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Corresponding author: Nicolas Bullot

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Toward a theory of the empirical tracking of individuals: Cognitive flexibility and the functions of attention in integrated tracking

Nicolas Bullot

How do humans manage to keep track of a gradually changing object or person as the same persisting individual despite the fact that the extraction of information about this individual must often rely on heterogeneous information sources and heterogeneous tracking methods? The article introduces the Empirical Tracking of Individuals (ETI) theory to address this problem. This theory proposes an analysis of the concept of integrated tracking, *which refers to the capacity to acquire, store, and update information about the identity and location of individuals in our environment. It hypothesizes that certain functions of attention are a key to explaining how the cognitive flexibility of the human mind overcomes the heterogeneity of sources and methods in integrated tracking. At least two premises lend support to this hypothesis. First, heterogeneity of tracking sources is overcome by the combination of information from multiple perceptual modalities and a phenomenon of multisensory 'transparency'. Second, heterogeneity of tracking sources and methods may also be overcome by inferences that combine information across domains to acquire reasons to believe propositions about the target's location and identity.*

Keywords: Attention; Cognitive Flexibility; Cross-domain Inferences; File Semantics; Individual Integrated Tracking; Identification; Location; Multisensory; Reference

1 Nicolas Bullot is [redacted] at [redacted].
Correspondence to: Nicolas Bullot, Centre National de la Recherche Scientifique/Centre de recherche sur les arts et le langage (CRAL), 96 Bd Raspail, Paris 75006, France. Email: nicolas.bullot@gmail.com

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This article develops a new philosophical theory of the intentionality of the human mind: the ability to perceive, track, refer to, and think about real or fictitious things. Specifically, it analyses the intentional acts that are directed at real individuals. Here, the term *individual* is used to denote a particular agent (e.g., a human person) or particular material object (e.g., a stone, an artifact) that persists, changes, or grows and is located in the spatiotemporal world. Such an agent or object follows continuous paths in space and time, has connected parts, and has the power to causally affect other material entities. Not only can a human person perceive persisting individuals standing at different locations, or moving to new locations, but they can also re-identify individuals across changes in their appearance or intrinsic properties. How does one manage to keep track of a gradually changing individual as the same persisting entity despite the fact that the extraction of information about that individual must often rely on heterogeneous tracking methods or heterogeneous information sources?[1] To address this problem, the article outlines a philosophical theory called the 'Empirical Tracking of Individuals (ETI) theory'.

Section 1 introduces the ETI theory, which studies the conditions of *integrated tracking* understood as the ability to store and update coherent information on the identity and location of a set of individuals. It starts from a discussion of the distinction between intuitive and expert forms of integrated tracking. The theory proposes then four tentative generalizations about integrated tracking, which are bound to the project of a taxonomical analysis of human tracking procedures.

Principle 1 suggests that the integrated tracking of individuals is a necessary condition of the ability to entertain true empirical beliefs about individuals and to acquire the power to interact with them. Principle 2 appends that variations in tracking behavior must be accounted for by making the ways the tracker classifies its targets explicit. Principle 3 holds that integrated tracking depends on the flexible interplay, termed 'cognitive flexibility', between perceptual-motor tracking and more epistemic forms of tracking based on memory, reasoning and the use of communication and instruments. In association with this principle, I explain the distinction between perceptual and epistemic tracking and between synchronic and diachronic integrated tracking. Principle 4 proposes that the integrated tracking of individuals depends on procedures performed by attentional systems that can incrementally build singular representations (i.e., records of individuals, or singular files), assemble singular thoughts (i.e., thoughts about individuals) and guide singular actions (i.e., actions directed at individuals).

In contrast to accounts that confine the theory of tracking to the study of vision, section 2 argues in support of a cross-domain view, which holds that integrated tracking must be explained by cross-domain abilities that use cognitive flexibility, attention and language in order to integrate information about individuals across perceptual modules, domain-specific knowledge and tracking methods.

To specifically address the core problem, section 2 specifies the *attentional flexibility hypothesis* (Codicil 1 to Principle 4), which proposes that attention has cross-domain functions that are indispensable to cognitive flexibility and integrated tracking.

In association with this hypothesis, attentional procedures are viewed as building singular representations of tracked targets—termed 'singular files'—(Codicil 2) and that such representