kind can be used and seen in different way by subjects with different personality, for example social networking (at the time of the article in its very early days) is used by extraverted to increase their opportunity to socialise, whereas neurotics can feel comfort in the possibility of avoiding physical contacts offered by these services.
Similar conclusions are reported in (Gombor and Vas, 2008) that, more recently, has conducted a study on internet affinity and the big-five factors among medical student again of Israeli and Hungarian origin. Although some differences for nationality were found, this study shows how both extraversion and neuroticism can be positively related to Internet affinity. Internet affinity was measures by the five items scale proposed by Papacharissi & Rubin, see (Papacharissi & Rubin, 2000). Extraverted people have stronger communication needs, are more sociable and more externally oriented so they can experience the Internet as an extension and not as a substitute for social or interpersonal communication, whereas neurotic subjects, who tend to be more tenser, worried, anxious and to have more guilt feelings, may use the Internet in order to find relief from tension and anxiety. This latter effect, that was much more statistically evident among Israeli students, also shown that these subjects may be most likely using the Internet as a dependency tool, thus being at greater risk to develop an Internet addiction.

Other researchers have examined personality traits to explain information behaviours (Borgman 1989 Heinström 2003, 2006; Tidwell 2005, Hydegård 2009) drawing similar conclusions about neurotic and extraverted individuals. In their study consisting of 600 Indian college students, Halder et al. (2010) report solid association between personality traits and information seeking. A further tendency that can be observed is that introverted, personalities prefer information which confirms previous knowledge whereas acquiring new ideas appears more typical for outgoing, open and conscientious students. For example, browsing and wide enthusiastic exploration of information tend to be common among those who are outgoing and open to experience (Heinström 2003). This suggests that such traits increase the opportunity conducting successful searches to completion. In his research, Miculincer (1997) reports that people who were more emotionally secure tend to actively seek information and accept new knowledge. In contrast, those who are insecure tend to have difficulties in coping with unpredictability, disorder and ambiguity in the search systems. They have a tendency to finish the search process as soon as possible and this can result in premature decisions based on insufficient information with the consequence that insecure persons are less likely to change their views and accept
new information they are. This insecurity and nervousness could be linked to neuroticism and can indeed be a barrier to information seeking.

The findings reported above also suggest possible associations between personality traits and information competency. In a recent study Kwon and Song (2011) conducted a survey on a sample of 185 college students at a large public university in the southeastern United States. The study results show that three of the five personality traits were significant determinants of information competency among the population sample. Those students, who are more conscientious, open to experience, and extroverted tended to report greater information competency than students who are not. Neither neuroticism nor agreeableness was identified as determinants. According to previous findings, the study investigated on gender-specific personality traits that affect information competency. Specifically, the study finds extroversion to be a male-specific trait and openness to experience a female-specific trait. The results identify conscientiousness as the most consistent and robust determinant of information competency across both genders. Data about personality have been collected using standardized survey instruments, including Costa and McCrae’s NEO-Five Factor Inventory.

Finally, the association between personality traits and information behaviours is extensively investigated by Heinström, see for example (Heinstrom 2003; 2006) in her series of studies conducted in Finland and the United States. Heinström’s research explains unique behavioural patterns of information seekers using Costa and McCrae’s Five Factor Model. In particular, she identifies three unique information-seeking styles explained by different combinations of personality traits: ‘fast surfing’, ‘broad scanning’, and ‘deep diving’. Fast surfers tend to put minimal effort into searching and so their searches lack generally of thoroughness. They also exhibit the personality traits of emotional instability, lack of conscientiousness, and little openness to experience. Wide browsing and thorough information exploration using diverse sources characterize ‘broad scanning’. Broad scanners tend to have greater opportunity to encounter relevant information and feel at ease evaluating information. The characteristic personality traits of this group are strong extroversion and openness to experience, and low agreeableness due to their competitive tendencies. Deep divers
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tend to put considerable effort into finding information and very discerning of
information quality. A strong personality trait of this group is openness to experience.
These findings suggest that certain personality traits might be prominent among
competent in searchers and users of information, thus confirming the results on
information competency discussed above.
5 Spatial perception and surrounding context

5.1 Spatial cognition

Spatial cognition is the capacity to discover, transform and exploit spatial information present in the environment such as location, size, distance, direction, shape and topological relations between objects (Landau B., 2002). In the human and animal mind, spatial cognition is enabled by a combination of signals from multiple sensory modalities and motor signals (Colby & Olson, 2008). Distance as well as other spatial properties can be encoded through sensory modalities such as sound (Blauert, 1997) and touch, although the spatial aspect of cognition is more often linked to vision (Klatzky & Lederman, 2003).

The affinity of vision with spatial cognition led to the subordinate field of visuospatial thinking, which studies applications of spatial cognition in navigation and wayfinding, using visual clues from the environment, as well as spatial interpretation of 2D or 3D visual schematic representations, such as maps of user interface elements (Shah & Miyake, 2005). Spatial Cognition research also has close links with several disciplines, including psychology, philosophy, linguistics, neuroscience, computer and information science, and others (Montello 2009).

Objective vs. Subjective Space

Recent advances in the understanding of the neurological underpinning of spatial cognition led to the conclusion that multiple parallel systems are at work in spatial thinking, systems which make use of various reference frames (Burgess, 2008). These frames can for example be object-centred, focusing on the object of attention, or hand-centred, focusing on the hand during object handling. However, all frames of reference of spatial cognitive systems fall in two broad categories: egocentric and allocentric. Egocentric representations are body-centred and related to the receptors and effectors of the agent in an environment, while allocentric representations are centred on environmental landmarks independent of the agent (Burgess, 2008).

The dichotomy ingrained at the neurological level is reflected by more speculative work about space and in the approach to space itself. In existential phenomenology for example, which explores the human being’s perception of life and of the
environment, space also appears in two interrelated flavours (Malpas, 1999) corresponding to the above categories. Allocentric (or objective) space is the *flavour* of space commonly considered in science and in cartography, while egocentric, or subjective space is closely linked to human activity. The table below lists the characteristics of subjective and global spaces as explored in the philosophical work of Martin Heidegger, adapted from (Dreyfus, 1991).

<table>
<thead>
<tr>
<th>Objective space</th>
<th>Subjective space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical space</td>
<td>Lived space</td>
</tr>
<tr>
<td>Homogeneous, no centre</td>
<td>Personal, centred, process oriented</td>
</tr>
<tr>
<td>Pure extension</td>
<td>Orientation (up/down, right/left)</td>
</tr>
<tr>
<td>4-dimensional multiplicity of positions</td>
<td>Remoteness/nearness of objects, regions and places</td>
</tr>
<tr>
<td>Measurement of distance</td>
<td>Degree of availability</td>
</tr>
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</table>

**Naïve Geography**

According to the perception of space at work, i.e. egocentric or allocentric, the same portions of space-time can be experienced differently, for example as longer/shorter according to the individual effort needed to reach a destination, which is a measure of the subjective degree of availability of an activity, rather than measurement of distance (Egenhofer & Mark, 1995). Other aspects of subjective space constitute heuristics identified by Naïve Geography, according to which:

- Naïve geographic space is considered two-dimensional
- The earth is flat
- Maps are more real than experience
- Geographic features are ontologically different from enlarged table-top objects
- Geographic space and time are tightly coupled
- Geographic information is frequently incomplete
- People use multiple conceptualizations of geographic space
- Geographic space has multiple levels of detail
D1.2 COGNITIVE BEHAVIOUR FOR SELF-AWARENESS

- Topology matters, metric refines
- People have biases toward North-South and East-West directions
- Distances are asymmetric
- Distance inferences are local, not global
- Distances don't add up easily

**Places**

For the human mind, the geospatial environment is organised as places rather than sets of geospatial coordinates (Egenhofer & Mark, 1995). Places are more than their spatial footprints and the features that occupy them. Indeed, the human mind partitions space into places at different scales, coalescing as a conceptual nexus of various precisions and levels of detail according to the experience and knowledge one has of them. Places appear as complex thematic entities in relation with the physical configuration of the environment as well as with human cognition such as memory (Tuan, 2001). Moreover, they are spatial regions that support structures of functional significance for the agent in an environment and act as attention anchors, through salient features that make them useful or interesting, memorable because of past experiences, or desirable as expected loci of anticipated ones (Gibson J. J., 1986) (Jordan, Raubal, Gartrell, & Egenhofer, 1998) (Bennett & Agarwal, 2007).

Hence, places are essentially vague, contextual, and personal. Indeed, their boundaries are difficult to evaluate and their meaning changes according to the task at hand, varying according to the agent’s physical and cognitive characteristics. For example the notion of town centre considered as a place, seldom has a delimited area, is experienced differently in a business or a touristic context, and its meaning varies for distinct social groups.

Places and therefore their naming are often vague in their extent (as in Midlands, South Wales, in the UK) like more traditional geographic entities such as ‘valleys’ (Galton & Hood, 2005), ‘mountains’ (Smith & Mark, 2003) (Fisher, Cheng, & Wood, 2007) (Varzi, 2001), or ‘forests’ (Bennett B., 2001). Moreover, between places, topological spatial relations such as *near, at, between, north* and neighbourhood relations are fuzzy as expressed in the use of spatial language (Frank A. U., 1996) (Shariff, Egenhofer, & Mark, 1998) (Landau & Jackendoff, 1993)
Places, as part of the environment, present physical or social affordances (Raubal & Miller, User-Centred Time Geography for Location-Based Services, 2004), as well as opportunities for social interaction with other agents, or the absence of them (Clark & Uzzell, 2002). A restaurant for example can be described by a means-ends hierarchy that, for the purpose of having lunch, presents the place as allowing socializing, news and food consumption through the activities of eating, talking, reading newspapers and observing others (Jordan, Raubal, Gartrell, & Egenhofer, 1998).

**Affordances**

Affordances are the opportunities of action provided by the environment to an agent. The term, as well as the concept of affordance, was introduced in (Gibson J. J., 1986) as a basis for ecological psychology, a branch of psychology focussing on the study of a subject situated in their environment, rather than in laboratory conditions.

The notion of affordance can be seen as linking an agent to the environment in which it is situated: once detected, an affordance is meaningful and has value for the agent. It is nevertheless objective, inasmuch as it refers to physical and psychological properties of the agent (Gibson & Adolph, 1999). Moreover, affordances depend on the specificities of the agent: what is enabling and therefore meaningful for one agent would be meaningless for another. Simple human affordances such as ‘climbability’ have been verified experimentally: over a certain ratio between the riser height of stairs and the leg length of the subject, or their age, or their degree of fitness, the subject ceases to consider it climbable (Konczak, Meeuwsen, & Cress, 1992).

Gibson argues that for agents evolving in an environment, it is affordances that immediately matter, rather than other perceptual aspects of surrounding entities such as shape or colour (Gibson J. J., 1986, p. 134). Another claim of ecological psychology is *direct perception*, which states that the perception of real-world elements, here affordances, does not involve any (symbolic) inference or other (internal) logical process. The direct perception thesis supports the manner in which our bodies often seemingly act in the absence of conscious reasoning, or even knowledge. Direct perception can be seen as a heuristic, at least at a computational level, as it avoids the representation phase.
**ICT Use Cases**

Montello (Cognitive research in GIScience: Recent achievements and future prospects, 2009) has identified several domains of application for research in spatial cognition: (i) human factors of GIS, (ii) geovisualisation, (iii) navigation systems, (iv) cognitive geo-ontologies, (v) geographic and environmental spatial thinking and memory, and (vi) cognitive aspects of geographic education. Amongst these, navigation systems and cognitive geo-ontologies have a wide impact on end-user ICT applications. Indeed, around 14.4 million portable satellite navigation systems were sold in 2007 (GfK, 2008) and this trend increased with the popularisation of smartphones including GPS technologies and free navigation systems. Geo-ontologies are needed for applications using geospatial data and are implicit in location APIs providing business listings such as Foursquare\(^2\), Google Places\(^3\), Gowalla\(^4\), SimpleGeo\(^5\), OpenStreetMap\(^6\) or Yelp\(^7\).

**Navigation**

Navigation can be defined as “coordinated and goal-directed movement through the environment by organisms or intelligent machines” (Montello D., 2005). The support of ICT can be required for way finding and determining the appropriate amount of information to support that this activity (Montello D. R., 2009). Notably, research has been conducted to determine which level of schematisation is the most appropriate for navigation tasks, from highly schematic such as subway maps, to full digital imagery and combinations of each (Berendt, Rauh, & Barkowsky, 1998) (Agrawala & Stolte, 2001) (Klippel, Richter, Barkowsky, & Freksa, 2005). Other research has determined that successful navigation only requires approximate information, such as the general direction, through visual indication or other sensory clues such as device vibration, or whether or not having boarded the right vehicle or path segment.

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\(^2\)https://foursquare.com/
\(^3\)http://www.google.com/places/
\(^4\)http://gowalla.com/
\(^5\)https://simplegeo.com/
\(^6\)http://www.openstreetmap.org/
\(^7\)http://www.yelp.com/
Cognitive Geo-ontologies

High level semantics have been advocated in geographic information systems to help the integration of heterogeneous data between systems (Bishr, 1998), to allow reasoning in GIS (Fonseca & Egenhofer, 1999) (Fonseca F., Egenhofer, Agouris, & Camara, 2002), and accommodate the user's cognitive abilities (Egenhofer & Mark, 1995) (Montello D. R., 2009).

In ICT, high level semantics are often expressed as ontologies, which described taxonomies of entities. However, there is a strong consensus that geospatial knowledge is somehow “special” (Anselin, 1989) (Goodchild, 1992) (Peuquet, 2002), which constitutes a challenge for taxonomy based approaches. Hence the use of elements such as “classes, relations, functions, distinguished objects, and axioms”, similar to previous approaches such as formal data models, formal specifications, or semantic networks has raised concerns regarding its possibility of success (Winter, 2001).

In an attempt to address these issues help has been sought in cognitive approaches (Kuhn, 2003). This exploration resulted in alternative representation approaches such as affordances (Jordan, Raubal, Gartrell, & Egenhofer, 1998), image schemata (Frank & Raubal, 1999), conceptual spaces (Raubal, Formalizing Conceptual Spaces, 2004), multi-representation (Spaccapietra, Parent, & Vangenot, 2000), processes (Reitsma, 2004) or distinctions-based approaches (Frank A. U., 2006).

Location-based services

Location-based Services (LBS) are services that consider the user’s physical location (Küpper, 2005). LBS are “any [wireless-IP service] service that exploits the position of a mobile terminal.” (OGC, 2008, p. 4). A LBS of special interest to users are directory services that allow them to find the nearest and specific places, products, or services (OGC, 2008 p. 8). Given a position and a symbolic request (keyword, category, etc.) the directory service returns ranked results within a specific area.

Possible use cases of directory LBS are (OGC, 2008 p. 8):

1. “Where is the Red Dragon Chinese Restaurant?”, uses a known identifier and therefore corresponds to a so called White pages query, since the proximity of the retrieved location is irrelevant.
2. “Where are the Chinese Restaurants?”, using a request by attribute and therefore corresponding to a yellow page query.

3. “Where is the nearest Chinese Restaurant to my hotel?”, a proximity query based on a given location.

4. “Which Chinese Restaurants are within 500m of my hotel?”, a bounded proximity query based on a given location.

The widespread adoption of smart mobile devices, supported by the continuous development of so-called Web Mapping 2.0 (Haklay, Singleton, & Parker, 2008) has led to an increased usage of social-driven location-sharing applications, such as Foursquare, Gowalla, Google Latitude and Facebook. Users of these applications retrieve places daily for the purpose of checking in, i.e. confirming one’s location to keep a record of it or share it with their contacts. Moreover, demand for place-oriented search is growing, driving visitors towards specialised Web services such as Yelp, Qype and Google Places.

Notable APIs available to developers are Foursquare, Google Places, Gowalla, DBpedia, SimpleGeo, OpenStreetMap, Yelp, Facebook Places, Factual, CitySearch and Twitter Places. POIs can be queried by radius centred on a point location, by bounding box, or both. Typical query results are lists of geofeatures, in JSON or XML syntax following a proprietary model.
6 Related concepts

This Section outlines a further group of related psychology areas that can potentially be applied to the development of ICT systems. These include areas not directly related to cognitive psychology, such as neurophysiology and clinical psychology, whose methodology could, however, be incorporated into information systems. In addition, we provide a brief overview of a very broad existing area such that of human computer interaction, here trying to focus on those aspects mostly related to human cognition.

6.1 Concepts from neurophysiology

Understanding of the neurophysiological basis of cognition has been often reported as one of the greatest challenges faced by neuroscientists with concerns of the scientific study of the nervous system and the representation of the brain by networks of neurons. Although originally considered as a sub-area of biology, it spans multiple disciplines including psychology, neurology, clinical neurophysiology, neuro-anatomy and cognitive science, with applications to other broad fields as mathematics, physics and computer science. Within this context electroencephalography of cognitive functions and spike train modelling will provide some important links with the neurophysiology underlying the heuristics and the awareness node. Our aim will be to acquire some expertise on the “bio” side which could improve our capability of understanding heuristics and their implementation.

Electroencephalography (EEG) analysis of cognitive performances

EEG analysis is an efficient non-invasive method for people to understand the mechanism of brain activity. With the increasing research into cognitive progress which includes sense, consciousness, memory, recognition, thought, reasoning, problem-solving, learning, imagination and language, EEG analysis has become one of the most important approaches in this field [1,2,3]. EEG has been used for assessing attention deficit hyperactivity disorder (ADHD) and sleep deprivation [4]. Experiments trying to emerge patterns of creativity resulted in alpha activity in frontal brain regions, while in temporal cortices of brain, a small alpha desynchronization was observed. A publication in PLOS ONE reported on an experiment on 21
volunteers with EEG as they tackled verbal problems in an attempt to uncover what happens at the moment of problem solving [5]. New experiments focus on decision making, conflict monitoring and reward feedback and errors in problem solving. Alpha brain rhythms are associated with a relaxed and open mind; volunteers who unwittingly solved problems showed more robust alpha rhythms than those who knowingly adjusted their thinking to come up with the answer.

There are also correlates with meditation; for instance paroxysmal gamma waves (PGW) were observed in eight subjects practicing a yoga technique of breathing control called Bhramari Pranayama [6]

Researchers reported that electroencephalography (EEG) brain wave sensors and electromyography (EMG) muscle sensors on the leg can be used to detect braking intention before the driver depresses the brake pedal. Similar for pressing buttons in a mobile phone.

In the study of cognitive activity, Event-related potential (ERP) is one of the main approaches recently [3]. ERP carries more information of brain structure and corresponding functions because of its specificity, namely the association of specific stimulation and the close relationship with specific feeling cycle. Studies show that ERP's are capable of reflecting the alternation of neural physiology in cognitive progress, and this advantage makes ERP become the main information source of understanding the neural basics of cognitive science. When people are in different kinds of cognitive activities, the dynamic characteristic of human brain is different as long as ERPs are different. The ERPs in subjects with brain disease such as epilepsy and schizophrenia are of great difference to that of normal subjects in cognitive activities.

The main contribution that this field could provide to the Recognition project is to develop methodologies for cross comparing and meta analysis of electroencephalography signals from a large variety of cognitive performances available through databases and personal contacts with researchers. One possibility is to investigate brain areas involved in earthography (grid cells).

_Spike train methods for the study of patterns in human mobility and proximity_
The field of *neural coding* (Fetz 1997) offers methods and tools for analysing and classifying different patterns in human mobility and encounters. In the case of neural coding, scientists deal with networks of animal neurons and the electrical and chemical signalling that occurs within them. The impulses at a particular neuron are often modelled as an abstract series of zero-duration spikes, referred to as a *spike train* (Brown et al. 2004). The motivation to understand the spike trains of individual neurons and how ensembles of neurons interact has produced a vast body of literature. Scientists in both domains (human mobility analysis and neural coding) are dealing with similar data types and measuring similar properties. In the case of mobility, an individual's visits to one of their significant locations can be viewed as a spike train, with each visit corresponding to a spike. For encounters, a period of proximity between a pair of individuals represents a spike on the pair's train. Spike train methods such as synchrony and clustering can be applied to detect regularity in mobility and encounter data or find communities of individuals with similar patterns.

Both fields of neural coding and human mobility analysis have sought to detect and exploit temporal structure present in their respective data. In the context of neural coding, methods to measure the temporal properties (such as regularity) of neuron spike trains are important for understanding how the brain works. Recently, the focus of study of human networks and behaviour has moved from static characteristics to dynamic characteristics. The daily and weekly cycles of human routine give rise to a degree of regularity in mobility allowing for high predictability in many cases (Gonzalez et al. 2008). The presence and utility of regularity in mobility and encounter patterns has been proven by various sources and applied in a variety of domains (Scellato et al. 2011; Clauset and Eagle 2007; Lahiri and Berger-Wolf 2009; Scellato et al. 2010; Musolesi and Mascolo 2009; Mashhadi et al. 2009).

An ensemble of spike trains with near-synchronous spiking patterns is said to exhibit high *synchrony*. Many measures of synchrony have been proposed. A common approach is to consider the *interspike intervals* (*ISIs*) of the spike trains (Kreuz et al. 2009; Kreuz et al. 2011). *ISI-Diversity* (Kreuz et al. 2009) is a distance metric based on the ISI approach, and produces a measure of the dissimilarity in an ensemble. This
can be used to develop a regularity metric for a user's visits to a particular location or a user's encounters with a particular acquaintance. To do so, an $N$-week period of visits (or encounters) is taken and segmented into $N$ week profiles to form an ensemble of spike trains. In each week profile, the spike times are transformed to become an offset from the start of the week; thus, a spike time offset $t$ in a week profile falls in the range $0 \leq t < 604,800$ seconds. Formally, we denote with

$$\{t^n_i\} = \{t^n_1, \ldots, t^n_{M_n}\}$$

the spike times of the $n$th week, where $M_n$ denotes the number of spikes in week $n$. The interspike interval (ISI) is the time difference between two consecutive spikes of the same profile. The instantaneous interspike interval at time offset $t$ for week $n$ is defined as

$$x^n_{\text{ISI}}(t) = \min(t^n_i^a | t^n_i^a > t) - \max(t^n_i^a | t^n_i^a < t)$$

for values $0 < t < M_n$. The coefficient of variation $C_v(t)$ quantifies the variability of ISI values among the $N$ spike trains at time offset $t$ and is obtained by

$$C_v(t) = \frac{\sigma(\{x^n_{\text{ISI}}(t)\})}{\langle \{x^n_{\text{ISI}}(t)\} \rangle}$$

where $\sigma(.)$ denotes sample standard deviation and $\langle . \rangle$ denotes sample mean. Finally, the $\text{ISI-Diversity}$ metric is obtained by averaging over the week period; that is,

$$D_{\text{ISI}} = \frac{1}{T} \int_{t=0}^{T} C_v(t) \, dt$$

where $T=604,800$ seconds (i.e., a seven-day window). The metric is non-negative with $D_{\text{ISI}}$ indicating identical week profiles.

This simple metric allows the comparison of individuals in terms of their regularity. Various factors may cause some individuals to be highly regular but others more erratic. Examples include profession, age, and income. Regularity may even be correlated with personality traits. Highly conscientious individuals are likely to follow stricter routines and thus exhibit clear week-by-week visiting patterns while extraverted individuals may seek out diversity in the places and people they visit.
6.2 Group Dynamics

A further related area is that of clinical psychology, that is the branch of psychology which deals with pathologic behaviour. The concept of small group dynamics originated from this field (Bion, 1952). As noticed by W. Bion, the dynamics of a small group is interesting, since it does not relax on a stationary state.

According to many studies (Dunbar, 1992) the dimension of human groups has a deep (evolutionary) relationship with our neural structures. One can distinguish several groups dimensions: the chat group, formed by two up to four people (easily recognizable during a party), the social group dimension (around 150 individuals, Dunbar number) that corresponds to the maximum number of people of which one can track mutual relationships, and the small group, up to 10-12 people, which is the “working unit” that presumably is related to the need of “keeping track” others’ mental processes. It is well known in military and work organizations that the ideal size of a unit should not exceed this value (a typical patrol or squad is formed by 8-13 individuals). Also in job organization, a group of 7 up to ten individual is considered the best for productivity. As Bion observed, the dynamics of such group is however complex. While a chat group has a simple dynamics (it forms, lasts for some times and then disaggregates), and a social group is essentially stationary, that of a small group has an oscillatory character: sometime it fractions into chat groups, sometimes it is all focussed at one individual, sometimes it has a tree-like organization. Clearly, the “network structure” of a group is also related to the task that the group has to perform. However, even the most important task like a war action or an important delivery of work results cannot maintain the group coherent for a long time. The well-known practice of breaking the work each hour or each two hours with a “relaxing” coffee break is due to the impossibility of keeping the group focussed without having it to fraction in chat discussions.

Beyond work organization, the dynamics of social groups is interesting because it gives information about our evolutionary origin and on the cognitive structures that are in action. Moreover, the mental disposition inside a social group (chat, small and social sizes) is different from, for instance, the acceptance of a broadcasting message.

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This fact is sometimes exploited by advertisers that tries to deliver information about a product by means of “peer contacts” (using catchy words, jingles, or paid agents) instead of relying on broadcasted advertisements.

Indeed, the group structure is deeply related to the dynamics of opinion formation, including the perception of risks. The simplest model of opinion formation is that based on a linear decomposition of the opinion on a match between personal preferences and object properties. The “ideal” opinion would be the given by the match of these two set of factors, and should be detected by a factorial analysis. However, it is well known from the practice of performing analysis by questionnaires that there is a strong dependence on the order of questions and the environmental factors. Moreover, the “permeability” of a message depends on the social channel used. So, the simple model of pattern matching should be at least complemented by the evolution of personal preferences, due to the interactions with others. One of the simplest ways of accomplishing this task is by introducing the “affinity” among couples of individuals; this affinity grows with matches and decreases with mismatching. In mathematical terms, the introduction of the affinity corresponds to shift from a first-order to a second-order dynamics, with the possibility of oscillations, chaotic behaviour, etc. Clearly, this does not exhaust the field of modelling. The fatigue (temporary decrease in the interest) is surely a component of the dynamics of small groups. A non-linear correspondence between matching, social pressure and response is to be considered. As examples, one can consider the appearance of social norms (attracting configuration of neighbours) or anti-conformity (the opposite behaviour in the presence of a marginal majority, related to the cognitive dissonance). Clearly, nonlinearities can easily induce “chaotic” oscillations, and make factorial analysis more difficult.

6.3 Cognitive aspects of HCI and information relevance

Cognitive models have been frequently used within the Information and Communications Technology (ICT) domain. In particular, concepts related to information processing and relevance have been applied to information retrieval systems.
The notion of relevance.

Relevance theory (Sperber, and Wilson, 1986) postulates that people generate consequences from rules according to accessibility and stop this process when expectations of relevance are met. This theory can reflect implications of psychological relevance for research in evaluation of information retrieval systems (Arvola and Kekäläinen, 2010). Combined with fundamental cognitive behaviours, it is of particular interest because it explains how wide-ranging inputs can be used to guide a human towards true meaning. This is fundamental because it enables autonomic components in translating from data to information and knowledge, thus enabling a seamless shift between different levels of abstraction.

The theory of relevance is based on an inferential model that takes into account context via ‘utterances’ defined as complete units of speech in spoken language, usually separated by intervals of silence. Utterance representations also exist in written languages and can be defined in several ways, as well as their interpretations and their cognitive effects. In fact, the understanding of an utterance not only relates to knowing the meaning of the sentence uttered. Inferential communication has a basis in human cognition since individuals represent, process and pay attention to different phenomena in different ways with the aim of maximizing the relevance of their representation as well as that of the act of processing. This has direct consequences in human communication: the speaker purposefully gives cues to the hearer suggesting the information she offered is relevant enough to be worth their attention. The hearer infers the intention from them and the context-mediated information. The hearer must interpret the cues, taking into account the context, and surmise what the speaker intended to communicate. He will then interpret the utterances considering the specific context and take decisions on its meaning, that can be for example literal, metaphoric, ironic and so on.

The relevance principle states that ‘Every act of inferential communication creates a presumption of optimal relevance’. Therefore the communicator will try to create a presumption an expectation of relevant content and will dose the effort required in order to both gain attention and make the information conveyed accessible to user that are processing it. How much is required in terms of contextual effects will depends on the particular situation and audience and constitutes one of the main outcomes of the
whole relevance theory (Sperber, and Wilson, 1986).

In (Harter, 1992) the concepts of information, information need, and information-seeking processes are explored, considering different aspects such as topic relevance, bibliometrics, relevance judgments and retrieval testing. (Brumby and Howes, 2008) investigates the impact of label relevance for assessment and selection during web searches. Here people often estimate the likelihood that labelled links on the page will lead to their goal. A rational analysis of this activity suggests that people should adjust their estimate of the likelihood that any one item will lead to the goal in a manner that is sensitive to the context provided by the likelihoods that other items on the page will lead to the goal. Two experiments have been designed to provide evidence to discriminate between this account and others found in the literature (e.g., satisficing and assess-all accounts).

Xu (2007) analyses the significance of information retrieval in information searches. It focuses on non-problem solving information searches, i.e. when users search information for epistemic value or entertainment and not to solve any specific task. When users search information just to satisfy their desire for knowledge rather than to solve immediate problems, we describe this as an epistemic information search; when they search information for fun or affective stimulation, we define it as hedonic information search. The work explores the concept of relevance in both these scenarios attempting to answer questions such as: is the concept of relevance as used in other context still valid for this type of searches? The literature about the concept and use of relevance in information searches is broad. Only referring to the work of Saracevic (1996) ‘subjective topicality refers to how a document as related to the subject of interest as perceived by the user; cognitive relevance refers to how a document affects the current state of knowledge in a user; situational relevance refers to the pragmatic utility of the document in problem solving and, finally, motivation affective relevance refers to the emotional reaction to a document, as to whether it satisfies the intents, goals, and motivations of the user’. A further classification relates to the validity of a document: epistemic value is the utility of a document as perceived by the user to the extent of fulfilling its desire for knowledge or information; functional value is the document utility in terms of the actual contribution to a specific task (there can be also a conditional value, that is the future potential value of
a document under certain circumstances). Finally the *emotional value* concerns feelings, affective states, and the sensory-emotive reactions aroused in the users. The authors conducted a group experiments in which a questionnaire was compiled to identify which specific characteristics of a document relates to both the classifications above in terms of relevance and document utility.

The variables considered for a generic document were *topicality, novelty, reliability, scope* and *understandability*. Results indicate topicality and novelty as the principal variables related to informative searches (i.e including cognitive and situational relevance and the functional value) whereas scope and understandability are not (or they are only to the extent that allow the user to have a sufficient idea of the goal and overall meaning of the document). This reflects the results obtained for normal problem solving searches, with the difference of the further importance of reliability for the non-problem solving case. Classifying all the other definitions of relevance and utility under the category of affective searches, it results that topicality and understandability have the main impact (so users feels happier when the document matches the topic of their searches and it is easy to understand). Note that novelty does not seem to have a significant impact in terms of affective reactions, at least not as important than for informative searches (so users feel happy when a document is novel because of the new information and content produced rather than novelty itself).

As future suggestions the authors aim to investigate more in depth the differences between epistemic and hedonic information searches and the fact that different contexts can have different emphasis on all the relevance criteria considered.

**Cognitive aspects of HCI**

An important application of cognitive models to ICT systems is within the intensely active domain of *human-computer interaction* (HCI, Carrol, 2003). The cognitive aspects of human computer interaction form, nowadays, an important and interesting part of human behaviours. There exist several approaches to incorporate knowledge on these aspects into the design cycle of HTC architectures. They range from using a list of general heuristics based on previous experiences with HTC interfaces to a direct use of complete model of human cognition (Faonti et al., 2007).
Dirive (2010) emphasises the relation between the concept of relevance (and the other parameters characteristic of information searches) and the HCI domain. In particular the article looks at the concept of exploratory searches under a HCI perspective. Exploratory searches are here considered as intermediate between the problem and non-problem solving searches described above and defined as searches that aim to solve a specific task but may present poor familiarity of the user with the domain of their search goal as well as high level of uncertainty to the goal itself and the methods used to achieve it. Concepts as conceptual complexity (based on how much of the how much of the task’s requirements, process and outcomes can be a priory determined) and procedural complexity (how complex are the sub-tasks and sub-steps needed to achieve the task) are also discussed. In particular it is recognised that procedural complexity could be dramatically reduced by the search functionality provided by HCI, for example by implementing tools that facilitate searches activities, but also the cognitive complexity could gain benefits from the design of suitable interfaces, for example in in terms of provision of interactive feedback about the (even estimated) users objectives.

A second paper (Wilson and Schraefel, 2007) investigates the connections between models derived from information retrieval and the evaluation of exploratory searches interfaces. It directly relates to known theoretical works of previous authors, including again to the classifications of searches proposed by Saracevic (1996), by proposing a simplified classification of information seeking strategies in terms of method (users either searching for an information object, or scanning a set of information objects); goal (users learning about a topic or selecting a specific piece of information); and mode (in between recognising and specifying information or topics). The authors then consider three existing systems for exploratory searches and conduct an evaluation by analysing and visualizing in graphs a number of statistics about identification, summarizing metrics, and strength analysis of features (e.g. presence of browser columns, collection spaces, preview players and information panels) and tactics (e.g. for making, changing or conducting multiple selections as well as filtering, sorting and keyword searching facilities). The study suggests that the same approach used for such evaluation could be used to design novel exploratory search interfaces that provide support for search tactics and feature identification and analysis.
Related to the concept of affective relevance (Boehner et al., 2005) points out as in its current interpretation it can operate in concert with the context of traditional cognitive science as a supplement to traditional cognitive accounts and located within the same information-processing frame. This can have a direct effective application in HCI systems in order to optimize the interaction and interface between humans and computer systems. The paper presents two applications for working environments. The first one is a screen representing a famous painting (Blue by J. Miro) that is animated according to the emotional responses of the workers (detected through a complex mechanisms of non-obtrusive sensors), while the second goes a step further, substituting the painting with a video representation of the office (the screen here acting as a window) in which individuals appear distorted in ways that may be read as representing emotion, using specific visual algorithms. Mapping between sensors (e.g. movement in the office) to effectors (specific distortions) is accomplished through a set of rules defined by the office occupants themselves. In this broader sense this form of experience focused HCI becomes not only about computational responses in order to increase the easiness of interaction with computer systems, but can also provide computational influences upon the emotions of a system’s users and can be then exploited to create intelligent systems which can effectively simulate human behaviour.

Affective relevance also links to the work of (Brugnoli et al, 2006) that have investigated the role of implicit and non-verbal communication in mediated environments observing how new technologies appear not yet suitable for conveying social, non-verbal and contextual information. The authors focus on how context and emotional cues to users could be effectively communicated for example using sensor technology for the detection of attention and emotion, high accuracy eye tracking for control and feedback systems, sensor technologies to enhance emotional involvement and social presence in communication networks.

An application of this concept is proposed by (Gamberini et al, 2007) in the context of an online game (with the task of fully exploring a virtual space) where players talk to each other exclusively via textual chat. A social network analysis is conducted during a first phase and then the game is repeated by providing social feedback to some group of players by displaying the results of the analysis on a screen during the actual
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game. Players benefiting of this extra input appear to produce higher scores during the second phase of the game. Applications of social networking analysis by means of display of feedback and statistics on screens have been also used in Morris (2005) that daily displays to elder individuals a visual representation of their social contacts in order to raise awareness to them and their carers and encourage them to a more active social life, and in DiMicco (2004), in which during work meetings a statistics about number and duration of individual speeches is used to balance the intervention time of each participant, thus encouraging those less involved to a more active participation.

This type of social feedback is extensively investigated in Chi (2009) that presents an overview of applications for augmented social cognition. The paper makes a distinction between the concepts of cognition and social cognition, as the ability to remember, think, and reason and the ability of doing so as a group; and augmented social cognition, defined as ‘the enhancement via technical systems of the ability of a group of people to remember, think and reason, acquire and use knowledge’. The paper discusses three examples in which this concept can be applied. The first one is a social feedback system that visualizes on Wikipedia pages statistics about the use and number and type of revision for specific pages, as well as displaying feedback from users. In the second part, the article presents a research with 150 participants conducted using mechanical turk surveys in order to investigate to what extent information-seeking activities are engaged in some with social interactions or information from social sources. The survey consisted in a questionnaire asking questions related to users social participation before, during and after a search. Particular attention was given to the impact of social feedback that could come from usage logs implicitly, or systems could explicitly ask users for votes, tags, and bookmarks. It is pointed out that, although generally effective, the social cues representing users feedback are inherently noisy, thus the discovery of patterns within such data is likely to become increasingly difficult as the data size grows.

Finally, the article proposes an interesting study on the use of tags in the website Delicious. Here the authors are interested in analysing the history of the evolution of the distinct tags used since the website was launched, looking at functions like the entropy which appears to reached a stable plateau after an initial sharp increase. They
also conducted a small group study on a tagging interface called MrTaggy, that aims to facilitate bookmarking and web searches; results have then been evaluated by standard statistical procedures.

Similarly, Bernstein, (2010) proposes a similar system, called Eddy, based on a tag browsing interface, implementing an effective algorithm for topic detection, that acts as a client application for the on-line micro-blogging service Twitter. Users can interactively browse micro-blogs by topic as well as explore and update the corresponding status of data-streams (also visualized in the interface together with a number of statistics). Note that the use of such tags browsing interfaces for generic web searches has not been free from criticisms, see Muller (2007) which looks at the patterns of tag usage in enterprise tagging services as a possible constraint on exploratory searches (or in general searches in which the overall task is not sufficiently defined).

An ideal target for the application of these studies is the field of audio consumption (music, talk program, entertainment, information). With the increasing presence of portable devices, the audio sphere has become pervasive. However, the simple playlist approach is unsatisfactory: people have to maintain their own repository, organize it, etc. and moreover they are disconnected from the outside world. A partial solution to the first disadvantage comes from personalized audio services like Pandora\(^9\) that classify music according with a large set of properties (genre, rhythm, etc.) and delivers, online, music similar to the one proposed by the user. However, this is not a cognitive approach to the expectation of users: one would expect a selection based on personal status (mood), and location (work, commuting, relaxing, etc.). A partial solution is given by moodagent\(^10\). In this case the music (stored on the device) is classified according to five attributes: Sensual, Tender, Happy, Angry, Tempo. Again, this approach might be satisfying for listening music, but does not approach the problem of “interacting” with others. An approach that allowing also social interaction (peer to peer and broadcast: direct suggestions/communication and news) would be welcome, in order to promote participation instead of simple

\(^9\) [http://www.pandora.com](http://www.pandora.com)

\(^10\) [http://www.moodagent.com/](http://www.moodagent.com/)
listening.

Eye tracking
Eye tracking technologies have been used in different fields as a window to cognitive processes. In its exhaustive survey Duchowski (2002) shows as eye tracking has moved from a traditional diagnostic use to the development of new interactive applications. For a diagnostic analysis eye movements are generally recorded to ascertain the user’s attention patterns over a given stimulus. These applications typically implement an unobtrusive use of the eye-tracking device and the stimulus being displayed does not usually need to change or react to the viewer’s gaze whereas the opposite characterizes modern interactive applications. The survey categorises eye tracking into three main disciplines: neuroscience, psychology, and computer science.

Neuroscience is a complex area that concerns the identification of inter-connected neural components of vision and how brain neurons activate in response to visual patterns. These are not always clearly identifiable since it is possible to visually fixate one location while simultaneously diverting attention to another (this is common for astronomers looking for star clusters with their naked eye). Recent research is now focused on the relation between eye movements and brain imaging based on simultaneously recording cortical activation during attention tasks, in order to identify functional brain structures (combined eye tracking and brain imaging equipment are not in widespread use, although such devices are beginning to appear).

Within the psychology area the first well-known use of eye trackers in the study of human visual attention were those conducted during reading experiments whose findings relate to the different patterns (top-down - left-right for English readers), fixation duration (increasing with the complexity of the text); and differences between silent and loud reading. Different behaviour can be observed for other tasks such as scene perception in which the observer appears firstly to focus on getting a general idea of the scene and then start retrieving the details. In particular for complex objects, such as art pieces, paintings but also films, new data have confirmed some of the earliest evidence that eye movement patterns during complex scene per are related to the information in the scene, and by extension, to perceptual and cognitive processing of the scene. Further patterns are observed in other tasks, such as auditory
language processing where eye movements are recorded as people listen to a story or follow instructions regarding an object they are looking at (spontaneously directing their line of sight to the elements that are most closely related to the meaning of the language currently heard); visual searches (looking for specific targets in a display) in which fixation to a specific area is alternated with random eyes movements (although fixation time and saccade length are functions of the particular search task); and other natural tasks (Duchowski, 2002).

Ranyner (1998) provides an exhaustive review of eye moments from several domains that include mathematics, numerical reading, problem solving, dual-task situations, face perception, brain damage, and dynamic situations such as driving, basketball, foul shooting, golf putting, table-tennis, baseball, gymnastics, walking in uneven terrain, mental rotation, etc. For example in aviation eye and head movements of professional pilots were recorded under realistic flight conditions in an investigation of human-machine interaction behaviour relevant to information selection and management; in driving recent studies have identified that experienced drivers obtain visual information from two sections of their view of the road ahead, in order to maintain a correct position in lane whilst steering their vehicle around a curve (one, more distant, to predict the road’s future curvature and a nearer section used by a feedback reactive mechanism to fine tune the driver’s position in lane). Other application areas include generic visual inspections, in which tracking eye movements can lead to predictive analyses, if certain recurring patterns or statistics are found in collected scan-path such as an expert inspector’s eye movements may clearly exhibit a systematic pattern; and applications in advertising and marketing, in which eye tracking can aid in the assessment of ad effectiveness in such applications as copy testing, print, advertising images, video, or graphics, and in disclosure research involving perception of fine print within print media and within television displays.

However, one of the most recent application fields is within computer science in the study of human computer interaction. Duchowski (2002) classifies eye-tracking systems into two types of interactive applications: selective and gaze-contingent. The selective approach uses an eye tracker as an input device that employs gaze as a pointing modality, for example using gaze in a similar manner to a mouse pointer. A first range of systems developed at the beginning of the nineties concerned the
determination of intended activation of features with the proposal of different solutions based for example on blinking or the use of dwell time to act as a selection mechanism (Jacob, 1990). Gaze-based communication systems offer clear advantages providing an often faster pointing modality than a mouse or other pointing device, especially if the targets are sufficiently large (archetypical gaze-based pointing application is eye typing for patient with severe handicap). However, gaze location may not be as precise as with a mouse since the fovea limits the accuracy of either the measured point of regard or that of the eye tracker itself. For this reasons hybrid systems are often used as well as applications implementing predictive pointing aid rather than a direct effector of selection. Gaze can also be utilized to aid communication in collaborative systems, such as tele-conferences and document sharing systems.

Further applications for HCI relate to system usability where eye movements can significantly enhance the observation of users’ strategies while using computer interfaces. For example (Byrne et al, 1999) tested the arrangement of items during visual search of click-down menus contrasting two computational cognitive models designed to predict latency, accuracy, and ease of learning for a wide variety of HCI-related tasks. Usability studies of web pages are also reported in (Goldberg et al, 2002), that derives specific recommendations for prototype web interface tools and discusses gaze-based evaluation for navigation across multiple pages (multiple web pages scenarios are difficult to analyse due to the synchronization of gaze with windows that scroll or hide from view). (Granka et al, 2004) investigates how users interact with the results page of a web search engine using eye-tracking with the goal of gaining insight into how users browse the presented abstracts and how they select links for further exploration.

A second group of systems does not use eye tracking directly as a pointing device, but rather as a passive indicator of gaze. These are the so-called gaze-contingent applications that are based on an interactive adaptation of the screen displays in response to the user’s eye movements. For example a display can adapt by degrading in a way that can affect either perception (more sensitive) or performance (as it is possible to degrade a display quite noticeably without necessarily degrading performance). In either case the main parameter to be considered is the system
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latency. We can identify two main types of gaze-contingent applications screen-based and model-based. The former deals with image pixel manipulation, while the latter is concerned with the manipulation of graphical objects or models prior to rendering (see Duchowski, 2002). Areas that involve these types of systems include those related to virtual reality systems with examples applications in health (Satava, 1995), fire-fighter training (Gamberini et al., 2003), and clinical psychology (Albert et al., 2005).

Finally, in general data obtained from eye-trackers are very noisy due, for example, to eye blinking and hardware failures to detect corneal reflection. Common solutions are based on the use of non-linear filters such as the medians that, however, tend modify both noisy and noise free data and they are therefore difficult to use in real time applications. As a consequence, the research aiming to produce more effective types of filtering constitutes a very active field, see for example (Chartier and Renaud, 2006) that proposes a filtering mechanism that can detect and replace noisy data using only past records, while leaving the remaining signals unaffected.
7 Analysis of concepts for self-awareness

In order to prioritise functions for self-awareness (and ultimately develop an architecture for self-awareness) we provide an evaluation of the concepts and models that have been identified in the literature under the five main headings. Our interpretation of awareness is knowledge of what is going on around us and why. For each of these we briefly provide analysis against the following criteria:

- The potential functions that the concept can support for an awareness framework;
- The extent and usefulness of supporting frameworks and models for subsequent development;
- The potential for the concept to realise a computable form and how this may be realised;

Each of these criteria is assessed using the scale:

- *Strong* – good fitness with the desired outcome
- *Possible* – fitness with the desired outcome but some issues
- *Weak* – problematic fitness with the desired outcome

and in each case we provide a brief justification.
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<tr>
<td>Mental models and heuristics</td>
<td>Reasoning (varying degrees of problem solving) Filtering and discovery through recognition of cues Memory processing Knowledge representation Learning Information exchange Decision making</td>
<td>Almost the totality of cognitive function could be reduced to mental schemas, supported by heuristics, which then show high potential for development of ICT components. Heuristic methods have been recognised as the closest representation of the procedures applied by human cognition to make judgements and providing solutions. The diversity and scope of human cognitive heuristics is massive. Only a primitive set of behaviours can be modelled.</td>
<td>Heuristics have been applied in computer science and artificial intelligence to provide approximated solutions of complex mathematical problems. The challenge comes in the diversity and sophistication of possible alternative heuristics.</td>
<td>Strong</td>
</tr>
<tr>
<td>Cognitive Areas</td>
<td>Summary of the supported Cognitive Functions</td>
<td>Potential for ICT Development</td>
<td>Potential for computable representation</td>
<td>Overall Score</td>
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<tr>
<td>-----------------</td>
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</tr>
<tr>
<td>Personality traits</td>
<td>Personalisation and preferences Social cognition and networking Personal attraction and affinity Establishing priorities Recognition and cues Filtering and Discovery of knowledge in key areas</td>
<td>Personality traits can be mapped to physical behaviours and preferences, including use of ICT. This can be used to better match a users’ needs and requirements on a semi-predictive basis and it can be used to increase user satisfaction. Personality traits can also be used as a basis for interactions. This can be applied in a wide range of domains.</td>
<td>Direct applicability to computational processes requires obtaining user input, feedback and making deductions. Collection and establishing accurate personality indicators can be time consuming and participation is a potential problem.</td>
<td>Possible</td>
</tr>
<tr>
<td>HCI</td>
<td>Recognition of cues Filtering and relevance Implicit communication Information processing</td>
<td>The study of HCI covers a wide range of ICT applications. With this project the scope exists for potentially eliciting implicit information from the user concerning behaviour and preferences in unstructured or “messy” environments where there is potentially a lot of noise.</td>
<td>Cognitive aspects relevant to enhance human and device awareness focus on non-verbal communication. Computable representations are possible for different types of scenarios but need development to map user intentions using feedback indicators.</td>
<td>Strong</td>
</tr>
<tr>
<td>Cognitive Areas</td>
<td>Summary of the supported Cognitive Functions</td>
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<td>Potential for computable representation</td>
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</tbody>
</table>
| Relevance Theory | Filtering and relevance  
Recognition of cues  
Knowledge acquisition  
Reasoning | Relevance theory has been used in cognitive science to explain inference mechanisms in human communication. The “principles” underpinning Relevance Theory can be used at the design stage in ICT systems, in particular the use of cues in nudging behaviours and the way in which the brain seeks to make decisions from communication of small “utterances”. | Direct translation of Relevance Theory into a computable form is challenging. However the principles underlying the Theory can be embedded in design to increase synchronisation with human cognition. | Weak |
| Neurophysiology | Mental models  
Knowledge representation  
Memory processing  
Problem solving | The study of the nervous system has been at the base for the development of artificial models to represent cognitive and perceptual functions. Techniques that analyse the performance of measurable brain components (e.g., neurons) are useful to metrics and modelling. | Because of its complexity the most immediate application for a computational components lays in the identification of the mechanisms and procedures used for analysis and representation of data derived from the complexity of the brain. This can be used for example to derive metrics and cues for awareness functions to operate. | Weak |
## Cognitive Areas

<table>
<thead>
<tr>
<th>Cognitive Areas</th>
<th>Summary of supported Cognitive Functions</th>
<th>Potential for ICT Development</th>
<th>Potential for computable representation</th>
<th>Overall Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial perception</td>
<td>Knowledge acquisition</td>
<td>Spatial cognition concerns the acquisition, organization and representation of the spatial surroundings, including content that can be embedded within it from local cues or other markers. This is strongly aligned with making key aspects of the long tail accessible to those in the situated environment, and can align with other aspects including the social dimension.</td>
<td>It has great potential for computable representation in self-awareness since it encompasses not only the geospatial context of places but also the affordances, activities and possible actions offered at those places.</td>
<td>Strong</td>
</tr>
<tr>
<td>Social cognition</td>
<td>Social networking, Situated context and the effects of others, Social representations and influence, Social learning and personalisation</td>
<td>Social cognition relates to the acquisition, representation, processing, and storage of information about individuals. This is influential in gaining awareness and self-awareness.</td>
<td>High potential for awareness when transposed into computational components, since the perception of others and how others perceive us has high impact on individual’s actions. Networks offer the natural computable representation.</td>
<td>Strong</td>
</tr>
<tr>
<td>Group dynamics</td>
<td>Social influence of others, Information exchange, Knowledge acquisition and discovery</td>
<td>The potential for ICT development concerns the dynamic analysis and implementation of procedures representing the behaviours of communities in relation to single individuals actions or those within aggregation to groups.</td>
<td>Potential for computational representation concerns the computational components for socially inspired mechanisms for processes such as search, acquisition and dissemination of information.</td>
<td>Possible</td>
</tr>
</tbody>
</table>

Table 1 - Cognitive Functions and potential for development of the identified sub-areas
7.1 Summary

The areas concerning the modelling of human reasoning appear as the most suitable for immediate conversion into computational procedures and methods. These include fundamental concepts such as mental schemas and how knowledge is encoded and represented. Of particular interest to our research is how human cognition applies and uses them to adapt to different situations and problems. In particular, the cognitive areas of heuristics relates directly to the modes employed by human cognition to make judgements and providing solutions. Software models designed for artificial intelligence and inspired to the cognitive filed of human practical reasoning, such as the belief desire intention (BDI) model, can be also integrated in our more general representation of cognitive functionalities for ICT components.

The field of personality psychology and human behaviour is of great interest for our study not particularly in terms of how the different personality traits are originated, formed, and could be identified and measured (also object of psychological studies) but rather for their applicability to different attitudes and approaches that humans show when facing problem solving situations (for example how personality has different effect on specific tasks such information retrieval and processing). Note that the literature provides a large background of studies about the relation between personality and the so called social problem solving (how personality affects individuals in communication and social interaction) but has not yet been largely applied to generic problem solving concerning more practical and ordinary tasks.

The above is also related to the more general and broader area of social cognition that include concepts such social representation (of others within the surrounding environment), social identity (how others are representing us and our social role), social schemas (how the knowledge of the social world is maintained and structured), social evaluation (what attitudes we adopt towards people and things). This has clearly great potential for ICT development not only in social networking (i.e. how the dynamic of the social groups could enhance management and dissemination of useful content) but also how the perception of others and how others perceive us has high impact on individuals actions this requiring the use of different methodologies and procedures.
As social cognition can be defined as a social representation of the environment around us, the concept of spatial cognition concerns the acquisition, organization and representation of the spatial surroundings. This constitutes a fundamental aspect of cognitive science for example in the study of adolescence allowing individuals to sharpen their perception through the process of spatial images. This area shows great potential for self-awareness since it embraces not only the geo spatial representation of places but also the affordances, activities and possible actions offered that can have high influence on decision making processes.

Neurophysiology is an area that investigates the several functions of the nervous system and the different methodologies that the brain implements for various human activities, also relating to some broader areas such consciousness and perception. For our research we are primarily interested in how the different mechanisms that are activated (for instance in fields as Electroencephalography) when implementing different cognitive tasks such as reasoning, problem solving, information processing, and decision making can be utilised for computational procedures and methods.

The cognitive aspect of HCI is a well known and active area that merges psychology with computer science investigating how devices interact with ICT devices and how this affect human communication and the acquisition and dissemination of information and knowledge. In particular, we focus on aspects such as techniques for non-verbal communication; support of visual and interactive feedback; and the investigation of how HCI mechanisms (e.g. eye tracking) could facilitate and enhance tasks as, for example, information searches and seeking. This is a very broad area that has wide connections with many other psychological fields, for example the social component social network analysis techniques can be implemented as a feedback component in support of a number of task form increasing efficiency in meetings and working environment in general as well as support for the elderlies. Finally, Information relevance and related theories focus directly on the mechanisms of communication and how different cues are integrated and highlighted in our language for the transmission and processing of information.
8 Organisation of functions for self-awareness

This final section shows how the most promising cognitive behaviours from the previous section’s analysis can be organised and classified to accomplish an overall systemic approach for self-awareness.

The inspiration for this approach comes from considering the literature on cognitive processes for information analysis, and broadly developing a classification of this as described extensively in Section 1.1 of Appendix A. We refer to our approach as a tri-partite model for human cognition and it refers to different classes of cognitive functions that the brain carries out. Thus the model also provides an overall classification for different cognitive functions and it identifies the communication that needs to take place between different cognitive areas. Thus we are proposing and adopting this tri-partite model for human cognition as a basis to categorise the functions that we are to adopt for an overall self-awareness framework.

8.1 Tri-Partite Model for Human Cognition

8.1.1 Introduction

The general framework is based on the idea that the cognitive brain relies on continually generated memory-based predictions, either based on the information gathered from the senses or from the knowledge. This framework integrates three primary components.

- The first connects the domain’s related concepts of associations, which are formed by a lifetime of extracting repeating patterns and statistical regularities from our environment, and storing them as a particular form of memory (Rao, 1999).
- The second is the concept of analogies, whereby we seek correspondence between a novel input and existing representations in memory/knowledge.
- Finally, these analogies activate associated representations that translate into predictions or inference processes.

After a century of research, evoked potential and fMRI studies have confirmed that cognitive functions such as perception and attention can be distinguished from the
others superior cognitive functions by measuring the timescales of neural activations or by estimating the cognitive costs and monitoring the development and the learning dynamics (Gibson, 1996; Downing, 2001; Calhoun, 2001; Ganis, 2004; Friston, 2005). This first stage of the information analysis has been described as able to autonomously solve many problems by applying learned schemes. Psychophysics and neuropsychology have revealed that rather than passively waiting to be activated by sensations the human brain is continuously busy generating predictions that approximate the relevant future (Schank, 1975; Minsky, 1975; Bar, 2007).

An overview of the cognitive and psychological literature about the reasoning, decisional processes and problem solving shows that the cognitive information processing can be differentiated into three classes:

- Unconscious knowledge processing
- Conscious knowledge processing
- Learning/Developmental processing

This is the basis for our model and each of these processes can be understood in terms of their timescales, cognitive costs and evolutionary features as follows:

- Timescales (Reaction times)
  - Unconscious knowledge leads to very fast perception and preattentive activations, typically less than 500 milliseconds.
  - Conscious knowledge is derived from the brain having to actively undertake reasoning, which occurs on a medium time scale, ranging from seconds to hours.
  - Long-term learning and development occurs over a sustained period, where activities may be repeated or deductions made that contribute to evolution. These may occur over minutes to months.

- Cognitive cost (Cognitive Economy principles and amount of neural activation).
  - Unconscious knowledge requires a light cognitive load, involving small and local activations.
  - Conscious knowledge requires a heavy cognitive loading, with larger and diffused activations.
  - Learning and development requires a medium cognitive loading, with diffused activations.
• Evolutionary features (cognitive development)
  o Unconscious knowledge involves critical periods and classical Hebbian learning ('associative learning' based on simple repetition, Daucé (2002)).
  o Conscious knowledge involves trial and error, from which observation, imitation and induction are carried out.
  o Learning and development involves the development of fixed and hard-wired rules.

The overall presentation of the tri-partite model is given in Figure 1. This can be described in terms of “modules” in which different cognitive functions, as analysed in the previous section, can be mapped.

Figure 1: The overall tri-partite model

The modules and linkage with psychological development theories are described
Module I: Unconscious Knowledge

In the first module of our model we allocate those processes (schemes) that extract a small component of the available information to derive analogies by linking the input with representations in memory. Examples are the Gestalt laws of perception (regularities in visual perception). These processes are well detectable and easy to map at the neural and psychophysical levels due to their related reaction times.

Moreover the linked stored representations have to activate the associations that are relevant in the specific context, in order both to drive the subsequent information encoding (e.g. the pre-attentive effects on perception) and to provide focused predictions. These predictions facilitate perception and cognition by pre-sensitizing relevant representations. Predictions concerning complex information, such as those required in social interactions, presumably integrate multiple analogies.

The perceptive processes allow the interpretation of the environment, and strengthen previous representations (consolidation) in a way that favours increasingly flexible future analogies (Liang, 2002; Ullman, 1995; Mumford, 1992). The psychological theory of Relevance (Sperber, 1995) where in a very short time our cognition is able to reduce the ambiguity of a piece of (linguistic) information with a very small neural activation, could be considered an example of the activity of the first module. Moreover this cognitive function evolves in time dynamically changing with the subject experience (Legendre, 1993; Prince, 1991).

In general this first module models the unconscious knowledge, furnishing theoretical support to this process (Augusto, 2011; Chisholm, 1977; Damsio, 1996; Dienes, 1995). Therefore, the analogy itself also provides an important top down prediction regarding the identity of the input using initial bottom-up information (French, 2002; Bar, 2006). These processes are not very flexible during execution (mainly because they act faster than conscious control) but can be evolved rather easily (if not hard-wired). In particular, these processes are not "targeted" to a given goal, but rather act blindly. It is the process of learning and reinforcing (module 3) that has the task of selecting the "right" schemes and adapting them (Collins, 1978). An alternative
definition of this module belonging to the classical psychological field is "scheme-oriented processes" (Sims, 1992).

The psychology of Perception and Attention (psychophysics) show that cognition is able to extract the relevant features from a given context ‘unconsciously’, integrating them continuously within the higher decisional processes. e.g. the active process of perception (Data encoding) is the results of the combination of the external information with the pre attentive activations. We will refer to the resulting schemas belonging to this module as A-Schemas. An example of the application of this first module is given by the Relevance Heuristic. This heuristic integrates the ‘external information’ (EI) with the ‘pre-attentive activations’ (PA) in order to choose whether to activate a specific mental scheme. Then the activated schemes are continuously accumulated in a multidimensional and sparse representation of the reality which integrates also a projection from the second module described in the next sub-section. The dimensionality of this representation is continuously reduced by a factorial analysis which drives the new steps of encoding/perception (weighting/selecting the new and mostly relevant information - aka searching heuristics), and extracts the Relevant Features (RF) for the next stages of the decisional process (see Appendix a for further descriptions about the relevance heuristic).

**Module II: Reasoning - Inference, or problem solving**

The second module could be naturally defined as those processes that act on and within the cognitive representations (context) activated by the module I. These processes can be controlled by a conscious activity, even though the attention threshold could be minimal.

Inside this wide definition are comprised a lot of models of cognition ranging from the probabilistic reasoning to the social cognition (Heyting, 1930; Kolmogorov, 1932; Shepard, 1967; Johnson, 1983; French, 2002; Hummel, 2003; Pearl, 1988; Bergert, 2007; Gallistel, 1991; Gigerenzer, 1993; Gigerenzer, 1991; Gigerenzer, 2001; Gigerenzer, 1999; Gigerenzer, 2011; Goldstein, 1996; Goldstein, 2002; Anderson, 1991; Oaksford, 1998; Payne, 1993; Juslin, 1994; Sniezek, 1993; Brown, 1993; Huttenlocher, 1988; Hammond, 1964; Tversky, 1974; Rottenstreich, 1997; Tversky, 1994; Fox, 2002; Idson, 2001; Lorraine, 2001; Pleskac, 2007; Rieskamp, 2006; Lee,
2004; Newell, 2003; Hertwig, 2008;). All these models can be connected by means of the way they computationally represent the operation of comparing, elaborating and using mental representations (or knowledge) in order to solve abstract problems, using a data oriented approach.

It is important to note that the input is rarely mapped with a single analogy directly to memory. Instead, the function of analogies can be based on the integration of multiple analogies that accumulate to complex mapping. The activation of associations for prediction would not be useful if it simply activated automatically all the information associated with the linked representation(s) in memory. Instead, this activation needs to take into account the context in which the input is encountered, and selectively activate the most relevant associations (Friedman, 1979; Kuipers, 1975; Minsky, 1975; Piaget, 1973).

While the first type of schemes are activated in module 1 (A-Schemas) by directly linking the external input to the “memory”, in module 2 the input is considered not only for the activation/refinements/combination of appropriated schemes but also for projecting attributes and generating predictions (Shapiro, 2007; Fiske, 1990; Cottrell, 2005; Friston, 2005; French, 2002; Hummel, 2003; Devine, 1989). Consequently these processes have to be slower and more expensive than those in the module 1, and are asked to choose the best scheme (algorithms), among those coherent with the projected attributes, and which maximize the generated prediction’s value (Bar, 2007; Marewski, 2011). The variety of predictive and psychologically plausible cognitive algorithms proposed in the latest years could be all representable as the results of some complex functions (cognitive heuristics) which combine: the input information (perceptive schemes), the subject’s knowledge (correlated mental schemes), and the target/goal expectations. We can interpret the resulting cognitive procedures as schemas of a different lower level (B-Schemas) that can be then ‘activated’ by the specific processes concerning this second module. Therefore there is the possibility of mapping all these models into a unifying framework based on mental scheme and evolution rules, inspired by bounded rationality assumptions (Simon, 1982; Gigerenzer, 2008).
A relatively new definition of cognitive heuristic can be taken as those cognitive mechanisms comparing the different and competing mental schemes required to drive the organism towards an efficient solution of the problem (e.g. the most economical, accessible and acceptable goal/result). The separated neural basis of the recognition and evaluation processes have been confirmed by some fMRI studies (Volz, 2006; Yonelinas, 2005; Pachur, 2006; Ratcliff, 1989).

To summarize, module 2 maps novel inputs to representations in memory that most resemble this input. Subsequently, information associated with these representations is activated to provide predictions about what else might be expected in the same situation. By taking context into account in this associative activation, only the most relevant predictions are generated.

The theoretical structure of module 2 has been developed on the basis of the most relevant models of probabilistic reasoning and social cognition theories, and tries to integrate in a general and psychologically coherent framework their crucial features. Moreover very recent neurophysiological evidences suggest the existence of different kind of Heuristics (processes) at this stage. Significant examples of the application of this module are given by the three heuristics outline below:

The Goal Heuristic that uses some of the pre-acquired schemes to create the most probable Goal Scheme (i.e. representation of the goal). This low dimensional scheme could be updated (if necessary) with ‘components’ the sparse representation of the reality deriving from the first module.

The Recognition Heuristic (see Section 2.2) integrates the Relevant Features coming from module I with the goal scheme in order to activate the most relevant B-Scheme. This could be considered as a continuous and incremental process (which can interrupted only by the Solve Heuristic described below) and where a temporary new B-Scheme can be built if required as a linear combination of the previously activated ones (see also the Representativeness, Anchoring, and Availability Heuristics).

Solve Heuristic explicitly explores (frontal activity) the probability of success (measured in terms of a ‘distance’ between the goal scheme and the and activated B-
Scheme) and the cognitive costs of the activated/newly created B-Scheme. With a simple function of the previous two arguments the recognition heuristic is stopped (Fast and Frugal Heuristics, Less is More Effect) when the ratio among goal closeness and cognitive costs find a local maximum. Alternatively it drives the gathering of new information by the modification (enlargement) of the ‘relevant features’ and ‘sparse representation of reality’ deriving from the first module.

For an exhaustive description of all the heuristics cited above see Appendix A.

Module 3: Learning
While our existing memories are used to derive analogies and activate predictions, they are constantly being updated.

The last module concerns learning, which in many cases can be seen as a reinforcement of schemes by means of comparisons between expected goals and obtained results. In this sense it can be considered analogous to the Hebbian reinforcement assumption (Bobrow, 1975; Bower, 1979;).

A fundamental ingredient of learning is the forgetting process, which for instance enables the recognition heuristic and the fluency heuristic to make better inferences (Schooler, 2005). One way of modelling this process is by means of a competition among scheme for ”getting attention”.

From the simple phenomenon of the habituation to the most complex social learning, the cognitive system appear equipped with a particular talent for extracting generalizable knowledge from a few specific examples, even with only one example. The ability to generalize from sparse data is crucial not only in learning word meanings, but in learning about the properties of objects, cause/effect relations, social rules, and many other domains of knowledge.

The habituation phenomenon is a decrease in psychological and behavioural response to a stimulus after repeated exposure to that stimulus over a duration of time (Bear, 2007; Domjan, 2010). Similarly, others forms of learning such as the evolutionary learning (Gibson, 1977; Hutchinson, 2005; Pinker, 2002), the inductive learning or
feedback learning (Tenenbaum, 2006), the imitation (Menz, 2009), the social learning (Rendell, 2010; Boyd, 1985), and the social development (Bremner, 1994; Anderson, 1977), can be represented as an increase of certain selected psychological and behavioural responses to a stimulus (a set of activated schemes) after repeated and positive exposure to that stimulus over a duration of time.

This module requires the ability of evaluate the adequacy of the consequences of a certain behaviour/cognition (or mental scheme) with the expected goal, both using experience and the observation of others (Brunet, 2000; Norman, 1973).

Inside this framework the Learning function can be seen as a reinforcement of schemes by means of comparisons between expected goals and obtained results. In this sense it can be considered analogous to the Hebbian reinforcement assumptions. Hebbian learning is probably the simplest form of associative learning, e.g. a form of learning in which a newly produced response can be associated to a specific stimulus (in its broader sense this includes the most frequent types of learning with the exception of ‘habituation’). Hebbian reinforcement learning in a modular dynamic network. Emmanuel Daucé in Order A Journal On The Theory Of Ordered Sets And Its Applications (1992). In particular, reinforcement learning (Hebbian learning) is defined as a learning paradigm in which the environment occasionally sends the agent reinforcement signals, either positives in the form of rewards, or negatives in the form of penalties. Here the overall goal of the learning algorithm is to maximize rewards while minimizing penalties (Daucé, 2004). Nevertheless a fundamental ingredient of learning is forgetting, which for instance enables the recognition heuristic and the fluency heuristic to make better inferences.

With concern to the dynamics of this module, a significant example is the Evaluation Heuristic, which integrates ‘external information’ coming from the first module with the B-Schemes from the second module, and assesses the goodness of the answer (Emotional activations).

Other examples include cognitive processes of Spontaneous Learning which are active on both schemes from the first and second module and can be seen as an immediate implementation of Hebbian like reinforcement algorithms, since
exclusively characterized by the frequency of occurrences (and absence of any form of ‘teaching’ processes).

Further examples are given by other basic cognitive mechanisms that activise exclusively the mental schemes of the second module. These include:

Mechanisms for *Observation and Imitation*, which activate observed B-schemes consequent Hebbian evolution on the bases of the Evaluation Heuristic result (Symbolic Interactionism theory and Attribution theory).

*Trial and Error*, directly linked with the Evaluation heuristic and Hebbian managing of the B-scheme and probably representing the most immediate representation of the learning module.

*Mental Simulation or Induction*, in which new associations or acquaintances can be represented as new B-Schemes, which are compared with the existing ones by the module II and then possibly reinforced by the module III (Cognitive dissonance theory).

Further details about all heuristics outlined in this section are provided in Appendix A.

### 8.2 Cognitive functions and the tri-partite self-awareness model

![Tri-partite Model](image)

**Figure 2: The tri-partite model**
This section proposes a mapping of the five broader cognitive areas identified in Sections 2 to 6 with the tri-partite model introduced in Section 8.1. This means that we have an overall organisation of the different cognitive functions and allows us to consider, down stream, the communication that needs to take place between them. Below we consider in turn each of the cognitive areas and their mapping.

- **Modelling human reasoning**

  This area maps primarily modules one and two

  - **BDI models** map all three modules since belief (e.g. when it is established) belongs to pre-defined knowledge (module one), whereas desires and intentions derive from the internal processing phase that belongs to the decision-making module (module 2). Then the implementation of the model could be also extended to the learning component (module three) since intentions of actions will be adapted to feedback mechanisms and the response of the system.

  - **Mental models** themselves constitute module one and module two is directly defined as the use of **heuristics for decision making**.

- **The influence of others**

  This area mainly applies to the second and third module, since it clearly belongs to the internal processing phase that elaborates knowledge already established in memory by modifying it in relation to the social context of what is around us. This is affected by both our representation of what is around us as well as the vision that others have about our beings.

  - **Social cognition** is directly based on module two since it is primarily constituted by the social representation of what is around us and its social evaluation. However, when these elements consolidate into social schemas then this sub-area can be seen as applicable to
module one representing knowledge already established in individual’s memory

- **Internal embedded disposition**

  This area constitutes an important component of module two, although it could also be secondarily related to module three. However, it does not belong to the first module since the application of direct knowledge (when it exists) cannot be related to different personality and behaviours.

  - **Personality traits and information behaviours** link directly to the internal processing the individuals engage before eventually taking decisions. Different personalities can affect indirectly also the adaptation phase (module three) since the learning mechanisms can vary in relation to different personalities and behaviours.

- **Spatial perception and surrounding context**

  This area primarily relates to module one and two

  - **Social cognition** interacts directly with newly established or pre-existing knowledge whenever concerns information about locations and places directly retrieved from different sources. It also relates to the second module in terms that the representation of places as part of the environment is a dynamic component that presents physical and social affordances as well as opportunities for social interaction with other agents. Therefore affordances cannot be either considered as a static predefined component but should be instead considered as an active part of the internal processing that individuals engage to deal with their decision actions.

- **Related areas**

  These final areas of psychology mainly concern the process of elaboration (module 2) and adaptation (module 3) and how these affect human decisions.

  - **Neurophysiology** is primarily considered in terms of the different mechanisms and methodologies that the brain applies when processing information for reasoning and decision making.
The cognitive aspects of HCI primarily concern decisions and problem solving activities as well as their adaptation and how these can be enhanced by different ways of interactions with ICT devices. In addition, information relevance directly concerns the mechanisms that affect the acquisition and dissemination of individuals' knowledge and how knowledge is processed by individuals (module 2).

Group dynamics mainly integrates the social aspect with the learning component (module three) as it concerns how our social representations and schemas evolve in relation to the dynamic of actions of our social communities.
Figure 3. Mapping the cognitive areas with the tripartite model

Summary

Figure 3 visualises a summary of mapping of all the relevant cognitive areas identified from cognitive psychology with the tripartite model described above. This also addresses at a lower level the identification of key cognitive behaviours needed for self-awareness shown in Table 1. Here, the main objective will be the creation of a dynamic multi-level awareness through the design of appropriate hierarchical structures that build on atomic blocks from cognitive and psychological sciences. Cognitive models will be identified with respect to the specific key cognitive functions, as well as the interactions between the functions.
The first area representing the knowledge base is directly associated to cognitive functions concerning the direct acquisition and representation of knowledge as well as functions closely related to mental schema representations such as attention, perception and consciousness. In particular, this includes the immediate filtering of external input based on pre-acquired knowledge about relevance of the information made available by the surrounding environment that consider only the most immediately recognisable cues (awareness cues recognition).

The second module is primarily formed by functions based on cognitive procedures for decision-making and reasoning. This also involves aspects related to human practical reasoning such as the determination of human desires and the consequent intentions based on pre-ordered knowledge deriving form module one (belief). In particular, we will focus on situations when environmental conditions (like a too vast amount of information or a lack of an important part of it) may prevent from a complete analysis of all the available cues. As described earlier a common way the human reasoning tackle this problem is by the use of heuristics models. Recent studies investigating the neural basis of the recognition and evaluation processes suggest that the recognition heuristic (see Section 2.2) may be relied upon by default, as opposed to being just one of many strategies.

The social aspects of human cognition could generally link with all the main components of the proposed cognitive model. However, its direct concern with the dynamic that regulates the formation and evolution of social communities constitutes one of the primary components of the learning module concerning both individual and social learning. In particular, the latter (learning through observation or interaction with other individuals) is widespread in nature and is central to the remarkable success of humanity, yet it remains unclear why copying is profitable and how to copy most effectively (Bagnoli et al, 2011b, Menz et al 2009, Rendell et al., 2010). Social learning opposes directly to individual learning that stems solely through direct interaction with the environment, for example, through trial and error. At first sight, this appears advantageous because it allows individuals to avoid the costs, in terms of effort and risk, of trial-and-error learning. However, social learning can also cost time and effort, and theoretical work reveals that it can be error-prone, leading individuals to acquire inappropriate or out-of-date information in non-uniform
and changing environments. Current theory suggests that to avoid these errors individuals should be selective in when and how they use social learning, so as to balance its advantages against the risks inherent in its indiscriminate use. Accordingly, natural selection is expected to have favoured social learning strategies, psychological mechanisms that specify when individuals copy and from whom they learn. An innovate move always returned accurate information about the payoff of a randomly selected behaviour previously unknown to the agent. Observe represented any form of social learning or copying through which an agent could acquire a behaviour performed by another individual, whether by observation of or interaction with that individual (Guazzini et al., 2011).

Intermediate to the reasoning and learning component is the definition of situated context intended as a cognitive function and directly related to the concept of active data/entities self-containing a description of their content, functionalities and purposes of use as well as an indication of their utility in relation to the current model or systems and their integration with other models and functionalities. The evaluation of the utility of a specific component will also reflect the concept of spatial context-awareness where context-aware information about location (in case of systems composed by mobile devices), query suggestions and user profiles, can be used to enhance retrieval performance and recommendation results. This has, for example, applications to document retrieval scenarios, where concepts like expected search length (number of document that a subject expect to process during a search) directly simulate the process of considering only a limited fraction of available spatial-context cues (Cooper, 1968). Moreover, document searches can also be enhanced by the use of suitable HCI interfaces as well as driven by personality factors that, may lead, for example, to distinctions between epistemic information searches (when users search information just to satisfy their desire for knowledge rather than to solve immediate problems), hedonic information searches (when they search information for fun or affective stimulation), and problem solving searches (when they search to solve immediate problems), see (Xu, 2007).

Personalisation of content is a feature that has recently been incorporated into the most popular Internet services such as web engines as Google with its personalised searches, social networks as Facebook and Google+ with their personalised news
streams, and e-commerce services such as Amazon with its users personalized recommendations. This has, on the one hand, the clear advantage of facilitating a provision of content that closely reflect individual user preferences but, on the other hand, may incur in issues as selection bias and heavy restrictions in the choices offered, thus dangerously converging towards a uniform point of view and preventing users from a wider range of other potentially interesting options (Pariser, 2011).

This finally leads to further overlapping functionalities related to self-expression of human behaviours and *personality*. This is a function strictly connected to the idea of self-awareness itself, as suggested by a recent business publication (T. Bradberry, 2009) claiming that better understanding of the *personality traits model* and learning and understanding your own personality are key functions to better recognize the personality traits in the people around you at home and work, discover and empower your own self-awareness and can give individuals a real advantage in starting and developing their own business career. Similarly\(^{11}\) evaluating personality in filtering selection in work environments is considered an important variable for assessing employees’ qualifications.

9 Conclusions

This deliverable has been developed around two main tasks that constitute a virtual decomposition into two parts. The first part concerns the identification and analysis of relevant cognitive science literature and identification of a small pool of prominent cognitive areas able to synthetize those fundamental attributes of humans' cognition which could be harnessed for self-awareness. We identified five main broad areas based on: the modeling of human reasoning and decision making processes; the social aspect and representation of ourselves in relation to other individuals; an area related to personality psychology and its influence on people information behaviours; an area related to the external context in terms of temporal and spatial influence; and finally a group of related areas including concepts from neurophysiology and cognitive applications in the field of human computer interaction. For each of these areas we have reported and discussed a number of relevant publications from the literatures.

The second part of the document starts with the identification of a number of basic cognitive functionalities, derived from within each of the five specific areas, that could be used to model those key cognitive behaviours that would be needed for implementing self-awareness in an ICT context. In particular a large part of this research has been based around the notion of cognitive heuristics an their application for human problem solving and decision making processes. Principal outcome of this research was then the identification of three key cognitive modules representing the main cognitive activities of representing knowledge; human reasoning; and learning that can be used for the definition of a basic model for human cognition.

An exhaustive survey has been produced to provide the basic description of the resulting ‘tri-partite model’ and to illustrate how each of its modules relates to the background literature in the cognitive psychology and can be activated by specific cognitive heuristic procedures. Finally, the document concludes with a brief description of a short range of cognitive functions that, in relation to the proposed three state models, have the highest potential for a direct application to the development of self-aware functionalities within the ICT domain. This will constitute
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the basis for the technical definition of a preliminary architecture for self-awareness object of the second work-package of the project.
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Appendix A – [Cognitive Heuristics Review]

This appendix contains the reprint of the following technical report:

Cognitive Heuristics Review

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Introduction

1. Introduction

The scientific advancements in modern Cognitive Sciences have been coupled with new concepts and ideas that have made this discipline more scientifically rigorous, even if frequently too much qualitative to be implemented/nested into other domains [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14].

1.0.1. The cognitive heuristic concept

Among these key concept probably the most attractive and recently quite inflated is that of Cognitive Heuristics (CH).

A rigorous definition of CH is currently very hard to get, and the problem becomes more complex due to the large and authoritative literature about it. This chapter will draw a little history of this concepts and of the still-opened theoretical ways seeded after its introduction.

Getting a good definition of Cognitive Heuristics should be distinguished from the most general definition of Heuristic, very frequently used and with different meanings from many different scientific disciplines. While the Greek definition of the word is literally "serving to find out or discovering" the most accepted one in the modern sciences would be "One (efficient?) list of rules (algorithms) sometimes inspired by human behaviour, that can be used to solve a problem." The concept of Cognitive Heuristic was born at the beginning of the 20th century as those rules which seemed to be followed from cognition to solve elementary and mainly perceptive problems. Despite, this probably the most general and insightful formalisation of the concept of cognitive heuristics has been given only 50 years later from Social Cognition [15, 11], as: C.H. are those strategies that guide information search and modify problem representations to facilitate (ndr. and reach) solutions.

Nevertheless, after one century from its birth, a new reformulation of this concept should be attempted in order to recompose the theoretical idiosyncrasies produced by the different approaches used to investigate it.

We thought that the large number of works produced by different scientific domains during the past century, allows to delineate a coherent set of theoretical concepts and processes with the goal of reaching a more general definition of the Cognitive Heuristic concept.

1.1. History

The common question of the psychological research throughout the past century is the way an organism is aware of the environment and able to make decision inferring unknown aspects of it.

Different psychological domains has offered different directions in which to look for an answer. Given the generality of the topic, the compilation of an exhaustive overview would be an hard work, anyway the state of the art suggests some interesting convergences among different domains.

The human mind has long been "modelled" as tailored to register and to exploit frequencies of events. David Humes believed that the mind unconsciously tallies frequencies and apportions degrees of belief, arguing that the mechanism for converting observed frequency into belief was finely tuned in the brain [16].
Since the first approaches to the cognitive reasoning, many others scholars have argued that the laws of human inference are shaped by the laws of probability and statistics [17], and until nowadays research in psychology, cognitive and social sciences, has assumed the tools of statistics to be the normative models for decision making and human problem solving [18, 19, 20, 21, 22]. In the evolution of the modern cognitive heuristics framework four main tributes can be identified.

**The Gestalt**

The word Heuristic has been adopted first by Gestalt psychologists Karl Duncher and Wolfgang Khler in their studies to describe the strategies used by experimental subjects to face with different perceptive and cognitive tasks [23, 24, 25, 26, 6].

Gestalt psychology first adopted a computational approach to the study of human perception and cognition, isolating and describing regularities and principles of the cognitive activity, to explain the *innate mental laws* which determined the way in which objects (and later thoughts) were perceived (and transformed).

**The Cognitivism**

A second age of the cognitive heuristics started with the birth of the Cognitivism. This psychological framework started to study the human mind as an information processor, describing heuristics in terms of strategies that guide information search and modify problem representations to facilitate solutions [27, 7, 28, 29, 30].

**The Social Cognition**

The main advancement in the cognitive heuristics theory has been operated by a particular approach to the Social Psychology termed as Social Cognition. The Social Cognition movement born as the merging of Social and Cognitive psychology in the late 1960s, and became rapidly the dominant approach to the cognitive social dynamics [31, 32, 33, 34, 35].

According with the methods of cognitive psychology and information processing theory the Social Cognition investigated explicitly the encoding, storage, retrieval, and processing, in the brain, of information related to the social aspects of cognition. The framework developed by these disciplines is grounded on the idea that the information is represented by means of cognition as particular objects called *mental schemes* (or *context frame*), identifiable at different levels of the cognitive elaboration [36, 37, 38, 39].

The Social Cognition experiments were designed to investigate how these cognitive objects are processed, transformed and evolved (learnt). Applying and extending many theories and paradigms from cognitive and social psychology, Social Cognition started to study the human decision making and problem solving processes as characterized by three main *cognitive levels (domains)*, using the same labels respectively the *attention level* (automaticity, perceptive salience, priming), the *reasoning level* (heuristics, confirmation bias, inference), and the *memory level* (schemas, primacy and recency).

Contemporary a "new meaning" of heuristics emerged in the 1960s when statistical procedures such as analysis of variance (ANOVA), factorial analysis and Bayesian methods became entrenched as the psychologists tools. Until about 1970, this term had been used to refer just to the useful and indispensable cognitive processes for solving problems that cannot be handled by logic and the probability theory [40, 41].

It soon became clear to scientists that within this theoretical rationalization many models of rational inference treated the mind as a *impossible machines*, equipped with unlimited time, knowledge, and computational might, while humans and animals make inferences about the world with limited time, knowledge and computational resources.
The works of Herbert Simon are commonly cited among others as the inspiration of the modern cognitive approach to the modelling of problem solving strategies and decision making, because of their capacity of translating the Hebbian’s consequence of the Cognitive Economy Principle in the field of the superior cognitive processes.

The modern age

The modern age of cognitive heuristics is represented by some works and research programmes devoted to collect and modelling the fundamental features of the problem solving process, creating a sort of zoology of computational recipes used by cognition.

Many authors have proposed in the last 30 years some families of algorithms based on simple psychological mechanism, explaining how the cognitive mechanisms are capable of successful performance in the real world without the need to satisfy the classical norms of rational inference neither to look up or integrate all pieces of information. Nowadays, the Social Cognition theory is able to provide the fundamental criteria for assessing the plausibility of a cognitive model [42, 43, 44], indicating in many cases the requirements which make a model consistent with what we know about cognition [45, 31, 46].

1.2. A three partitioned model for cognitive heuristics

The general framework is based on the idea that the cognitive brain relies on predictions based on the memory that are continuously generated, either based on the information gathered from the senses or from the knowledge.

This framework integrates three primary components.

The first connects the domain related concepts of associations, which are formed by a lifetime practice of extracting repeating patterns and statistical regularities from our environment, and storing them as a particular form of memory [47]. The second is the concept of analogies, which is the term that represents the process of seeking correlations between an event and existing representations in memory/knowledge. Finally, these analogies activate associated representations that translate into predictions or inference processes.

In this work we propose a relative shift of perspective from the previous and “classical” one, maintaining a three partitioned structure for the models but generalizing some recent insights coming from both neuropsychological and cognitive literature.

After a century of research, evoked potential and fMRI studies have confirmed that cognitive functions such as perception and attention can be distinguished from the other superior cognitive functions by measuring the time-scales of neural activations, or by estimating the cognitive costs and monitoring the development and the learning dynamics [48, 49, 50, 51]. This first stage of the information analysis has been described as able to autonomously solve many problems by applying learned schemes.

The psychophysics and neuropsychology have revealed that rather than passively waiting to be activated by sensations the human brain is continuously busy generating predictions that approximate the relevant future [52, 53, 54].

An overview of the cognitive and psychological literature about the reasoning, decisional processes and problem solving clearly shows that the cognitive information processing should be differentiated in three main stages depending on their time-scales, cognitive costs and evolutionary features.

Module I: Perception and Attention

In the first module of our model we allocate those processes (schemes) which extract a small component of the available information to derive analogies by linking the input with representa-
tions in memory. Examples are the Gestalt laws of perception (regularities in visual perception). these processes are well detectable and easy to map at the neural and psychophysical levels due to their related reaction times.

Moreover the linked stored representations activate the associations that are relevant in the specific context, in order to drive the subsequent information encoding (e.g. the pre-attentive effects on perception) and to provide focused predictions. These predictions facilitate perception and cognition by pre-sensitizing relevant representations. Predictions concerning complex information, such as those required in social interactions, presumably integrate multiple analogies.

The perceptive processes allows the interpretation of the environment, and strengthens previous representations (consolidation) in a way that favours increasingly flexible future analogies [55, 56, 57]. The psychological theory of Relevance [58] describes how our cognition is able to reduce the ambiguity of a piece of (linguistic) information, in a very short time and with a very small neural activation, and can be considered an example of the first module’s activity. Moreover this cognitive function evolves in time dynamically changing with the subject experience [59, 60]. In general the first module models the unconscious knowledge, furnishing a theoretical support to this process [61, 62, 63, 64]. Therefore, the analogy itself also provides an important topdown prediction regarding the identity of the input by using the initial bottom-up information [65, 66].

These processes are not very flexible during execution (mainly because they act faster than conscious control) but can be evolved rather easily (if not hard-wired). In particular, these processes are not "targeted" to a given goal, but rather act blindly. It is the process of learning and reinforcing (module 3) that has the task of selecting the "right" schemes and adapting them [67].

An alternative definition of this module in the classical psychological field, is "scheme-oriented processes" [68, 69].
Module II: Reasoning - Inference, or problem solving

The second module could be naturally defined as the process that act on and within the cognitive representations (context) activated by the module I. These processes can be controlled by a conscious activity, even though the attention threshold could be minimal.

Inside this wide definition are comprised a lot of models of cognition ranging from the probabilistic reasoning to the social cognition [70, 71, 72, 73, 74, 65, 75, 76, 77, 78, 79, 80, 81, 82, 83, 22, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 42, 96, 97, 16]. All these model can be connected by means of the way they computationally represent the operation of comparing, elaborating and using mental representations (or knowledge) in order to solve abstract problems, using a data oriented approach.

It is important to note that the input is rarely mapped with a single analogy directly to memory. Instead, the function of this module can be based on the integration of multiple analogies (i.e. schemes) that accumulate to complex mapping.

The activation of associations for prediction would not be useful if it simply activated in an automatic way all the information associated with the linked representation(s) in memory. Instead, this activation needs to take into account the context in which the input is encountered, and selectively activates the most relevant associations [98, 99, 53, 100].

While a first type of schemes are activated in module 1 by directly linking the external input to the "memory", in the module 2 the input is considered not only for the activation/refinements/combinations of appropriated schemes but also for projecting attributes and generating predictions [101, 14, 102, 51, 65, 75, 103].

Consequently, these processes have to be slower and more expensive than those in the module 1, and have the task of choosing the best scheme (algorithms), among those coherent with the projected attributes, and which maximize the generated prediction’s value [104, 43].

The variety of predictive and psychologically plausible cognitive algorithms proposed in the last years could be represented as the results of some complex functions (cognitive heuristics) which combine: the input information (perceptive schemes), the subject’s knowledge (correlated mental schemes), and the target/goal expectations.

Therefore, there is the possibility of mapping all these models into a unified framework based on mental scheme and evolution rules, inspired by bounded rationality assumptions [31, 44].

A relatively new definition of cognitive heuristic can be taken as those cognitive mechanisms comparing the different and competing mental schemes required to drive the organism towards an efficient solution of the problem (e.g. the most economical, accessible and acceptable goal/result).

The separated neural basis of the recognition and evaluation processes have been confirmed by some fMRI studies [105, 106, 107, 108].

To summarize, module 2 maps novel inputs to the representations in memory that most resemble this input. Subsequently, information associated with these representations is activated/retrieved to provide predictions about what else might be expected in the same situation. By taking context into account in this associative activation, only the most relevant predictions are generated, that is the generation of a prediction depends on the context in which the association is performed.

Module 3: Learning

While our existing memories are used to derive analogies and activate predictions, they are constantly being updated.
The last module concerns learning, which is many case can be seen as a reinforcement of schemes by means of comparisons between expected goals and obtained results. In this sense it can be considered analogous to the Hebbian reinforcement assumption [109, 110].

One of the main ingredients of learning is the forgetting process, which for instance enables the recognition heuristic and the fluency heuristic to make better inferences [46]. One way of modelling this process is by means of a competition among scheme for "getting attention".

From the simple phenomenon of the habituation to the most complex social learning, the cognitive system appears equipped with a particular talent for extracting generalizable knowledge from a few specific examples, even from only one example. The ability to generalize from sparse data is crucial not only in learning the meanings of words, but in learning about the properties of objects, cause-effect relations, social rules, and many other domains of knowledge. The habituation phenomenon is a decrease in psychological and behavioural response to a stimulus after repeated exposure over a duration of time [111, 112]. Similarly, others forms of learning such as the evolutionary learning [113, 114], the inductive learning or feedback learning [115], the imitation [116], the social learning [26], and the social development [117, 118], can be represented as an increase of certain selected psychological and behavioural responses to a stimulus (a set of activated schemes) after repeated and positive exposure over a duration of time.

This module requires the ability to evaluate the adequacy of the consequences of a certain behaviour/cognition (or mental scheme) with the expected goal, both using experience and the observation of others [119, 120].

Suggestions for ICT applications

It is possible to derive some suggestions from the previous analysis.

First of all, the knowledge can be represented as the set of "confirmed" schemes and their interconnections.

The schemes and the perceptive heuristics belonging to the first module can be generally modelled using frequency-based approaches such as neural networks, which indeed originated from the modelling of the perceptive mechanisms. These schemes are activated by the input, they are fast and automatic. All cognitive computational algorithms postulated at this level should be implementable (i.e. for example on the ACT-R software), and consequently testable.

While the schemes in module 1 are essentially deterministic, those of module 2 act evaluating the probability of an event, and by comparing the presumed consequences of the act with the goals [69].

An common name for these behaviour is "cognitive heuristics".

Important aspects of this process are those contained into the principal assumption of Social Cognition and psychological plausibility, i.e., economy, tractability, time requirement, robustness. These constraints can be identified with those denoted "human heuristics".

Therefore, we assume the existence of a "simulation" feature, presumably analogous to an associative memory, with a "linear" extrapolation mechanism. These features resemble the working of associative neural networks [121]. The effective implementation of the action occurs by means of schemes, which are activated or inactivated by heuristics mechanisms.

There are many mathematical instruments for implementing the learning phase, it is possible to identify a common reinforcing mechanism not only for schemes but also for the cognitive heuristics, that act essentially as a connection among schemes. Many psychological learning theories can be reinterpreted within this framework as a reinforcement of schemes and of relations among schemes.
Module I

2. Unconscious knowledge: perception, data encoding and pre attentive processes

2.1. Introduction

A review of the models and frameworks developed to investigate the cognitive information analysis clearly shows the existence of two main regimes of such activity. Experimental measurements and theoretical inductions have converged in the last century toward a separation between perceptive and attentive processes and the rest of the superior cognitive functions.

A brand new definition for these processes is that of *Unconscious Knowledge*. This concept is currently associated to the lack of meta-knowledge of subjects concerning their epistemic states (i.e. subjects are not able to explain why they decided in a certain way; they do not know what they know).

In cognitive sciences, knowledge has been frequently defined as the information or data about the environment that can be acquired, stored, and retrieved by living organisms, and cognition was consequently defined as the processes of acquisition, storage, and retrieval of that knowledge [7, 8]. In this theoretical framework, unconscious knowledge refers to knowledge that is revealed by task performance alone, subjects being unaware that they are accessing it, whereas we speak of conscious knowledge when subjects are aware of possessing and accessing it [122, 123, 124].

The feature that fundamentally distinguishes unconscious from conscious knowledge is the fact that the former appears to be purely procedural, while the latter seems declarative in nature. In other words subjects exhibit a dissociation between performance and repeatability, being incapable of verbally expressing actions they perform and behavior they display. Common examples of this kind of knowledge are riding a bike, speaking a language as a native speaker, judging faces, etc.

Neurophysiological evidences have clearly shown that the classification of unconscious knowledge can be applied to other aspects of cognitive processes such as reaction times, neural activation and evolutionary features [125, 126, 127, 128], indicating the existence of a first phase of the cognitive activity that should be investigated and modeled independently.

The cognitive processes that belong to the unconscious knowledge domains are clearly identifiable by some objective and effective features. They are fast (i.e. faster than 500 ms), rigid and automatic processes (bottom-up processes), produced by a relatively small and localized neural activation [129]. Their evolution is frequently characterized by *critical periods of development* [130, 131, 132, 133, 134, 28, 135, 136] and after that a substantial hard wiring is detectable for such processes characterized only by a ‘classical’ hebbian evolution [137, 138].

The previous insights were actually well established in the most important psychological approaches of the last century and maybe a coherent paradigm for modelling of the unconscious knowledge processes could be nowadays derived as a generalization and unification of such approaches.

2.2. Gestalt: the born of the concepts of Cognitive Scheme and Psychological/Perceptive Laws

Gestalt psychology has introduced in the approach to the cognitive phenomena some specific criteria, such as a careful selection of new experimental observables to describe the higher cognitive activity, consequently promoting the birth of a new science. Particularly, along with the early studies in psychophysics its collection of experimental phenomena has been the first
attempt to build a physics of the psychological processes, thus with the concepts of law and function [139, 140, 141].

Fechner and Weber guessed that a logarithmic function could explain how the sensations are perceived by human senses. The gestalt goes further by defining some laws seeking to explain how a "superior" order perception occurs, and since from the sensory areas the human being is able to extrapolate from the percept informations that are not derivable from the simple sum of the parts that make up the primary stimulus.

Gestalt first described, through its "laws", how the perception is able to extract relevant information from a percept, and how through this selection it is possible to actively build a perceived reality very different from the real one. [142, 1]. in this sense the Gestalt law refers to the property of the image that seems to emerge from the single parts that compose it, in a kind of bottom-up process. This mean that what was first considered a passive process - the perception - was to be thought of as something far more active as a subordinated experience to some organizational and general principles. The gestalt laws refer principally to the contrast between figure and ground, and how the image and the perception is an holistic process of perceptual re-organization: some parts of the visual field join with others to give the shape of an object, while others are separated from different parts of the field, which define the background of the image perceived image [143, 144, 145, 146, 147, 148, 149, 150].

Gestalt theory holds that the humans are an open systems in active interaction with the environment, and from this experience they form an interpretation of psychological events, their order and their structure. This concept was at the base of Lewin’s field theory, which has expanded the theory of Gestalt perceptual phenomenon to something about the continuous exchange between individual and the environment in which it is inserted [151].

Furthermore, the Gestalt theory in recent years has led to the definition of schema or mental representation. Its key contribution lies in having unbounded the human sensory apparatus from the simple receptive action, to give it a first degree of selection, processing and decision of what is to come to consciousness. A good examples of this is the gestalt psychology law of "past experience".

This law suggests that if the stimuli are part of a familiar configuration, and therefore well known, they tend to be organized by perception into a unit. The elements which in our past experience have been frequently associated each other, will tend to be united in "Gestalt good shapes" as in figure 2.2.

In this case appears both the bottom-up strength of the stimulus and the top-down influence resulting from the activation pattern corresponding to the letter "E". An observer who does not know the Roman alphabet can not see the letter “E” in these three broken lines. In addition, it is very difficult do not to perceive the letter "E" once the schema associated with the recognition of this letter is activated.

Moreover, recent neurophysiological studies and neuropsychological evidence suggest that some phenomena described by the Gestalt theory could be mediated by more patterns, partially
integrated, and not always equally accessible to awareness [152, 153, 154].

Generally, the visual perception is an incomplete representation because a system that can encode all the properties of external objects, and do it quickly to offer an effective support to the action, would be very difficult to assemble and perhaps not convenient.

In conclusion the Gestalt theories have introduced the theoretical fundamental concepts of perceptive/cognitive scheme, underlining the apparent process of dimensionality reduction of the percept toward a complex and associative-oriented representation (i.e. map).

2.3. The connectionism: the structural organization and the evolution of the concept of scheme.

The discovering of the implicit computational capacity of the neural system.

The connectionism was the first approach to the cognitive phenomena able to replicate some perceptive and pre-attentive cerebral mechanisms, by means of the investigation and simulation of brain’s models (i.e. mainly but not only by neural network models). Starting from the psychophysiological and psychophysical studies, the connectionism suggested that the computational assumption underlying the cognitive sciences could be used to build the computational architecture of the mind, uniting cognitive psychological theories with neuroscience’s statements. Neural plasticity, topological organization (column of dominance, neural circuits, associative area, Hebbian learning) and synaptic dynamics are only the most important concepts that the connectionist approach introduced and validated, providing a fundamental link between the microscopic feature of the neurons and the cognitive functioning [155, 129].

The connectionism considered the whole brain as a neural network, where the neurons, representing the nodes of the network, are linked each others by many incoming and outgoing synapses per neuron. For the connectionism each neuron behaves as a single unit of calculation, which operates in parallel with others neurons, and could be detailed until to reach the same dynamics of the signal processing and transmission of real neurons.

The complexity of cognition was principally explained by the connectionism as a natural result of the interaction of a large number of densely interconnected elements. And the principal aim of connectionism has been to explain how the neural network works, and how they presumably analyse, reduce the input contemporary evolving with it. Several kind of neural networks, as the human perception, show the ability to autonomously learn how to extract the relevant components of a frequently presented information pattern, and how to use them to optimize the encoding and the abstract representation of the knowledge [156, 157, 158].

For example, connectionism has been the first approach that deeply understood the visual information processing, undoubtedly the most explored cognitive function. The processing path that undergoes the visual input requires the analysis carried out by single neurons programmed to respond and to process specific characteristics, and the temporary use of some neural buffers or memories where the signal is preprocessed and accumulated (i.e. craniotopical mal of the world) [159].

Neural network models explain the observed neural involvement of the occipital brain areas during the first stages of the visual processing, the role of the several layers which characterizes that neural structures [160], suggesting some solutions to investigate the complexity of neural signals structure and dynamics [161]. Finally working in parallel on the basis of feedback from the upper layers and lower [162].

Connectionism finally demonstrates that the neural system organization equips the cognitive system with some intrinsic computational capacities, describing an grounding effectively the first stages of the cognitive analysis of information on the results of the interplay between associative
areas and the neural pathways dynamics which encode the representation of the environment [163].

The approach to the early stages of cognitive information processing (eg. encoding and recognition processes) inspired by the connectionism has been fundamental to understand the role played by the complexity of the neural signals [164, 165]. Moreover it has revealed the role of neural plasticity and complex patterns of neural signals on the primary and secondary associative processes during the first stages of the information encoding [166].

Finally, within this theoretical framework, the Gestaltic concepts of scheme and law found an experimental and computational definition as the result of the hebbian learning and pruning evolution of the neural representation of the information, due to their frequencies of occurrence.

The wide legacy of mechanisms and features discovered by the connectionists represents nowadays one of the building blocks of the ACTr approach to the cognition modelling [22].

2.4. Psychophysics: the role of the pre attentive processes and the complex internal representations of the information.

Psychophysics can be really described as one of the first multidisciplinary domain of cognitive sciences, because its origin can be considered as the intersection between Gestalt psychology, psychology of perception and neurophysiology. Psychophysics uses the quantitative approach proper of physics to the study of the cognitive processes accessible in the laboratory. Despite its principal field of investigation has been the dynamics of perception and attention, its concepts and models have became fundamental for the superior cognitive function investigation [139, 167, 168, 169].

Traditionally, psychophysics investigates and describes how an organism uses its sensory systems to detect events in its environment, and the functional description is based on the abstract processes of the sensory systems rather than on their physiological structure.

The psychophysical theory of Signal Detectability (TSD), played a central role in the psychophysical framework, using a combination of statistical decision theory and the concept of the ideal observer to model an observer’s sensitivity to events in its environment. Consequently TSD is stimulus-oriented, because the properties of the stimuli are used to determine the theoretical best, or ideal, observer for a given detection task. For instance, the ability of humans to detect simple acoustic waveforms has been modelled as a linear system composed by filter, rectifier, integrator, and sampler [170, 171, 172, 173].

The importance of the psychophysical studies for the comprehension of the cognitive activity is not only related with the experimental effects and laws described by this discipline, but mainly with its discovering of quantitative computational functions that couple the perceptive and the attentive processes.

The modern multidimensional psychophysics actually was born very early in the past century, since the 1940s some authors argued against the one-dimensional classical psychophysics of Fechner and Stevens, that treated perceived features as independent from the context variables [174].

A classical and prototypical example of the new paradigm is represented by the study of how the estimation of the number of coins depends on their size and value and vice versa, in other words how the world representation is a perceptual compromises, and not just an accurate and automatic counts of frequencies [175, 176].

The modern concept of stimulus in psychology and the development of an ecological approach to the study of human perception are among the important results gained by the psy-
Psychophysics researches. How a stimulus is structured, filtered, represented at various stages of the perceptive pathways has been discovered and described within this framework [177, 178].

Psychophysics described computationally also some relevant features of the complex maps which characterize the early stages of the cognitive representation of the environment, and the role of the complex features of the neural signals on the cognitive processes [164, 179, 180]. For instance, the complex time and space representation of the visual stimuli has been fundamental to understand and reproduce the efficiency of the human perception and information encoding ability [181, 182, 183, 184], and the importance of the synaptic plasticity on the intrinsic capacity of data reduction of the cognition (e.g. factorial analysis) [185, 186, 187].

Finally, psychophysics is linked on one side to the neurophysiology of the perceptive and attentive processes with their functional role in the processes of information encoding and storing, and on the other it has described the attentive and cognitive (reasoning) related effects on the human perception of the world, defining a computational framework to design the first stages of the superior cognitive processes and maps [188].

2.5. Neurophysiology: recent evidences of the associative processes

Evoked potentials and functional imaging techniques have been fundamentals to define the time scales, localizations and neural underpinnings of the cognitive processes such as perception and attention.

2.5.1. Evoked Potentials

An evoked event-related potential (or ERP) is a low amplitude electrical potential recorded from the human nervous system and activated (e.g. evoked) usually by different types of sensory stimulus. ERP can be distinguished from the spontaneous potentials detected by electroencephalography (EEG) or electromyography (EMG). The different acronyms which refer to ERP usually indicate first the kind of potential and the related area/process (e.g. contingent negative variation - CNV, error-related negativity - ERN, early left anterior negativity - ELAN, closure positive shift - CPS, visually evoked potential - VEP, Brainstem Auditory Evoked Potentials - BAEPs, Somatosensory Evoked Potential - SSEP, etc), followed by a letter indicating polarity and a number indicating either the latency in milliseconds or the component’s ordinal position in the waveform (the most studied are: N100, N200, N200pc, N170, P200, N400, P300, P300a, P300b, P600, etc.).

The development of the ERP’s technique opened a new field for the cognitive electrophysiology of mind and brain. Concepts as neural maps, bottom-up, top-down, and pre-attentive processes, which were postulated theoretically from other domains (i.e. Gestalt, Connectionism, Cognitive Psychology, Psychophysics) founding experimental confirmations, and neurophysiological localization and description within this framework [189, 190, 191, 192].

Among the ERP, the most studied ones are the visually evoked potentials (VEP), which are gross electrical signals recorded from the occipital cortex in response a systematic change in some visual event. The recording electrode is placed over the occipital cortex and the amplitude and latency of the waveform generated can be measured. Their specificity is greater than that obtained with the electroencephalogram (EEG) and more sensitive to changes in the visual stimulus, thus, the investigations on these signals have provided ophthalmologists and vision researchers fundamental insights about the human visual system that were unavailable by other methods [193].

ERP-based researches have produced fundamental insights about the relation between perceptive encoding and pre-attentive activation (e.g. bottom-up and top-down processes). For
instance we knew from psychophysics and Gestalt that when attention is voluntary directed to a spatial location, the visual sensitivity increases at that location. This improved sensitivity has been explained by the monitorization of some frequency-tagged steady-state visual evoked potentials (SSVEPs) that clearly shown how the voluntary sustained attention multiplicatively increases the electrophysiological activity of the stimulus-driven population. These results suggested that the role of attention is complementary of that of perception and encoding in general, increasing or decreasing the single-neuron spike rates in a variety of ways [194].

This fundamental result implied the existence of both complex perceptive representations of the environment and an effect of this representations on the neural encoding of the signals. These two assumptions have found a large confirmation with regards to the ERP literature, moreover showing to be valid also for other sensorial modality and cognitive functions [195].

The most relevant result obtained by the application of ERP to the cognitive studies has been the quantitative validation of many psychophysical models of perception, and subsequent unification of many models coming from this domain with the theories coming from cognitive psychology and connectionism [196, 197].

An example is represented by the psychophysical Sensory Decision Theory (SDT) that has been used to quantitatively predict the evoked potentials, showing how the two methods measure a common perceptual process.

The investigated time scale for the processes was between 50 and 500 ms, and the peak-to-peak amplitudes and latencies were registered for the four categories corresponding to SDT response classifications: hits, false affirmatives, misses and correct rejections. The ERPs associated with hits and false affirmatives had significantly greater amplitudes at N157-P237 than those associated with misses and correct rejections. These results suggest that N157-P237 amplitudes associated with perceptive relevance assessment are appropriately described by the SDT psychophysical model, and they demonstrate that the two paradigms assess the single perceptual process [198].

Moreover, reviews of selective attention studies suggest that the disclose processing negativity, an endogenous negative brain potential elicited by the delivery of the stimuli, is the marker of the attentive processing onset. This negative potential is characterized by a very short onset latency (50-250 ms) from the stimulus onset overlapping the major negative components of the perceptive-related evoked potentials [199].

Thanks to the ERP techniques, the process of the information extraction and encoding has revealed to be fast and automatic, able to affect the subsequent neural associations (e.g. variate the semantic context or update an associative or perceptive map) but affected by them at same time, linking forever attentive and perceptive cognitive processes.

The P300 and the N400 are probably the most famous components of the human evoked potentials and are currently described as the stimulus salience and incongruence respectively. P300 is emitted by the brain in response to either expected events that are surprising or to unexpected events that produce orienting. P300 latency does appear to index stimulus evaluation time, it is not emitted until the stimulus has been cognitively evaluated. It has been proposed that P300’s functional role in human information processing is the updating of neurocognitive models concerning future events [200]. At the contrary the N400 is known to be an indicator of the input semantic/visual/acoustical incongruence, confirming how in the domain of the early cognitive processes there is a non-trivial process of information. The N400 is a negative-going deflection that peaks around 400 milliseconds post-stimulus onset, and is typically maximal over centro-parietal electrode sites. The N400 is part of the normal brain response to words and other meaningful (or potentially meaningful) stimuli, including visual and auditory words, language
signs, pictures, faces, environmental sounds, and smells. When it was discovered, the researchers were looking for the response to unexpected words in sentences, expecting also to elicit a P300 component. The authors used sentences with anomalous words like “*take a coffee with cream and dog*”, and were surprised to observe a large negativity instead of the known P300, relative to the sentences with expected endings (*i.e.* He returned the book to the library).

In the same work they confirmed that the negativity was not just caused by any unexpected event at the end of a sentence, since a semantically expected but physically unexpected word (*i.e.* She put on her high-heeled SHOES) elicited a P300 instead of negativity in the N400 window. This finding showed that the N400 is related to semantic processing, and is not just a response to unexpected words [201, 202, 203].

A simple combination of P300 and N400 studies suggests that during the first 500 ms from the input administration the cognition is able to assess explicitly the relevance of a stimulus (P300), or later, its incongruence (N400). In order to accomplish this task, the existence of some complex sensory maps, like those theorized from psychophysics and connectionism, was required, and the link with the superior (and abstracted) cognitive functions considered [204, 205, 206, 207].

Throughout the investigation of the affecting psychophysical factors of the principal ERPs has been possible to validate important computational models and mathematical insights of information encoding, producing the stabilization of a coherent theoretical framework where the concepts of attentive and perceptive processing finally have been really distinguished by those of reasoning and learning [208, 209, 210, 211, 212].

2.5.2. Brain imaging

The old idea that the brain is frequently busy with associative processing, has been a key concepts for Plato, Aristotle, Hobbes and the Empiricists.

Recent works about the relation between the neurophysiology of the associative processing and the cortical activation that characterizes the brain’s default mode [104, 51, 65, 213] definitively supports this idea. Significant parts of the default network, which refers to the collection of brain regions that are consistently activated when subjects are not engaged in a task-specific cognitive effort, overlap with the regions activated by tasks that recruit associative processing showing that associative activation is an integral process of the brains mental default mode [54].

Among the other, an insightful basis for this proposal is provided by the wide literature on priming and salience (*e.g.* perceptual, semantic and contextual). These studies discovered that the perception of a certain stimulus co-activates the representations of related items, independently from the real presence of the items as part of the present physical environment. Recent neuroimaging studies demonstrate again that the involvement of associative predictions in cognitive facilitation is the factor that continually engages the brain in generating predictions, and that these predictions rely on associative and pre attentive activation [52, 53, 75, 47, 66, 214].

The neurophysiological evidences for the interplay between perceptive and attentive structures are related to the many reciprocal cortical projections that connect separate regions, which suggests bi-directional cortical communication [215, 103, 216, 217, 218, 219].

According to some estimates, the number of feedback (top-down) projections might even exceed the number of feedforward (bottomup) connections [220]. Although this aspect of the anatomy is known, and the implication of omnipresent bi-directional flow consequenty seems highly reasonable, this finding has not yet been sufficiently incorporated into contemporary thinking regarding cognitive processing. However, this provocative anatomy findings implies something profound about how the brain works. Specifically, the reciprocal connections might provide
the infrastructure that supports the continuous top-down involvement of internal representations with the interpretation of the world around us.

Associations have largely been found in the medial temporal lobe (MTL), in the hippocampus [221, 222], and in the parahippocampal cortex (PHC) [223]. With regards to the overlap seen between associative processing and the default network, other medial regions, such as the medial prefrontal cortex (MPFC) and medial parietal cortex (MPC) are involved.

Summarizing, the most recent neurophysiological evidences confirm that the encoding phase of cognitive analysis of information is linked to with the attentive structure and by these with the higher cognitive functions like the reasoning.

In particular, in experiments of dividing (e.g. impairing) attention during encoding and/or retrieval changed the consistency of judgments during a statement verification task. While the divided attention at the time of the information encoding decreased the strength of the stored information thereby decreasing the participants ability to decide effectively, the divided attention during retrieval had no effect.

This data implies that the variables that affect the encoding processes should also affect and be affected by the judgment processes [224, 225].

At the same time such findings support a characterization of the analogical processes as protected processes [226, 227] suggesting a different mechanism for the analogical projections that does not depend from the attentive buffer/resources.

2.6. ACT-R: a production system theory

During the last quarter of the past century the new challenge of the post-cognitive and post-connectionist was to unify the cognitive theories coming from Gestalt and perceptive psychology, with the insights of connectionism and with the neurophysiology of the brain. Within this situation Anderson in the 1983 published his architecture of cognition, devoted to the definition of the irreducible cognitive and perceptual operations. Ten years later, in the 1993, Anderson presented the first computational implementation of ACT-R as a tool to investigate how the brain is organized in a way that enables individual processing modules to produce cognition [228, 229, 30, 22, 230, 231, 232].

The ACT-R theory has a computational implementation as an interpreter of a special coding language and most of if success is due to the fact that any researcher may download the ACT-R code and gain full access to the theory in the form of the ACT-R interpreter, in order to encourage researchers to specify models of human cognition in the form of a script in the ACT-R language.

The primitives of this framework and the data-types are optimized to mimic the theoretical representations of cognition coming from experiments in cognitive psychology, psychophysics and cognitive neuroscience.

With this tool it is substantially possible to accurately describe the cognitive information processing of simple cognitive functions as ACT-R models, specifying each cognitive operation (i.e., memory encoding and retrieval, sensory encoding, motor programming and execution, mental abstraction and manipulation). A running model simulates step-by-step the human cognitive behaviour, associating each step with a quantitative predictions of latencies and accuracies. The ACT-R models are continuously validated and tuned by comparing their forecasting with the data collected in real experiments.

The goodness of the ACT-R framework is demonstrated by the recent cognitive neuroscience literature, where it is largely used to make quantitative predictions of patterns of activation in the brain. fMRI experiments have shown that ACT-R predicts the shape and time-course of the
neural response of several brain areas, including the hand and mouth areas in the motor cortex, the left pre-frontal cortex, the anterior cingulate cortex, and the basal ganglia. Its effectiveness in the prediction of the prefrontal and parietal activity in memory retrieval, is of particular interest for the cognitive heuristics domain [233, 234, 235, 236].

The ACT-R rationale can be seen as grounded on the Gestalt concept of scheme and the connectionist concept of buffer. The human knowledge is mainly divided in two kinds of representations: declarative and procedural. The first are vector representations of properties, held and made accessible through buffers, which are the front-end of modules. Modules are specialized and autonomous brain/cognitive structures and divided in two classes by the ACT-R theory: the perceptual modules that are interfaced to the external world, and the memory modules. Finally, the memory modules include the declarative memory, that is related with the explicit knowledge, and the procedural memory, where are represented the list of rules (i.e scripts) required to do things.

All the modules communicate with each others through their buffers, and the contents of a buffer at a given moment in time represents the state of the cognitive activation at that moment.

The ACT-R defines a syntax to represent vectors and scripts, as schema-like representation containing a field specifying the category of knowledge, and additional fields to encode the knowledge.

Cognitive tasks are performed by assembling production rules by setting goals, and by reading and writing to buffers. Goals are usually represented on a structure called the goal stack.

The two core processes defined in ACT-R are pattern matching and conflict resolution. Pattern matching is the process which determines if a production conditions are met by the current state of working memory. The conflict resolution is the process that determines which production should be applied if several production rules are applicable.

The ACT-R framework defines two levels of abstraction: the symbolic level and the subsymbolic level.

While the symbolic level is related with vectors and scripts, the subsymbolic structure is represented by the collection of massively parallel processes (modelled by mathematical equations) that represent the implementation of the symbolic level. Consequently, this subsymbolic system should accurately model the neurological information processing modules of the human neural system.

Since its introduction, the ACT-R framework has been used in a wide range of scientific publications and models, ranging from perception, attention, and learning to the social problem solving and the probabilistic reasoning.

The associative nature of the human memory has been successfully modelled using ACT-R and a large number of well known effects (e.g. interferences at the encoding, primacy, recency, serial recall, stroop effect, task switching), have been reproduced [237, 238, 239, 240, 241, 242, 243, 244, 245].

In the field of the natural language theories, ACT-R models have been produced for syntactic parsing, understanding, language acquisition and metaphor comprehension [246, 247, 248, 249].

The applications of the ACT-R theory to the human problem solving are also relevant, problems like the Tower of Hanoi and the algebraic equations resolutions, as so as the human behaviour in driving and flying have found a computational cognitive oriented implementation within this framework. Despite at this level the forecasting abilities of ACT-R are reduced by the complexity of the neural activations, the rapid development of the neural imaging techniques, as
well as the availability of more computing power to run the ACT-R-models could fill this gap in the future [250, 251, 252, 253, 254, 255].

2.7. Module I: The state of the art

The efficiency of the human ability to extract a gist, a minimally analysed and frequently implicit information, from a given frequently noised and biased scene or sensory experience, has been the focus of the first experimental studies in psychology. Despite the advancements in the neurophysiological and neuropsychological description of the cognitive activity, its intimate dynamics remains largely unknown.

This is mainly due to the fact that the brain, instead of being passively activated by information the human brain is continuously busy generating perceptive predictions that approximate the future. A rudimentary information is extracted rapidly from the input to derive associations linking the input with representations in memory.

The early stages of the perceptual transformation of raw sensory inputs into conceptual objects and properties are characterized by complex and non-linear rules mainly due to the interaction between the vast number of receptive elements and the particular projections represented by their integration in the working and associative memories.

The representations are not passively activated but are driven/facilitated by the attentive structures which weight the perceptive input depending on their relevance for the specific context. These mechanism of prediction facilitate the perception and cognition by pre-sensitizing relevant representations, and actually represent the coupling factor of the Module I and II. So pre-attentive activations are continuously generated either based on information gathered from the sense or produced by the reasoning.

Moreover, complex information patterns such as those present in social interactions, can be represented by the integration of multiple associations in a form of an immanent and temporary representation of the reality and not just of the perceived information.

The associative nature of perceptive and attentive processes makes it possible to take advantage of frequent trends in the environment to help the interpretation and the anticipation of immediate and future events. For example, contextual framing has a direct influence on our judgments of the emotions of others [256].

The key concepts of associations and analogy have been the focus of rich and active researches for a long time, and probably will be fundamental in all the computational formalization of the cognitive information encoding.

Perceptive associations can be seen as the process of extracting repeating patterns and statistical regularities from our environment, stored in the brain’s connections and directly related to the perceptive/physical features.

What we introduced as pre-attentive activations could be considered related to the concept of analogical activations, while we actively search correspondence between the novel input and its existing potential representations in memory, up to affecting the perception of the world in order to fit the perceptive data.

The previous two theoretical concepts require or suggest the existence of associative and an analogical maps, possibly hard wired in the brain (as suggested by the connectionism), and represent the bridge between conscious and unconscious knowledge.

The central role of the analogical mapping in perception is an issue that has received a lot of attention [51, 75, 65]. Analogy-based mappings of properties manifest themselves in processes ranging from perception and memory [215] to stereotypic judgements and prejudices [103], they
appear to be frequently based on similarity on various levels, including perceptual similarity (e.g. in shape or smell), abstract conceptual dimensions, and goals.

Finally, the interplay between the associative and analogical-based mapping of reality seems able to explain how important top-down prediction regarding the identity of the input are affecting the initial bottom-up information encoding [47, 66].

Our experiences and knowledge are represented in structures that cluster together related information, linking at on some level objects, attributes and emotions that tend to appear together. Such representations include properties that are inherent to and typical of the same experience and for them the terms context frames [257, 214], schemata [258], scripts [52] and frames [53], have been coined. All this concepts imply a unified, global representation of perceptual and semantic associated attributes, a sort of prototypical representations of the reality used to approximate the environment.

The structure of such scheme (e.g. context frames) enables co-activations that prime our subsequent perception, cognition and action by remaining online and making available predictions of what to expect in the immediate environment.

Since it is now computationally explained how mental representations are perceptual compromises, not accurate and automatic counts of frequencies independent of context, prominent cognitive theories such as the Relevance theory and Optimally theory give an explanation of how people generate analogical-based expectations from rules according to their accessibility and stop the process when the expectations of relevance are met [60, 58, 59].

So the central theoretical elements that arise from this module are the perceptive associative patterns (e.g. schemes, context frames, script), the analogical based representation of the environment/reality and the rules that couple this two levels.
Module II

3. The reasoning and the cognitive inference processes

3.1. Introduction

Module II accounts for those higher cognitive processes which complete the problem solving processes started by perception; these processes operate on the complex map generated by attentive and perceptive processes of cognitive information encoding, making inferences and planning abstract strategies. The processes that belong to this module are characterizable as more expensive in computational and neurological terms than those in module I, more flexible and accessible to the conscious inspection (e.g. meta-knowledge) and capable of evolving also through mental simulations and induction.

The sum of such cognitive processes is usually referred as human reasoning and the modern approach in this matter can be dated back to the 18th century with the publication of A Treatise of Human Nature by David Hume in the 1740 [259]. Hume’s concept of Vivacity of an idea anticipates the formulation of modern cognitive concepts as arousal, salience or relevance and it is related in Hume’s theory with the unconscious mind capacity to use frequencies to assess the degree of a belief. Starting with this enlightening treatise mechanisms by which the brain/mind converts observed frequencies into beliefs, credences, expectations and plans represented the main challenge of cognitive sciences.

A coherent theoretical framework has been implicitly developed and validated from the probabilistic approach to the human inference, adopted and defended by researchers as Pierre Laplace, George Boole and Jean Piaget, and crumbled in the early nineteenth century, to current non-linear models of probabilistic reasoning [260, 261, 29, 17].

Human rationality has been studied for decades in psychology by classic logical or statistical rule as normative in all situations, consequently constructing artificial and biased problems in which this rule could be followed, such as the Wason Selection Task or the Linda Problem [262, 263, 264].

The turning point of this honored tradition is probably represented by the work of Herbert Simon entitled Rational Choice and the Structure of the Environment. Simon argued against the dominant classical rationality that ... minds are adapted to the real world, and that human rationality is shaped by a scissors whose two blades are the structure of task environments and the computational capabilities of the actor [83, 265, 266].

Consequently, the minds of living systems should be understood relatively to the environment in which they evolved, and with respect to their cognitive resources, rather than to the tenets of classical rationality [44].

After the advent of Social Cognition, the theories of inference and reasoning have been largely reformulated or changed, such systems have been designed to satisfy rather than to optimize [267], choosing for instance the first ”good” solution instead of exploring all possible alternatives. Cognitive models should consider algorithms which operates with simple psychological principles that satisfy the constraints of limited time, knowledge, and computational might, instead of those of classical rationality. At the same time, they have to be designed to be fast and frugal without a significant loss of inferential accuracy (e.g., in artificial intelligence [268], in cognitive psychology/cognitive science [269, 270]; in philosophy and semantics [271, 272].

The end of last century has been characterized by the controversy on the appropriate algorithmic level of description [273] of theory of reasoning, producing sometimes mismatching computational models or algorithms of cognition.
In recent years, most of interesting research directions on cognitive reasoning models has inverted the strategy: instead of starting from modelling the cognitive performance on logical reasoning tasks to generalize to the everyday inference, they start from attempting to model everyday inference, generalizing it to laboratory reasoning performance.

Nowadays, the general challenge of human reasoning modelling is to explain the cognitive performance in experimental procedures in terms of the adaptive function of cognitive mechanisms in the real world [274, 22], adopting the concept of probabilistic reasoning strategies for the calculus of the uncertain reasoning [275, 276, 84, 76].

Many statistical models are currently assumed as an implicit theory of reasoning from different scientific domains [18, 19, 20, 21, 22]: these models suggest and imply a coherent vision of the required cognitive middle-ware, i.e. required atomic components of a coherent architecture for the human abstract reasoning.

Such middle-ware is composed by an integrated representation/mapping of the external information, encoded in the associative activated map of module I, on the subject’s knowledge, which is defined as all the accessible mental scheme of reasoning (B-Scheme). Contemporary, in the same way, another required mechanism has to abstract a mental representation of goals, probably comparable with the B-scheme (with partially the same neural shape).

Then a first cognitive process is required to assess and the relevance of such schemes with respect to attentive activations, selecting only adapted ones. Later, a second process should assess either the probability of success (expectancies) and the cognitive and temporal cost of a certain B-scheme in order to decide if activate or modify it.

Finally the same mechanism which selects the relevance of an adapted B-Scheme appears to be able to merge and partially modify previous existing schemes, indicating the existence of a complex analogical based representation of the strategies (i.e. the cognitive heuristics) at the cognitive level.

3.2. The Cognitive Psychology

Cognitive psychology considers the stimulus as the starting point of the perception of the outside world, but the core of this approach is the mental representation, or schema, that the individual constructs on the basis of such perceptions. The birth of this approach goes back to 1967, year of publication of cognitive psychology, although the movement was already established at least since one decade [7, 8].

Cognitive theory represents the first theoretical formulation, applied to several areas as memory, thought, language, perception, including a wide variety of guidelines and research areas that can be joined by a series of fundamental principles. First of all the principle of the biological bases of mental processes. Essentially, the cognitive psychology studies the structures and functions of the nervous system, in its maximum complexity, and the psychological processes that control the adaptation of the organism to the environment. Moreover, the psychic processes develop according to the maturation of the nervous system. Along with this development, the mental processes actively operate on the environment, filtering the external information and producing motor responses on its own schema of knowledge and action. Cognitivism specifically refers to the typical organization of the mental processes, not so much characterized by the production of responses to stimuli, but by models (e.g. mental models), often aware that guide the human behaviour through an internal representation of the outside world. The building of mental models takes place through the external and internal information processing made by the specialized areas of the brain. The processing can be simulated on non-organic machines because both
the mind and the computer processes and operate on the basis of similar rules - HIP Paradigm, the dominant paradigm of the movement, the human information processing. This paradigm could explain some cognitive processes such as perception, attention, memory, language, thought and creativity. These processes are intended to be autonomous from a structural point of view and functionally interdependent and interrelated. A model that refers to the concept of HIP is that proposed by Broadbent in 1957 [277].

This model assumes that information reaches the designated areas of the sensory analysis filtered by the attentional mechanism known as "Broadbent filter", and sent to other structures and areas for storage in memory and other coding and processing. This process occurs in a serial manner, stage by stage. The mind is conceived as a processor of information characterized by a specific organization and by a sequential processing, with a limited capacity along its transmission channels. To explain this relationship between structural and functional organization spread, the system has been represented by means of flow charts, each consisting of units that define tasks (i.e., perception, attention, etc.) and communication links. Another important contribution of cognitive psychology is the emphasis on the aimed character of mental processes. The concept of feedback developed by cybernetic became central to explain the goal-oriented behaviour. The problem solving strategies can be seen as the peculiar product of the cognitive information processing. Behaviour is considered to be the result of a continuous process of retroactive monitoring of the behavioural strategies, according to the unit TOTE (test-operate-text-exit). The output does not follow directly to a sensory input or motor command, but is the result of previous verification operations (tests) of environmental conditions, intermediate executions (operate) and then new tests (test) [278].

Particularly worth of attention is the Affordance Theory, a framework arose at the end of the 1970 and representing an attempt to couple the associative representation of the external information with the analogical representation exploited by the problem solving processes.

The affordance can be defined as a quality of an object, or an environment, which allows an actor to perform an action or a thought. For example, a knob affords twisting, and perhaps pushing, while a cord affords pulling, however, the possible affordances are defined as relative to an individuals prior experiences with an object.

The term has been used in a variety of fields: perceptive psychology, cognitive psychology, environmental psychology, industrial design, humancomputer interaction, interaction design, instructional design and artificial intelligence. The original definition faces with the description of all possible physical actions of which an actor is aware.

The psychologist James J. Gibson originally introduced the term in his work 1977 defining affordances as all "action possibilities" latent in the environment, objectively measurable and independent of the individual’s ability to recognize them, but always in relation to the actor and therefore dependent on their capabilities [279].

The evolution of the concept of affordance is nowadays related to those of context frame and mental scheme, in particular suggesting the existence of behavioural/motor related components directly into the knowledge mental scheme, e.g. the associations of perceptions with motor answers are encoded in memory [280].

The cognitive approach to the mental processing has been evolved at the end of the past century toward an Unified Theories of Cognition (UTC). Several authors argued for the need of a set of general assumptions for cognitive models that accounts for all the cognitive activity, as the only effective way to investigate the complex network of processes that define the brain activity.

The first assumption is that an UTC must explain how intelligent organisms react in a flexibly way to stimuli from the environment, how they exhibit goal-directed behaviour and acquire goals
rationally, how they represent knowledge, and how they evolved such structures (e.g. learning). The UTC argues that the mind functions as a single system and that the cognitive models are vastly underdetermined by experimental data. Therefore, an UTC accounting for the experimental data would provide constraints on the modelling process, resulting in more rigorous and predictive models. An UTC could also be applied as theoretical constructs to a much wider range of cognitive phenomena [281].

3.3. Social cognition:

The most interesting evolution of the cognitive paradigm has been its application to the social sciences [33, 34]. It is essentially concerned about how the individuals process, transform, encode and recall the information coming to the environment when they are into a social context. The basic idea of social cognition is that the social and environmental informations do not have only an intrinsic and absolute meaning, but depend largely by the subjective processes of attribution of meanings and values. Inside this theoretical framework the typical objects are represented by the results of the processes of subjective interpretation of the information, such processes are dependent of both the past knowledge or experience of the subject and its current state [282, 283, 32, 284, 285, 286, 287, 288].

In order to understand the cognitive processes that characterized social psychology, the individuals included in a social context has to be intended as exposed to the group dynamics that involve them, as proposed by Kurt Lewin in its Psychological Field theory [151, 10, 289]. Lewin and his school introduced the concept of group mind to indicate that certain collective entities present emergent behaviours and specific characteristics, which are not present at the individual level. This concept of group mind recall the gestalt concept of dynamics totality and it presents different features with respect to the simple sum of its single components. In this way group started to be considered a different entity from the individuals that compose it.

Furthermore, one of the main contributions of cognitive psychology at the Social Cognition provides how people have limited skills and capacity of information processing [11, 290, 32], and that probably this ecological constraints represent the shaping mechanism of the human cognitive architecture and information processing.

Moreover social psychology has shown how to understand the social environment around us, cognition often presents simultaneously conscious and unconscious processes, depending on the amount of accessible information and the time available for their processing. An example of such processes, both conscious and automatic, is the social categorization process. In social perception there is an initial automatic (e.g. spontaneous) categorization of people we meet, followed usually by the possibility of a conscious control. For instance some experiments show how this effect is experimentally revealed as based on their ethnic group, their gender and their age [291, 292, 293, 102].

Blumer explained how people operate an interpretation of the social environment, suggesting that the human behaviour is driven by the meanings ascribed to the things, and this meanings are derived from the social interactions with others. In addiction, the meanings evolve dynamically depending on the interpretative processes. This perspective, named Symbolic Interactionism, focused on the interaction in the social environment and on the interpretation of symbols and signification to define the others actions, moving the core of social research from the group level to the individual level, but keeping the significance of the interrelation between group and individual [294, 295, 296, 297, 298].

Within this scaffold the social cognition developed several theoretical model for the knowledge representation and for the processes acting on it.
Festinger (1957) underlines how the knowledge is organized in a schematic way and how consciousness perceive this organization in the subjects. The theory is centered around the observation that human beings have a natural tendency to seek a consistency between what he does or says and what he thinks, that is between the behaviours and schemes. The gap between actions and the mental representations produces an unpleasant feeling of inner inconsistency, which is called dissonance. To reduce this phenomenon, we tend to restore the coherence between scheme and behaviour, acting on one or other, and then realigning the scheme on behaviour or, conversely, behaviour, on the scheme. When the dissonance becomes intolerable, the less resistant cognitive element is modified to switch off the source of dissonance. Therefore the cognitive dissonance theory fundamentally describes a crucial feature of the cognitive knowledge organization. Knowledge schemes are developed and reinforced through the experience until two schemes goes in conflict. In this case, cognition actively reduces this conflict by changing or deleting one scheme, and rearranging the knowledge as well. This enlightening theory has received a lot of experimental evidences, and have supported the modern schematic view of the human knowledge [299, 13].

Researches about the ways that cognition uses to summarize the maximum amount of information, with the minimal effort, or how it encodes, relates and exploits such knowledge have represented the core activity of this movement [14, 300, 301, 302].

The experimental validation of the models of human categorization and the empirical investigations of the social problem solving, has been used to discover the analogical mapping, as one of the central faculty of the human cognition. This vision of the human knowledge describes the fundamental capacity of the brain in relating and recalling accordingly two elements which have shared some features, or equivalently, frequently belonging to the same context. The concept of mental scheme was introduced to account for this cognitive faculty and was defined as cognitive procedure activated by context or by interactions which both help to recognize the "situation", and integrates the informative content of the incoming information, allowing predictions and pre attentive preparation. Mental schemes has been described as innate (e.g. reflexes actions) or learned (e.g. training) and in some context more than one scheme may be activated [101, 36, 37, 109, 110, 98, 99, 39, 53].

The fundamental concept of scheme, later evolved in that of context frame, was largely used by researchers to investigate the cognitive processing. If the concept of mental scheme fit the ecological constraints for the psychological plausibility, was within the bounded rationality framework that the cognitive processing found a valid building block, the concept of cognitive heuristic.

The cognitive heuristics were generally described as short cuts that we use to make judgments based on limited information. Social cognition discovered that, when a person should make decisions in conditions of limited information, the cognition do not search for optimal solutions but just for acceptable and optimized solutions [11]. Consequently, the heuristics started to be intended as fundamental faculty of cognition able to build effective shortcuts that reduce the time and effort required to reach a satisfying conclusion, even if not the best ever [303, 91].

The fundamental contribution of social cognition to the modern computational cognitive modelling can be summarized with the Criteria for Psychological Plausibility, evolved recently by Gigerenzer et al [44], and inspired to the Simon’s paradigm of ecological rationality (e.g. bounded rationality theory) [304, 31, 305, 12]. Starting from the assumption that evolution has shaped the mind to act effectively within the real environment, they defined five principal criteria for assessing the psychological plausibility of a computational model.
The first assumption was related to the developments gained by the connectionism and the artificial intelligence in the comprehension and theorization of the computational capacities of the mind, and has been labelled as Tractability [306, 307, 308]. This assumption postulates that a model of cognition need to be tractable in the real world in which people live, not only in the small world of an experiment with only a few cues. This eliminates NP-hard models that lead to computational explosion, and define the tractability as one condition for psychological plausibility that is easily met by simple heuristics. The second assumption that should be taken into consideration is the robustness of the cognitive answers, in fact the cognitive inferences and estimations appear to be robust (e.g. general) rather than optimal. In other words, cognition should be successful in foresight rather than in hindsight and not waste effort on computations and estimations that deteriorate performance. Moreover robustness increases with the simplicity of a model and decreases with the number of free parameters. The third assumption, known as Frugality, postulated that plausible models of cognitive processes need to specify not only how information is integrated but also when information search/elaboration is stopped. Stopping rules, in turn, motivate search rules, which can order cues such that good cues are likely to be encountered first. In an age of overwhelming information, it is clear that a crucial issue is knowing when to ignore further information, or when to forget it. The fourth assumption stated that the cognitive processes assumed by a model should be able to be executed quickly. The last assumption, or Evidence, affirms that models that satisfy previous requirements should be consistent with what we know about cognition.

Some authors have recently argued that implementing heuristics in cognitive architectures, such as ACT-R, fulfills this requirement [46]. Moreover recently the brain imaging research has shown new neurophysiological evidences supporting the models of social cognition [35].

3.3.1. Small group psychology

For several domains belonging to the social sciences the notion of group has represented one of the key concepts to understand the relationship that the individual establishes with other and with society as a whole. In the fifties, Merton (1957) provides a definition that a group is characterized mainly based on three criteria, namely as: - The group includes a number of people interacting with each other according to rules and norms; - Individuals in interaction are defined and perceived as group members; - These individuals are defined by others, whether they are or not members of the group, as belonging to the group [309].

Assuming this definition, a group is a set of individuals who are in direct and immediate relationship, who exert reciprocal actions of influence and who experience a sense of belonging that makes them feel part of the group, driven by a feeling both self-inclusion attribution and external recognition.

A group exists in the presence of factors of contiguity, similarity and interrelation between the members that compose it.

The study of group dynamics considers usually both the network structure (e.g. its social organization), and the quality of the relationship between subjects. Consequently a human group has been frequently described using both, the individual dimension, related to the individual and his needs, and variables related to the social dimension, embedded in the collective and the structural features of group life.

At the individual level the processes studied were labelled as: skills, attitudes, motivations, and personalities of individuals. This network of processes determines the social behaviour and thus indirectly the behaviour of the group.
On the other hand the group psychology discovered that if the group is considered as an entity, each person can be seen as a part of a larger system, and his behaviour related and reflecting certain features of the state of the system and of the events occurring in it [310, 311, 312]. This two dimension have been characterized by peculiar processes, computational capability and different heuristics.

The psychological field theory by Kurt Lewin has been the first framework theory to described the relationship between the two levels of analysis mentioned above. Lewin represented the group as a phenomenon in itself, and not as a sum of phenomena, in other words it started to be considered as an entity not reducible to the individual dynamics and to the characteristics of its members. The group is something more, it has its own structure, peculiar purpose and special relationship with the other groups, and what constitutes its essence is not the similarity among its members, but their interdependence.

It this way it has been defined as a dynamic totality. This means that a change of state of a part could affects the status of all the others, and the degree of interdependence goes from an indefinite to a compact unity. Based on the principle of symbolic interactionism, Lewin assumed that the behaviour of people is determined by the interaction between the individual and environment (i.e. the group).

Specifically, the behaviour has to be modelled as a function of the mutual interaction of individual characteristics with the environmental factors. In the field theory, the group is seen as a gestalt where the individuals are involved into a "force field" defined by the input of the external environment, by the interrelations with the other members of group and finally by a continuous feedback influence between individuals and environment.

Considering the group as a dynamical system involves both the concept of system as the organization of the elements that compose it, and the concept of dynamic, which characterizes the group as in constant evolution, inside a force field. The group life is described as evolving depending on a system of tensions, both positive and negative, where the behaviour of the group consists of a sequence of operations aimed at resolving such tensions, to restore a more or less stable of equilibrium. The dynamics of the group can be described as a sequence of meta-stable states, that attract the network dynamics for a certain time, and that can be lost as a consequence of the modification of the psychological field, e.g. the incoming of an external field (i.e. information) or the action of a member.

Our knowledge of the forces operating in groups derives largely from the work of Bion (1961). The experiences of Bion with groups led him to develop the hypothesis of the existence of a specific mind of the group. Bion’s theory remains a fundamental reference for researchers of group phenomena, despite its formulation is apparently very qualitative. The fundamental hypothesis of this theory states the existence of a collective mental activity that occurs when people join together in groups, an activity that often goes beyond the awareness of the members, and sometimes in conflict with their own conscious thoughts and expectations [313].

Bion also defined in a psychodynamic and psychoanalytic way that the individuals in group are subject to sudden changes of structural configurations of the entire group, postulating the existence of different phases, called basic assumptions (i.e. dependency, fight-flight, and pairing) that characterize the dynamics. In Dependency all members depend and tend to get in relation with the same individual, an individual thus represents the hub of the group network.

In fight-flight each individual is linked with every other member of the group, as so as to obtain a full connected network.

Finally, in the basic assumption of pairing the group is characterized by a configuration of the relationship network where the members are coupled or tend to form small sub-structures,
i.e. clusters, inside the group. The basic assumptions are important organizers of social relations, and provides us with a description of the phenomenology and of the dynamics that accompanies the aggregation of various individuals.

Recently some models have been developed to describe the different states and the various dynamics phases that describe the evolution of a group. These models describe the creation and the end of a small group into four different phases, providing that the group evolves from an initial unstable state, until to reaching the equilibrium or the fragmentation of the group.

Tuckman described such stages as forming, storming, norming and performing.

Groups initially concern themselves with orientation accomplished primarily through testing. Such testing serves to identify the boundaries of both interpersonal and task behaviours. Coincident with testing in the interpersonal realm is the establishment of dependency relationships with leaders, other group members, or preexisting standards. It may be said that orientation, testing and dependence constitute the group process of forming.

The second point in the sequence and it is characterized by conflict and polarization around interpersonal issues, with concomitant emotional responding in the task sphere. These behaviours serve as resistance to group influence and task requirements and may be labelled as storming.

Resistance is overcome in the third stage in which in-group feeling and cohesiveness develop, new standards evolve, and new roles are adopted. In the task realm, intimate, personal opinions are expressed. Thus, we have the stage of norming.

Finally, the group attains the fourth and final stage in which interpersonal structure becomes the tool of task activities. Roles become flexible and functional, and group energy is channelled into the task. Structural issues have been resolved, and structure can now become supportive of task performance. This stage can be labelled as performing [314, 315, 316, 317].

Nowadays is well known that the problem solving and the decision making strategies, i.e. the cognitive heuristics products, have to be intended as the result of the evolution of the human cognition within social structures as groups or cultures. Humans show the capacity of exploiting the computational potentials of the group in order to solve complex problems. Theoretical instances coming from social cognition suggest that it is not possible to understand the cognitive functioning at the individual level without considering the ecological constraints of the human groups, and the investigation on the small group dynamics is currently an active field of research.

3.4. Possible neural underpinnings

The brain regions that mediate the reasoning processes (e.g. the analogical thinking) are much less explored than those related with the perceptive and attentive network. Nevertheless, some types of analogical thinking have been recently found to activate the lateral and medial Pre Frontal Cortex (PFC) [318, 319]. Another fundamental ingredient suggest by the experimental psychology and psychophysics is the neural network that mediate predictions. Nowadays the opinion is that there are multiple sub-processes that need to be considered, such as their generation, verification and updating.

The expectations-based preparatory activation has been observed in numerous steps of the perceptive and attentive processing, but their role in the higher reasoning processes is not still clear [48, 49]. Cognitive neuroscience has widely demonstrated how anticipating a somatosensory stimulus activates the somatosensory cortex, pictures of food activate gustatory cortices, visual imagery, activates the visual cortex, and has even been shown to activate early visual cortex in a retinotopically organized way [320, 321, 322].
The associations relevant to the abstract reasoning processing seem to be represented by the medial temporal lobe (MTL) in general, and the Parahippocampal Cortex (PHC) in particular. The retrosplenial complex (RSC) in the Medial Prefrontal Cortex (MPC), which is consistently found to be recruited in associative tasks, has been suggested to represent prototypical, rather than episodic, information about associations [223]. In other words, the PHC represents stimulus-specific context and associations, which are sensitive to specific appearance (e.g. my car), whereas the RSC/MPC represents knowledge about associations related to the prototypical context (e.g. a car) [119, 50].

Recently their combined contribution has been supposed to elicits prediction-related representations in the PFC (orbitofrontal cortex - OFC, in particular), as well as in a domain-specific cortex such as the fusiform gyrus in the case of object recognition.

The neural mechanism that generates predictions is still largely unknown, but it is thought to be mediated, or at least balanced, by neural oscillations and synchrony [323], and some evidence for such a mechanism in the PFC exists [55]. However, in addition to synchrony, there are other promising proposals [56, 57] that are appealing and could benefit from further physiological and cognitive testing. Of course predictions are activated rapidly, using information that is available relatively early (i.e. lowspatial frequencies - LSF). Such LSF-based predictions can be triggered in the PFC for the purpose of object recognition while interacting with the visual occipito-temporal cortex, and for context-related predictions while interacting with MTL and MPC.

Starting from such neurophysiological data, recently some brain imaging researches have investigated the neural basis of the recognition and evaluation processes, which are the a sort of interface between the perception/encoding and the reasoning/processing of information. Some fMRI studies have tested whether the two processes, recognition and evaluation, can be separated on a neural basis [105]. The mere recognition judgments is characterized by an activation in the precuneus, which is an area that is known from independent studies to respond to recognition confidence [106].

Other experiments observed as expected in the inference task a precuneus activation, but and addition activation was also detected in the anterior fronto-median cortex (aFMC), which has been linked in earlier studies to evaluative judgments and self-referential processing. These results indicate that the neural processes elicited by the two tasks of recognition and evaluation are not identical, as an automatic interpretation of the use of the heuristic would imply, but suggest a separate evaluation process that determines whether to select the recognition heuristic for a given task.

The aFMC activation could represent the neural basis of this evaluation of ecological rationality. The neural evidence furthermore suggests that the recognition heuristic may be relied upon by default, as opposed to being just one of many strategies. The default can be overthrown by information indicating that it is not ecologically rational to apply the heuristic in a particular task because recognition is not predictive of the criterion. The default interpretation is also supported by behavioural data.

Moreover response time data suggest that recognition judgments are made before other knowledge can be recalled [107, 105]. Consistent with this hypothesis, these authors show that response times were considerably faster when participants inferences accorded with the recognition heuristic than when they did not. Similarly, participants inferences accorded with the recognition heuristic more often when they were put under time pressure. These findings are consistent with the recognition memory literature, indicating that a sense of recognition (often called familiarity) arrives in consciousness earlier than recollection [108].
Among the others a fundamental impulse toward the unification of the cognitive theories with the neurophysiological models has been given by the Cognitive Neuropsychology, which is a discipline aiming to the understanding and modelling of cognitive function in its relationship with the neural substrate that supports it. Cognitive neuropsychology is clearly inspired by an information processing metaphor of the mind, but it is also deeply based in empirical research with brain damaged patients [324]. The golden standard of cognitive neuropsychological methods is double dissociation, that is, documenting that two patients, A and B, performs at two different cognitive tasks $T_1$ and $T_2$ so that A is impaired in task 1 but not in task 2, and patient B is impaired in task 2 but not in task 1; if such a double dissociation can be documented one can infer that the two tasks are sustained by independent cognitive functions and that the neural substrate of these functions is non overlapping [325, 324]. Since a series of seminal works were published in the 90ies [326, 327, 328, 329] computational models have been produced that are able to show double dissociation in response to selective lesioning or to specific architectural constraint, and simulation as been accepted as a common tool for research aiming to explore structure to function relationship. This position is actually sustained by a large proportion of the cognitive neuropsychology community, and ground many recent works indicates the relevance of the investigations of the human inferences based on computational models in cognitive neuropsychology [330, 331, 332].

3.5. Module II: the state of the art

The first steps of the cognitive information analysis (e.g. perception and attentive related encoding of sensory input) are nowadays effectively modelled from computational cognitive neuroscience; however it is not true for the higher cognitive activity, frequently indicated as reasoning, problem solving or decision making processes.

Almost all aspects of cognition, from perception to problem solving, involve transforming given information into a new and more useful form, but cognition and memory involve more than encoding and retrieving facts, they also infer cue values and even update missing cue values [273].

The difficulty of getting insightful neurophysiological evidences of such processes, exploring the brain activity, is no longer related with the efficiency (i.e. spatial and temporal) of brain imaging techniques, but it seems mainly related with the peculiar organization of neural circuits and with their tendencies to operate contemporary (e.g. parallel computation) by positive and negative complex feedbacks.

The increase of complexity could be explained adopting again the connectionist/gestaltic dichotomy of associative-analogical processes. From a cognitive point of view the perceptive recognition process require a simple linking to knowledge structures (e.g. memory or mental state) in order to interpret the input: at the contrary in the analogical processing inputs are linked to knowledge both for the sake of interpretation and for projecting/extracting attributes and generating predictions/expectancies. Moreover analogical activations interact with the associative activated map (i.e. the perceptive representation/abstraction of the environment) through attentive structures. In other words analogies generate associative-based predictions by which they actively search and select the relevant information.

The concept of analogical mapping is fundamental in the contemporary modelling of cognition, and it has been used (sometimes implicitly) in most prominent models of reasoning. Analogical activations ranged to inferring what physical input has caused a certain percept Friston2005,French2002 to important top-down predictions regarding the identity of the input [47, 66]. The analogical mapping have shown to be an active process that can be based on
similarity on various levels, including perceptual similarity (e.g. in shape or smell), abstract conceptual dimensions, goals [75], perception and memory [215] and stereotypic judgments and prejudice [103].

In addiction, while our existing memories are used to derive analogies and activate predictions, they are constantly being updated. The analogical process assess the interpretation of our environment, and enforces activated representations, accumulating them into a complex set of associative and analogical maps.

The explicit role of memory structures in problem solving, decision making and inferential reasoning has received a lot of attention from the cognitive sciences [267, 224, 95, 333, 334, 335, 336, 46, 80], and the inference processing from memory has been distinguished from inference from external given information just in terms of extension of the cortical representation of the information [86, 87, 88, 89, 90]. Reasoning processes are characterized by a sophisticated representation of the knowledge which is analogically organized and that can be projected/abstracted in order to reduce its dimensionality, becoming computationally tractable.

A lot of experiments suggest that also at this level of inspection the cognition appears as characterized by structures that cluster together related information. As well as in perceptive laws of the gestalt and in the connectionist paradigm, objects that tend to appear together are linked on some level of abstraction, and the level of abstraction determines properties that are considered as inherent and typical.

Such structure implies an unified and global representation of knowledge as a complex network of associated attributes, which enable co-activations that both prime/drive the subsequent perception (i.e information encoding), and are used to make available predictions of what to expect in the immediate future/environment.

Moreover the tractability of a cognitive problem is an important condition for the psychological plausibility and usually the problem of finding the optimal attributes order rapidly turns out to be NP-hard also for very small knowledge matrices [337]. In addiction recent experiments have confirmed that people wrong in task of attributes relevance ordering, designing robust analogical based models and not as a result of a random process.

This cognitive limitation is nowadays put into a different functional perspective, accounting for instance how people make more accurate inferences when they ignore the dependencies between information, i.e. less can be more [338, 339, 340].

The unification of constraints, that are discovered by the social cognition (e.g. psychological plausibility) for the cognitive heuristics modelling, and principles of cognitive functioning, postulated by cognitive neuroscience, have produced in the last three decades some interesting framework to the modelling of cognitive heuristics. Moreover this experimental programs have isolated and described a multitude of cognitive heuristics algorithm, some of which reveal fundamental computational attributes of cognition.

3.5.1. Recent cognitive frameworks

The modern generation of cognitive models is referred as probabilistic mental models or model of probabilistic reasoning, and are opposed to the classical and linear cognitive models, known as mental logic and mental models [341, 342, 74, 343, 344].

The new generation of cognitive models is characterized by the introduction of non-linear and structural behaviours, inspired by the ecological rationality paradigm, in order to match cognition’s performances with less searching, less knowledge, and less computational might [267].
The cognitive framework proposed in recent years could describe ways of modelling inferences from memory respecting natural environment constraints: in this context good algorithms carried out inductive inferences that are classifiable depending on their frequency of occurrence within appropriate reference classes [80, 176, 79]. Consequently the challenge was to discover computational description for the simple, plausible psychological mechanisms of inference, that a mind can actually carry out under limited time and knowledge and that could have possibly arisen through evolution.

Almost all proposed frameworks could be assimilated to one of the two most general and cited frameworks, the Support Theory and the Adaptive Toolbox. The main difference among them is related with the architecture of the framework and deals with a different definition of knowledge scheme and cognitive heuristic. For the support theory a cognitive heuristic is just the result of the learning on the knowledge scheme, while the adaptive toolbox it has composed by the cognitive operations required to accomplished a task.

Despite this theoretical mismatching insights coming from both approaches, appear nowadays as easily integrable into a common framework, because their substantial different level of abstraction.

The Support Theory

The Support Theory underlines the role of subjective evaluations of degrees of belief (e.g. conscious and unconscious) on the decision making processes and the human reasoning. This theory was originally developed by Amos Tversky and colleagues to explain some of the more prominent regularities revealed in their studies [92, 93, 91, 345].

The Support Theory is grounded on an empirical base of results, which show for instance how different descriptions of the same event often produce different subjective probability estimates. This well known phenomena is explained in terms of subjective evaluations of supporting evidence. Accordingly it assumes that events are evaluated in terms of subjective evidence invoked by their descriptions, and that the observed numerical probability judgments are the result of the combining of such evaluations of support in a manner that is consistent with a particular equation.

One of the most prominent prediction of the support theory based models is the dramatical increment of subjective probability estimation of an event when it is divided into mutually disjoint sub-events and the subjective probabilities of the sub-events are added together [94, 346].

The theoretical frame of support theory consists of accounting for observed deviations of the probability estimates from what would be expected from a normative model based on a certain experience based scheme (e.g. B-scheme), and it is assumed that participants make their judgments based on certain processes (i.e. cognitive heuristics) and that appropriate variations of descriptions of the same event can manipulate such processes employed by participants.

Basic units in support theory are descriptions of events, and the first process of cognitive information analysis, described as judgmental heuristics, is the cognitive mechanism which evaluates descriptions of events through the concept the “Support function”. The support function is supposed to be able to establish the goodness/probability of a certain knowledge scheme, by means of the exploitation of a frequency based representation of the past experiences.

Cognitive representations on which the support function operates are defined by the support theory, as logical structures, and they are considered as naturally arising out of the judgmental heuristics: then different kinds of heuristics give rise to different kinds of logical structures.
Different heuristics or even different kinds of uses of the same heuristic may require topologies with properties that are peculiar to them. An important modelling scheme, used in some articles, implies that different roles can be given by elements of a mental scheme and elements of its boundary. The mental scheme is considered as an open set of attributes, e.g. which can be enlarged and filled up with new information, and it is interpreted as the set of recalled clear instances of the given description. Conversely its boundary is interpreted as either unrealized clear instances or various kinds of poor, vague, or ambiguous instances which are poorly connected with the scheme.

Among most important insights gained from the application of the support theory there are concepts of additivity, super-sub-additivity and non additivity. [72, 347]. Within this framework these phenomena have been observed as a different numerical value estimation for a disjunction of mutually exclusive events with respect to the sum of the values estimated separately.

Tversky and his collaborators have explained such sub-additivity showing, in particular that it should arise directly because the description of a disjunction of two propositions A and B; it usually brings to mind less evidence than the total evidence obtained when A and B are considered separately [92, 93, 348]. A recent extension of the support theory incorporates the previous asymmetry, explaining both sub and super-additivity [72].

The analogical mapping of a certain stimulus is accounted not only for the judgement of the probability of a certain event, but also, for instance, for the evidence against it. If we have two events A and B and we push them into the same abstracted representation (e.g. the resulting B-scheme given by some algebraic combination of the two schemes) we could obtain a double of dimensionality of the required map, when the events are totally independent, or smaller dimension if they are partially overlapped.

Since in this framework the probability estimation of a certain event has been computationally linked with the strength of a certain representation in memory, the linear combination of two different representations can elicit the sub-additivity both when there are substantial evidence (e.g information matching) in favour of both members A and B and members are independent, and when events are strongly related. Conversely the super additivity will tend to occur when the little evidence is perceived and consequently the linear combination of the two events corresponds to a less ambiguous knowledge scheme. Finally the non additivity describes the simple example of two perfectly unrelated and sub-sampled events/schemes [349, 350, 72, 347, 91].

The importance of the support theory has been fundamental to isolate and describe many cognitive features of the human reasoning and of its development. Its application to the cognitive problem solving has explained either how attributes of a certain event could be statistically encoded through the experience, and how particular projections (e.g within the support theory vocabulary the heuristics) of activated representations are used to estimate the probability of an event (e.g. availability, anchoring, representativeness heuristics).

Heuristics described in this framework represent an useful set of tools for the modelling of cognitive inferences, nevertheless it is characterized by a lack of description of mechanisms by which different heuristics were selected or possibly "evolved".

The Adaptive Toolbox

The most recent and original approach for the study of cognitive heuristics is directly connected to the problem of the heuristics selection. First of all they enlarge the concept of heuristics to indicate those processes which choose the appropriate projection of a certain set of activated representations and no longer to the projection itself. Anyway they maintain the idea of cognitive
heuristics as cognitive processes that dramatically simplify processing while maintaining a high level of accuracy [77, 81, 82].

They theorize that decision making processing results from the application of one or more simple heuristics, which mainly save the organism to make an exhaustive use of all available information. Such heuristics are thought to be adaptations to natural information environments, and are shaped by the ecological boundaries of the human cognition (e.g. bounded rationality) [267, 81, 351, 11].

As well as the support theory, the cognitive framework has been developed by model inferences from memory through a probabilistic approach; nevertheless it delineates and incorporates two principal phases composing their cognitive heuristic process. The first face with the extraction from memory of most adapted mental representations (e.g. B-schemes) for the incoming input, and the subsequent probabilistic estimation; the second step is represented by another mechanism which interrupt this incremental process whenever both the goal has been reached or if the cognitive and physical cost for the problem resolution increases without increasing the probability of success.

The previous enlightening vision has been consequently merged to the support theory (ST) approach into a wider perspective where; in ST inductive inferences are based on frequencies of events in a reference class, but cognitive algorithms are designed to be sufficient and not the optimal (e.g. general and not specific) way to cope with the problem as fast as possible [79, 80, 176].

Models proposed within the Tool Box framework can be classified in two main categories depending on their memory representation. The first and most simple model proposed is known as Perfect Memory Model, and despite it is well known that recognition memory is not perfect [73, 352, 95], its five assumptions clarify the algorithmic architecture of this approach [351].

The first assumption represents the brutal but useful simplification imposed to memory structures, and it is that a person recognizes all objects she has experienced while does not recognize any object she has not experienced.

The three subsequent assumptions specify inference rules and incorporate the fundamental capacity introduced by this framework, that is, the capacity of calibrate the computational/cognitive effort to different amounts of recognition information that may be available.

The second assumption states that if the subject does not recognize any object/content in the information, she considers which object has the higher criterion value. The third assumption states that the recognition of an object can be used as a decisional criterion, for instance when compared with an unknown and consequently not recognized opponent. The fourth assumption considers the case when a person recognizes both objects, and states that some inferential rules other than guessing or the recognition principle are used. This latter family of rules is labelled as knowledge. Consequently based on these assumptions if the person recognizes n of the N objects, she uses guessing, recognition principle, and knowledge with a certain probability.

Finally the last assumption simplify the model just stating that the accuracy of the recognition heuristic, and the accuracy of knowledge, are constant across N [353].

Moreover authors have shown that a more general class of imperfect memory models can be defined adding one more assumption to the previous five. If we label an experienced object that is recognized as a hit, an experienced object that is not recognized as a miss, a non-experienced object that is recognized as a false alarm, and, a non-experienced object that is not recognized as a correct rejection. The sixth assumption is that each experienced object has certain probability of being a hit, and each non-experienced object has a probability of being a false alarm.

In general this framework calibrates the processing used for different amounts of experience
information, explaining the accuracy of the inference as depending not only on which of guess-
ing, experience heuristic (e.g. recognition principle), or experience-based knowledge is used, but
also on if each object in the pair is a hit, miss, false alarm, or correct rejection [95, 353].

Moreover it seems to explain at least three essential experimental evidences of reasoning and
problem solving processes:

1. no heuristic is applied indiscriminately to all situations [85] but an explicit process of
   evaluation is required in order to choose the right projection/transformation;
2. less information, time, and computation can improve cognitive and motor performance in
   a number of situations [45], as demonstrated by the take the the best algorithm;
3. “oblito” enables the recognition heuristic to make better inferences [46].

Finally this approach has inspired an ACT-R model where the memory can constrain the set
of applicable heuristics[43], deciding which heuristic to use for a given task. The content of
individual memory determines whether an individual can apply the heuristic, and an evaluation
process (localized in the pre-frontal cortex) determines whether it should be applied. Recently
the Strategy Selection Learning theory (SSL theory) has been applied to provide a quantitative
model of heuristic selection [42], making accurate predictions about the probability that a person
selects one heuristic within a defined set; it shows that learning by feedback could lead to adap-
tive strategy selection.

3.5.2. The cognitive heuristics zoology

The support theory heuristics

The cognitive heuristics defined within the support theory framework can be represented all
as particular projections of an analogical representation of the information. Such projections have
been experimentally observed and described, and appear to be a peculiar faculty of the human
cognition. The dimensionality reduction operated by the projection processes on the problem,
make it resolvable by cognition tools.

The Availability Heuristic operates essentially on the follow notion: “if you can think of
it, it must be important.” This heuristic has been introduced in 1974 by Kahneman and Tversky;
said that there are situations in which people assess the frequency of a class or the probabil-
ity of an event by the ease with which instances or occurrences can be brought to mind. Support
Theory has produced in the years a solid base of empirical results, showing that different de-
scriptions of the same event often produce different subjective probability. It assumes that events
are evaluated in terms of subjective evidence invoked by their descriptions; moreover observed
numerical probability judgments are the result of the combining of such evaluations of support
in a manner that is consistent with a particular situation. Consequently the availability indicates
that an example can be easily brought to mind (e.g. its accessibility) and it has been related to the
frequency of occurrence of such example. Finally the available (e.g. frequently observed) model
of reality has been adopted when a lack of knowledge make the decision uncertain [91, 303, 354].

The Anchoring Heuristic describes the common human tendency to rely too heavily, or to anchor,
on one trait or piece of information when people make decisions. Sometimes subjects
overestimate a specific piece of information to get a decision, especially in the presence of un-
certainty. Once the anchor is set, it exercises a tendency toward the adjustment or interpretation
of other information to reflect the anchored information. This heuristic accounts also for the first
sight effect because the bias produced by the first information learned about a subject (or, more generally, information learned at an early age), explaining that they can affect future decision-making and information analysis. A more general formulation of this heuristic has been labelled as **Anchoring and adjustment heuristic**; according to this heuristic people start with an implicitly suggested reference point and make adjustments to it to reach their estimate. A person begins with a first approximation and then makes incremental adjustments based on additional information. From another point of view the anchoring heuristic is very important because it suggests that singular features belonging to a knowledge scheme can be accessed dynamically from cognitive processes and can be used to change the abstract representation of the problem [91, 355].

**The Representativeness Heuristic** can be described in some sense as the opposite of the anchoring heuristic. While the anchoring one exploits some partial features of the information in order to get a decision, the representativeness chose the prototype most similar to the information pattern taken as a whole. In other words it is a cognitive shortcut made when individuals assess the frequency of a particular event based solely on the generalization of a previous similar event. Furthermore it has been implemented as an assessment of the degree of the correspondence between a sample and a population or between an outcome and a model. In general, common instances are more representative than infrequent events. The representativeness heuristic mimics the tendency of people to judge the probability or frequency of a hypothesis by considering how much the hypothesis resembles/mimic available data. Researchers have observed that the representativeness heuristic is a smart way to solve problems in the presence of a lack of information. If from one side it could neglect the relevance of some singular features, most frequently it will infer some not evident relevant features by mean of the activation of an appropriate prototype, so filling the informational gap [356, 345, 91, 357].

**The Diversification Heuristic** has been described for the first time by Itamar Simonson: he was studying marketing and he formulated his theory in the context of consumption decisions by individuals and later revealed in the context of economic and financial decisions. This heuristic is based on the evidence that people making simultaneous choice people tend to diversify more than when making the same type of decision sequentially. It seems related with the ecological constraints of the environment, suggesting that when the cognition have no time to decide it reduced actively the risk by means of diversification. Alternatively when decisions appear as less relevant and dangerous the subject strategy became more error prone and orthodox [358, 359, 360].

**The Escalation Heuristic** is actually known as **Escalation of Commitment** and it is firstly described by Barry M. Staw in 1976. This heuristic is inspired by the so called **irrational escalation phenomenon** (sometimes referred to as commitment bias). This subject is frequently used in psychology, philosophy, economics, and game theory to refer to a situation in which people can make irrational decisions based upon rational decisions in the past or to justify actions already taken. It is evident, for instance, when parties engage in a bidding war; bidders can end up paying much more than the object is worth to justify the initial expenses associated with bidding (such as research), as well as part of a competitive instinct. This interesting heuristic has a double relevance: from one side it defines an implementation of the social cognition theory of the **Cognitive Dissonance**, and to the other it suggests the role of plans, strategies, beliefs and goals on the heuristic processes. In other words if the problem is more complex and articulated more time is required to taken into account subjective representations of the problem in order to predict its decision or probability assessment processing [361, 362].
The Affect Heuristic introduces a big domain of cognitive sciences: the relation among emotions and decisional processes. In this field a lot of neurophysiological and experimental evidences are nowadays observing in addition to models and theoretical descriptions. Within this heuristic affect indicates simply an emotive reaction as fear, pleasure, surprise, shorter in duration than a mood, and it is able to affect a strategy occurring rapidly and involuntarily in response to a stimulus. As psychological heuristic, it just introduces some more cues worth of attention by decision processing Melissa Finucane and others have described how a good feeling towards a situation (i.e., positive affect) would lead to a lower risk perception and a higher benefit perception, even when this is logically not warranted for that situation. It implies that a strong emotional response to a stimulus might alter a person’s judgment. Another common situation involving affective heuristic is where a strong, emotional first impression can form a decision, even if subsequent facts weigh cognitively against the decisions. In general the affect heuristic indicates that the assessment of a certain information pattern is intrinsically parallel in the brain, and that different kind of information can be integrated to reduce the uncertainty of a given decision. Finally this heuristic could account also for the effects of emotional priming and recency described in social psychology [363, 364, 365, 366].

The Effort Heuristic A particular declination of the anchoring heuristic has been introduced by Kruger and Wirtz in the 2004 indicated as the Effort heuristic. In this context a value of an object is assigned based on the amount of perceived/inferred effort that went into producing the object. The classical example is the comparison of earned and found money. While the second can be “wasted” easily the first has usually better managed. Another way that effort heuristic can be considered is the amount of effort a person will put into an action depending on the goal. If the goal is of little importance, the amount of effort a person is willing to put into it is going to be lower. The effort heuristic has appeared to affect the perceived quality rating and financial value of objects. The manipulation of appropriate experimental procedures have suggested that people are prone to rely on perceived effort to value objects when other criteria is not readily available. It indicates that one particular feature could be extracted by the scheme and used to generalize a prototype to infer the missing properties [367].

The Familiarity Heuristic The familiarity heuristic has been developed starting from the concept the availability heuristic: it is applied when there is a situation that appears similar to previous situations, especially if individuals are experiencing a high cognitive load. The availability heuristic suggests that the likelihood of events is estimated based counting various examples of such events come to mind. Thus the familiarity heuristic is defined as judging events as more frequent or important because they are more familiar in memory. The familiarity heuristic is based on using schemas or past actions as a scaffold for behaviour in a new (yet familiar) situation. Recent studies have used functional magnetic resonance imaging (fMRI) to demonstrate that people use different areas of the brain when reasoning about familiar and unfamiliar situations. Familiar situations are processed in a system that involves frontal and temporal lobes whereas unfamiliar situations are processed in frontal and parietal lobes. These two similar but dissociated processes provide a biological explanation for differences between heuristic reasoning and formal logic [368, 369, 370, 371].

The Peak-end rule Heuristic This heuristic has been suggested by Daniel Kahneman and others: it explains why people seem to perceive not the sum of an experience but its average.
In this context it could be an instance of the representativeness heuristic. Accordingly with this heuristic we judge our past experiences mainly on their peak (pleasant or unpleasant moments) taking into account especially the end of these moments. Other information are less used and generally less affecting the decision. These evidences suggest that emotional activations can be a strengthening factor for the scheme encoding. In one experiment, one group of people were subjected to loud, painful noises. In a second group, subjects were exposed to the same loud, painful noises as the first group, after which were appended somewhat less painful noises. This second group rated the experience of listening to the noises as much less unpleasant than the first group, despite having been subjected to more discomfort than the first group, as they experienced the same initial duration, and then an extended duration of reduced unpleasantness [372].

The Simulation Heuristic is a simplified mental activity; it was first theorized by Daniel Kahneman and Amos Tversky and it has been intended as a specialized adaptation of the availability heuristic to explain counterfactual thinking and regret. Specifically in the simulation heuristic people tend to substitute ‘normal’ antecedent events for exceptional ones. The theory states that people adopt this strategy to understand and predict others behaviours, and to answer questions involving counterfactual propositions. Substantially people mentally undo events that have occurred and then run mental simulations of events with the corresponding input values of the altered model. For example, in an experiment showed to a group of participant a situation describing two men who were delayed by half an hour in a traffic jam on the way to the airport. Both men were delayed enough that they both missed their flights; one of them by half an hour and the second by only five minutes (because his flight had been delayed for 25 minutes). Results showed that a greater number of participants thought that the second man would be more upset then the first man. Kahneman and Tversky believed that the explanation was that students used the simulation heuristic and so it was easier for them to imagine minor alterations that would have enabled the second man to arrive in time for his flight then it was for them to devise the same alterations for the first man. The subjective probability judgments of an event, used in the simulation heuristic do not follow the availability heuristic, in that these judgments are not the cause of relevant examples in memory but are instead based on the ease with which self generated fictitious examples can be mentally simulated or imagined. Moreover this heuristic has shown to be a salient feature of clinical anxiety and its disorders, which are marked by elevated subjective probability judgments that future negative events will happen to the individual [373, 374, 375, 376, 377].

The Social Proof Heuristic The social proof heuristic is also known as informational social influence, and is referred to a wide psychological phenomenon where people assume the actions of others reflect the correct behaviour or inference. This effect dominates the ambiguous social situations where people are unable to determine the appropriate interpretative model, and is driven by the assumption that surrounding people has more knowledge about the situation. The social influence is well described in a lot of cognitive and social psychological theories, and can be seen as the tendency of large groups to conform to choices which may be either correct or mistaken (e.g. social impact). Specifically we conform because we believe that other’s interpretation of an ambiguous situation is more accurate than ours and will help us choose an appropriate course of action, and we do not when we are confident within the situation. Social proof is more powerful when being accurate is more important and when others are perceived as especially knowledgeable [378, 379, 380, 381, 382].
The Adaptive Toolbox heuristics

Cognitive heuristics are defined by this experimental framework can be considered as an heterogeneous description of heuristics and meta-heuristics. The former, as the fluency heuristic or the experience heuristic, can be assimilated to those described by the support theory, as simple projections (e.g. scheme of knowledge) of the problem. Conversely the latter bring a most intimate representation of general features of cognitive processing. Heuristics as Recognition, Take the Best and Evaluation could be defined as meta-heuristic because their apparent role of drivers of the process of strategy selection.

The Experience Heuristic or the Recognition Principle has to be nowadays distinguished by the modern meaning of Recognition Heuristic. Nevertheless the two concepts are largely related and the second can be considered as a generalization of the first one. The recognition principle is invoked when the mere recognition of an object is a predictor of the target decision and states the follow statement: if only one of the two objects is recognized, then choose the recognized object; if neither of the two objects is recognized, then choose randomly between them; finally if both of the objects are recognized, then proceed to another projections (ndr). In other words: the recognition principle states that the number of the recognized features/components of an object affects the decision making processes and it is also known as one of the rules that guide food preferences in animals. For instance, rats choose the food that they recognize having eaten before (or having smelled on the breath of fellow rats) and avoid novel foods. The recognition principle has been recently disambiguated from the recognition heuristic assuming the new label of Experience Heuristics and a lighter formulation: if one object is experienced and the other object is not, the experienced object is inferred to have the higher criterion value [79].

The Recognition Heuristic The kernel of the first Adaptive Toolbox architecture was constituted by the Recognition heuristic. Authors indicated that the basic psychological capacity for getting a decision or making a choice in situation, with biased or absent information, can be related with their tendencies of consider not only the content of a recalled memory but also its existence or its latency (e.g. primacy) as criteria for the inferential processing. Recognition heuristic predicts inferences of a substantial proportion of individuals consistently, even in the presence of one or more contradicting cues [107]. People show to be adaptive decision makers when the validity is low or wholly indeterminable, and in the presence of contradicting cues, some individuals appear to select different strategies [83]. The classical definition of the recognition heuristic assumes inferences about criteria that are not directly accessible to the decision maker; furthermore it postulates that when the criterion is known or can be logically deduced, inferential heuristics like the recognition heuristic do not apply. Recently some evidences suggest that the recognition process may be tuned by a binary or threshold-like mechanism dependent on the evaluation of the reliability of the solution. Then the recognition heuristic could be designed as that cognitive general process which detect relevant features of the incoming information and interact with the attribute projections of the problem. Note that a model that assumes binary recognition judgments does not imply that organisms are unable to assess the degree to which something is familiar or frequent in the environment, as it is shown by models such as the fluency heuristic [46].

Moreover recognition judgments and the recognition heuristic performance depend on the size of the reference class, the frequency with which the recognition heuristic could be used affected the subject performance. If the recognition heuristic is used a lot of time then the subject’s
performance is better [383].

Among the others the Less Is More effect have attracted the interest of a lot of researchers from several scientific domains. Actually this effect is just a first consequence of the first recognition assumption. If a certain feature of an object is recognized it will be probably considered by the analogical knowledge based on inferential processes, e.g. the new representation of the problem will include that feature changing its general formulation/shape and possibly making the solution hardest [353]. So in general different amounts of information may lead to different processing [351].

Some authors have first deduced it analytically and then shown how the less-is-more effects are stronger in group dynamics than in individual decisions, extending the role of name recognition from individual to collective decision making.

In an experiment authors have reported a new fascinating phenomenon of the less-is-more-effects in group decision making. In a group of three in which one member recognized only the object A, while the other two members recognized both objects A and B, and individually chose A as the larger one, in most cases, the final group decision was A. This result suggests that a lack of recognition has a special status not only in individual decisions, as originally proposed, but in group decisions as well [384, 385].

A theoretical integration has combined a signal detection model of recognition memory with the recognition heuristic [95]. When recognizing an object, people can go wrong by erroneously recognizing something that they have never encountered before and by failing to recognize something that they have previously encountered. Some authors showed that, as the error rate of recognition increases, the accuracy of the recognition heuristic declines, and that the less-is-more effect is more likely when participants sensitivity is high, whereas low sensitivities lead to more-is-more.

Finally the recognition heuristic can be considered nowadays as the most general and consolidate attribute of the cognitive information processing, and its definition can be generalized as a recursive cognitive process of analogical based features selection.

The Take the Best heuristic The take the best heuristic has produced the famous Take The Best algorithm (TTB) whose rationale was expressed as "take the best, ignore the rest". This general heuristic is the second fundamental heuristic of the adaptive toolbox framework and it is crucial to introduce ecological constraints of the environment and cognition.

Substantially the TTB algorithm assumes the knowledge structure as representing problem as a subjective rank order of cues according to their validities (e.g. projections). This algorithm mimics effectively some evident features of cognition such as do not use all available information, to be non-compensatory and non-linear, and able to explain the violations of transitivity. The TTB implements the capacity of stopping the recognition activity, considering progressively the features of the alternatives in order to make a decision according with the first feature found that clearly distinguishes among the alternatives. Researchers have shown that in numerous natural-world environments, TTB strikes an adaptive balance between the quality of an agents final decision and the efficiency with which that decision is made Gigerenzer1999,Simon1956,Simon1976. Moreover TTB maximizes speed by making its decision on the basis of a single discriminating cue, but, the order of consideration of cues is crucial. TTB would make fast decisions if uninformative cues were examined first, but those decisions would be of poor quality. Therefore, to strike a balance between speed and decision quality, TTB is assumed to be able to inspect cues from the best predictor of the variable of interest to the worst [77]. As a consequence the capacity of making appropriate projection of the knowledge contents continue
to be a fundamental requirement. The predictor value of a feature for a certain variable, (its cue validity), is defined as the proportion of correct distinctions a feature has made in the past [96].

The TTB heuristic has been generalized by some authors towards a unification of the approaches to the decision making processes. The strong assumptions made by the classical TTB has been relaxed while preserving important component themes of the original models [77, 96].

The first implausible assumption is that all subjects learn and use the optimal feature weights, without occasionally make mistakes in their assignment of weights to cues [386]. In some models, the feature weights are simply free parameters; for each subject, the weights that yield the best fit to the subjects data are found, and the models predictions depend on these weights.

The second implausible assumption is that subjects respond deterministically. The original TTB model makes a deterministic decision in favor of the alternative with more evidence. Moreover the cues are always inspected in a deterministic, fixed order, and once a discriminating cue is found, the alternative with the correct discriminating cue value is chosen.

The generalized TTB model introduce mainly an error theory in the framework introducing for instance a guessing parameter to all models under consideration, such that a subject is assumed to guess with a certain probability on any trial and to use the model of interest otherwise. The guessing mechanism provided just a rudimentary form of error theory, so also the probability of inspecting a feature was modelled as proportional to its relative weight [77].

Among the extension of the TTB model one of the most used is the PHM or Probability Heuristic Model. PHM suggests that syllogistic reasoning performance may be determined by simple but rational informational strategies justified by probability theory as in the TTB model [273]. The algorithmic level analysis consists of a set of fast and frugal heuristics which generate likely syllogistic conclusions. All these heuristics rely on an ordering in the informativeness of quantified statements that serve as premises of syllogistic arguments. Finally the accuracy of frequency judgments depends on the reference class activated [80] and on the size of the reference class [387].

The Fluency Heuristic generalizes and extend the availability heuristic of support theory, suggesting a way by which the cognition can elude expensive search by exploiting information that automatically arrives on the mental stage, such as latency of the answer or number of analogical associated activations.

The fluency heuristic is a prime example of a heuristic that makes the most of an automatic by-product of the retrieval from memory (e.g. retrieval fluency). Retrieval fluency can be a proxy for real-world quantities, that people can discriminate between two objects retrieval fluencies, and that peoples inferences are in line with the fluency heuristic (in particular fast inferences). The fluency heuristic has been proposed as a tool of cognitive strategies that artfully probes memory for encapsulated frequency information that can reflect statistical regularities in the world [16].

Like the recognition heuristic, the fluency heuristic is useful whenever there is a substantial correlation, in either direction, between a criterion and recognition and/or retrieval fluency. The fluency heuristic relies on one inexpensive piece of mnemonic information to make an inference, namely, the fluency with which memory records are retrieved from long-term memory. That is, even if two objects are recognized, the fluency with which the names are retrieved may be different. Such differences can be exploited to make inferences about other properties of the objects.

While the classical vision of the fluency heuristic bases its inferences simply on the speed with which the event category itself is recognized [46], it can be generalized to the support
theory’s heuristic named *Availability Heuristic*.

In one version, the availability heuristic rests on the actual frequencies of instances or occurrences retrieved, while the retrieval fluency rests on the ease with which the operation of retrieval of these instances and occurrences can be performed. This two interpretations have been merged indicating the retrieval fluency as a function of the known relevant features or of their weights [16].

**The Evaluation Heuristic** Recently a new candidate to became the last fundamental heuristic for the cognitive modelling of reasoning has been described as the evaluation process. If the recognition heuristic satisfies the individual memory constraint (to recognize one of two objects), then an evaluation process is needed to determine whether relying on the recognition heuristic is ecologically rational for the particular inference being made. In other words a particular heuristic is invoked both to stop the recognition heuristic and to assess the goodness of the answer. Evaluating the recognition validity requires the existence of a reference class $R$ of objects: as so as the more uncertain one is about the identity of the reference class, the less one can know about whether relying on the recognition heuristic is ecologically rational. And assuming a substantial recognition validity, the successful use of the recognition heuristic presupposes that it has been representatively sampled from $R$, rather than selectively sampled in a biased way. Moreover strength of recognition validity has been experimentally related to the predictive accuracy of the decision making processes [83].
Module III

4. Learning

4.1. Introduction

The third module embraces the most general and fundamental features of human cognition: the capacity to evolve and learn in order to get adapted to the environment. Where for the perceptive and the attentive substrutures and processes is possible to draw insightful links with the neural underpinnings, the variety of cognitive processes labelled as reasoning and learning prevent from the possibility of doing the same. Moreover, while it is possible to describe functionally the reasoning cognitive processes as a black box of processes, which use the encoded information in order to abstract the situation (i.e. the information) into a knowledge based analogical map, it is not possible for the learning processes to do so.

The big ocean of developmental and learning psychological theories and framework can be divided in three big domains, the pre and postnatal neurophysiology of the human development, the psychological development of the higher cognitive structures before their maturation, and the psychological and cognitive modeling of the knowledge updating, i.e. learning [388, 28, 135, 29].

For the scope of this survey we will consider only the processes which, acting on an adapted cognitive system (i.e. the final product of the cognitive maturation), manage and update the associative and analogical maps (i.e. mental schemes) which represent the subjective knowledge.

Also restring the definition of learning within the previous boundaries, it remains largely the most expensive and slow cognitive process within our framework, for instance we need to sleep in order to be able to fix new memories. Moreover it acts at different levels of abstraction, affecting differently the perceptive/attentive and the reasoning processes.

4.2. The fundamental neurophysiology of learning

Despite the vast literature on the neurophysiology of learning, not many models have grounded or inspired the cognitive modeling of learning based on the Hebbian neurophysiological theory of learning.

Starting from the works of Skinner about the neurophysiology of the brain, and merging them with others approaches and frameworks to the study of the cognitive processes such as the Pavlov’s program and the gestalt program of Kohler. He argued that some fundamental features of the Organization of Behaviour [389, 390, 391] can be explained in neurological terms. He first suggested that repeated transmissions of neurological impulses between neurons lead to permanent facilitation of future impulses along the same pathway, defining assemblies of neurons which could contain up to thousands of individual cells, as reverbatory loops. Moreover he argued that thoughts could be designed as the activity of reverberating circuits of neurons, i.e. cell-assemblies. Finally the hierarchical connections among loops was used by Henn to explain the facilitative processes that ground the human learning [156, 392, 393].

Since the works of Eric Kandel, the experimental neurophysiology has provided many evidences for the involvement of Hebbian learning mechanisms at the synapses level. Many physiologically relevant synapse modification mechanisms that have been studied in vertebrate brains are well explained in terms of Hebbian processes [394, 395].

The modern Hebbian-based theories usually describe a mechanism for synaptic plasticity wherein an increase in synaptic efficacy arises from the presynaptic cell’s repeated and persistent stimulation of the postsynaptic cell. Biological and physiological experimental evidences have
supported in the last century this basilar effect. For instance: we know that when an axon of a cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A’s efficiency, as one of the cells firing B, is increased. The Hebb’s rule has been frequently summarized as Cells that fire together, wire together and represent the kernel of the so called Hebbian Learning.

The large implications of the Hebbian theory in the modern cognitive modeling of the learning processes can be understood by introducing the concept of Engrams.

Engrams are intended as neural substructures which store the memory traces as biophysical and biochemical changes in the brain in response to external stimuli. The existence of engrams is nowadays explicitly posited by some scientific theories to explain the persistence of memory and how memories are stored in the brain, but in general this concept has inspired deeply the cognitive sciences. If the existence of neurologically defined engrams is not significantly disputed, their exact mechanism and location is still a focus of persistent research [396, 397, 398].

Since the Hebbian theory concerns on how neurons might connect to become engrams, the general idea is that any two engrams or systems of engrams that are repeatedly active at the same time will tend to become ’associated’, so that activity in one facilitates activity in the other.

The enlightening definition of learning given by Gordon Allport in 1985, integrates additional ideas regarding cell assembly theory and its role in forming engrams, stating that If the inputs to a system cause the same pattern of activity to occur repeatedly, the set of active elements constituting that pattern will become increasingly strongly inter-associated. That is, each element will tend to turn on every other element and (with negative weights) to turn off the elements that do not form part of the pattern. In other words: the pattern as a whole will become ’auto-associated’. We may call a learned (auto-associated) pattern an engram [399].

Hebbian’s theory has furnished the primary basis for the now conventional representation of engrams as neuronal nets or neural networks.

From the point of view of artificial neurons and artificial neural networks, Hebb’s principle has furnished a method of determining how to alter the weights between model neurons, increasing it if the two neurons activate simultaneously, and reducing it, if they activate separately. Nodes that tend to be either both positive or both negative at the same time have strong positive weights, while those that tend to be opposite have strong negative weights [400, 401, 237].

Today, the term Hebbian learning generally refers to some form of mathematical abstraction of the original principle proposed by Hebb. In this sense, Hebbian learning involves weights between learning nodes being adjusted so that each weight better represents the relationship between the nodes. As such, many learning methods can be considered to be somewhat Hebbian in nature.

Finally, the concept of engrams and the Hebbian paradigm, can be considered nowadays as the common theoretical bases of the most important models of cognitive neuroscience.

Moreover they define a reliable framework to model the learning processes also at the abstraction level required by the cognitive heuristic models.

4.3. The state of the art: a classification of the learning processes

Learning is generally described as the faculty of acquiring new or modifying existing knowledge, behaviours, skills, values, or beliefs. It may involve synthesizing different types of information, and its progress over time clearly follow certain typical learning curves.

Although the study of how learning occurs is part of neuropsychology, educational psychology, learning theory, and pedagogy, it can be nowadays classified in three main categories with
respect to its conscious awareness. Learning may occur as a result of non-associative and associative simple learnings (i.e. without conscious awareness), seen in many animal species, or as a result of more complex conscious activities such as play, imitation, and mental simulation, seen only in intelligent animals.

The first kind of learning processes are also labelled as non-associative learning, indicating that the effect of the sensitization on the neural structures was not mediated by thoughts, emotions or any mental conscious activity. On the contrary the associative learning generally refers to the process by which an element is taught through a simple association with a separate, pre-occurring event/state, and it is also referred to as classical conditioning. Finally the third kind of learning can be seen as a complex interaction of the previous two, despite it appears as mediated by the cognitive representation of knowledge, and largely dependent by the superior cognitive processing (i.e. module II).

4.3.1. Non-associative learning

The non associative learning can be nowadays reduced as mediated by two main mechanisms, the sensitization and the habituation. Moreover these mechanisms are those which should manage the perceptive/associative schemes/patterns storing, while they constitute the building block for the associative learning [402, 395, 394].

**Sensitization**

Sensitization effect describes the progressive amplification of a response follows repeated administrations of a stimulus, and refers to the process by which a cellular receptor becomes more likely to respond to a stimulus (more efficient). Neurophysiological evidences for sensitization have been reached using an electrical or chemical stimulation of the cerebral circuits, observing the strengthening of synaptic signals, a process known as long-term potentiation (LTP). LTP of particular cerebral receptors are currently considered as a potential mechanism underlying memory and learning in the human brain. Sensitization involves changes in brain mesolimbic dopamine transmission, as well as a molecule inside mesolimbic neurons, indicating that sensitization may underlie both pathological and adaptive functions in the organism [403, 404, 405, 406]. Moreover, sensitization has also been related with psychological disorders such as post-traumatic stress disorder, panic anxiety and mood disorders [407, 408]. Finally sensitization could be considered as one of the fundamental mechanisms acting on the perceptive and attentive associative mapping. The perceptive scheme can be thought as activated by such Hebbian mechanism, and in the same way the attentive structures of cognition could focus on the relevant piece of information/perception.

**Habituation**

The other mechanism that operates as Non-associative learnings is known as Habituation, and can be described as the decrease in psychological and behavioral responses to a stimulus after repeated exposure to that stimulus over time. In other words: repeated exposure to a stimulus leads to decreased responding. The biology that underlies habituation is a basic and well described process and does not require conscious awareness to occur. Habituation process has been used among the other to explain how organisms distinguish meaningful information from irrelevant background stimuli, in this suggesting a cooperation with sensitization to manage the associative representations.
The generality of this mechanism is given by its applicability to decrease in behavior, subjective experience, and synaptic transmission. The changes in synaptic transmission that occur during habituation have been well-characterized, and it has been recorded in all animal species. Accordingly with the Hebbian paradigm predictions, two factors that influence habituation are the interstimulus interval (ISI), or the amount of time between each successive presentation of the stimulus, and the stimulus duration, or the length of time the stimulus is presented. Shorter ISIs and longer durations increase habituation, while longer ISIs and shorter durations decrease habituation [409, 410, 411].

Moreover, as Sensitization, Habituation needs not be conscious, for instance a short time after a human dresses in clothing, the stimulus clothing creates disappears from our nervous systems and we become unaware of it. In this sense, habituation is used to ignore any continual stimulus, presumably because changes in stimulus levels are usually far more important than absolute levels of stimulation. This sort of habituation can occur through neural adaptation in sensory nerves themselves and through negative feedback from the brain to peripheral sensory organs. In other words cognition could use this faculty to re-map continuously the somatosensory, visual and auditory cortical representations.

The phenomenon of habituation is frequently used to explain a wide range of psychological phenomena. Very interesting is the experimental evidence that the amount of time spent looking at a new stimulus after habituation (i.e. its perceptive/reasoning recognition) to an initial stimulus, indicates the effective similarity of the two stimuli. It is also used to discover the resolution of perceptual systems, by habituating someone to one stimulus, and then observing the smallest degree of difference that is detectable.

4.3.2. Associative Learning

The associative learning can be generally described as the process which relates two independent mental representation or behavior, when one is frequently associated (e.g. presented before) with the second.

The associative learning has been initially studied mainly applying the typical paradigm for classical conditioning, which involves repeatedly pairing an unconditioned stimulus (which unfailingly evokes a reflexive response) with another previously neutral stimulus (which does not normally evoke the response). Following conditioning, the response occurs both to the unconditioned stimulus and to the other, unrelated stimulus (now referred to as the conditioned stimulus). The response to the conditioned stimulus is termed a conditioned response. This classical phenomenon confirm that potentially different and independent engrams could be linked together by experience following the Hebb’s rules [412, 413, 414].

The other important paradigm which have investigated the associative learning is known as Operating Conditioning, and represents a psychological learning during which an individual modifies the occurrence and form of its own behaviour due to the association of the behaviour with a stimulus. The main distinction between the operating and the classical conditioning is that operating conditioning deals with the modification of ”voluntary behaviour” or operating behaviour. While the operating behaviour is defined as operating on the environment and is maintained by its consequences, classical conditioning deals with the conditioning of reflexive behaviors which are elicited by previous conditions. Behaviors conditioned via a classical conditioning procedure are not maintained by consequences [415, 416, 389].

Within the paradigm of operating conditioning several kind of learning effects acting on mental schemes and engrams have been observed and described. Such effects could be assumed as the
building blocks of the mental schemes memory management, and provide an useful taxonomy to validate computational cognitive models of associative learning.

The Avoidance Learning has been described as a type of learning in which a certain behavior results in the cessation of an aversive stimulus. In this case the learning is not induced by an experimental association but it is produced autonomously by the organism and then reinforced and coupled with the stimulus.

The Non-Contingent Reinforcement is observed when the delivery of reinforcing stimuli regardless of the organism's (aberrant) behavior. The idea is that the target behavior decreases because it is no longer necessary to receive the reinforcement. This mechanism is the basis of the modern behavioral psychoanalytic techniques known as Systematic desensitization, used to help effectively overcome phobias and other anxiety disorders [417, 418, 419, 420, 421].

The Shaping Learning is a form of operating conditioning in which the increasingly accurate approximations of a desired response are reinforced.

The differential reinforcement of successive approximations is a conditioning procedure used primarily by Skinner with pigeons and extended to dogs, dolphins, humans and other species. In shaping, the form of an existing response is gradually changed across successive trials towards a desired target behavior/scheme by rewarding exact segments of behavior. Recently some authors suggested how a particular form of self-shaping could account for the learning of complex and refined solving behaviour/scheme [422, 389].

The Chaining Learning is a procedure which involves reinforcing individual responses occurring in a sequence to form a complex behavior. Also chaining learning has been introduced by the work of Skinner, which used this techniques for training behavioral sequences (or "chains") that are beyond the current repertoire of the learner. Unlike shaping in the chaining learning the singular behaviours/schemes remain independent, and are just linked together into a certain sequence [423].

The Extinction of an association has been also detected, and it occurs when a behavior (response) that had previously been reinforced is no longer effective. The extinction mechanism has been associated with the oblivion process, nevertheless it is both an active and passive mechanism. We have an active extinction whenever a certain behavior/scheme is repeated without obtaining the expected reward, and we have a passive extinction when a not used and expensive (i.e. characterized by an high cognitive cost) behaviour/scheme is progressively weakened [424].

Classical and Operating conditioning have been clarified the fundamental features of this kind of associative learning, demonstrating how in the first case a conditioned stimulus could be represented as associated with the unconditioned stimulus within the brain, without involving conscious thought (i.e. just modifying the associative maps), while in the second it has to be represented as not associated with the simple unconditioned stimulus but properly with its mental representation (i.e. modifying also the analogical maps).

4.3.3. The "Conscious" learning

As conscious learning we indicate those cognitive conscious strategies used by humans for extracting generalizable knowledge from a few specific examples, that is to generalize from sparse data thinks like: properties of objects, causeeffect relations, social rules, and many other domains of knowledge [115].

Among the others, the most interesting perspective in the cognitive modeling of learning defines learnings as consequences of transitions between states, where the states can be considered as reasoning scheme (i.e. B-scheme) and the transitions happen as a consequence of the
combination of three factors. The first factor is usually indicated as the subject’s baseline preferences or knowledge, and can be assumed as the ensemble of its own mental schemes network (i.e., her knowledge). The second factor is represented by the so-called End-Effect, and is related with the subjective representation of the goal, i.e., with the expected consequences of a certain behavior/scheme activation. The third factor deals with the actions/thoughts of the others, and particularly with their intentions. The importance of this factor is given by its fundamental role in social learning.

This framework usually takes into account the learning agents knowledge (even if imperfect or incomplete), and each of the aforementioned sources of information (baseline preferences, end-effect, and inferred intention) is processed by the learner as a specific task [425]. From the perspective of cognitive heuristics the baseline preferences can be intended as the sum of subjective schemes, the inferred intention as the final product of an appropriate recognition heuristic and the end-effect as the result of a particular cognitive heuristic (evaluation heuristic) which compare the expected/desired incoming perceptive scheme with the obtained one, assessing the goodness of the adopted scheme.

In general, the task addressing the imperfect knowledge of the agent evaluates actions in terms of energy consumption, which it prefers to minimize, while the end-effect task computes a sort of utility function that evaluates the schemes in terms of their probability of reproducing the desired/observed result/effect. The last task is the intention replicating task and infers the others intended goals, and consequently implies the ability of inferring partially their mental representations of the information. Moreover, this capacity known in psychology as the Theory of Mind or ToM Ref Theory of mind, also allows other kind of learning, configuring them just as a cut-and-paste of certain well adapted mental representation (e.g., metaphor, synesthesia).

Within this scaffold the processes of conscious learning can be classified with respect of their architecture as, individual learning or trial-and-error learning, inductive learning and social learning.

**Trial-and-Error learning**
Learning by individual experience is a common way to manage and update knowledge structure. Nevertheless it is slow compared with inductive and social learning, and frequently it can be too dangerous or practically impossible when the events are rare or feedback absent or unreliable [426, 97, 427, 428]. The trial-and-error learning can be described as the general methods adopted by the human cognition to solve a problem, or to get additional knowledge, whenever it has not adapted mental schemes to use. The trial-and-error is not a simple associative learning, because it requires an explicit mental representation of the adopted scheme. Learning does not happen from failure itself but rather from analysing the failure, making a change, and then trying again. Consequently in this kind of learning all the modules I and II are activated (i.e., perception, attention and reasoning) but just the first two tasks are realized, modifying and repeating the scheme/behaviour selected by reasoning until it obtain the expected result. Finally the trial-and-error learning can happen occasionally as a secondary result of the subject activity [429, 430].

**Inductive learning**

The inductive learning can be assumed as the most important factor for the subjective knowledge development. It is strictly related with the inferential processes (i.e., reasoning processes) and allows humans to make powerful generalizations from sparse data -for instance when learning about word meanings, unobserved properties, causal relationships, and many other aspects. Traditional accounts of induction learning emphasize either the power of statistical learning, and
the importance of strong constraints from structured domain knowledge, i.e. intuitive theories or schemes. et al. Many authors successfully argued that both components are necessary to explain the nature, use and acquisition of human knowledge, and they suggested to model the inductive learning and reasoning as statistical inferences over structured knowledge representations [115]. This kind of learning involves only the second modules of our model, the reasoning, and realizes again only the first two task of the learning framework. The inductive learning assume implicitly that the module II and the module III can interact directly without the activation of the module I, and that the evaluation heuristic can be applied to such internal (i.e. mental) process. This last assumption bring to the formulation of a non conservative law of mental schemes, which should be intended as projection of metastable states of a coherent system called knowledge. As a consequence the modification of a part of a certain mental scheme, can promote possibly, after or before, a cognitive dissonance (i.e. conflict) with another scheme or behaviour. This process is well known in social psychology and has been reported as producing the modification of the conflicting schemes in order to reduce the dissonance [13].

Social learning

The cultural evolution is guided by three main transmission factors: teaching, imitation, and language. Each of these factors also enables learning by the same atomic mechanism considered for the others kind of learning. Encoding co-occurrence frequencies can be a slow and dangerous process as a fundamental strategy of knowledge updating, and in humans social learning is probably the most widespread method of learning if we do not consider the induction [431, 432].

Social learning consists of learning through observation or interaction with other individuals and is fundamental in nature to acquire adaptive behavior in a complex environment. Social learning proved advantageous because individuals frequently demonstrated the highest-pay-off behavior in their repertoire, inadvertently filtering information for copiers [26]. Moreover it allows individuals to avoid the costs, in terms of effort and risk, of trial-and-error learning.

The implications of the general principles of the social learning theory suggest how learning should be considered as a cognitive function and not just the passive result of a biological phenomenon [433, 434, 435, 436]. Many theoreticians agree about the fact that people can learn by observing the behaviour of others and the outcomes of those behaviours. This first fundamental assumption implies that by the Theory of Mind humans can simulate/reproduce the schemes activated by others, reinforcing or weakening them accordingly with their estimated consequences (i.e. evaluation heuristic). The second fundamental assumption is that learning can occur without a change in behaviour, because people can learn through observation alone, so that their learning may not necessarily be shown in their performance. This feature suggest that a sort of inductive learning can be elicited by the observation of others. The social aspects which affect the learning processes comprehend obviously all the reachable social reinforcements and rewards, that a social context could propose. Despite such factors affect in a complex way the motivational and attentive structures, their role can be seen as mediated by the reasoning module through the goal heuristic. However, social learning can also cost time and effort, and theoretical work reveals that it can be error-prone, leading individuals to acquire inappropriate or outdated information in non-uniform and changing environments [26]. Finally currently many theories suggests that individuals usually develop mixed and complex strategy trying to be selective in when and how to use social learning [437, 438].
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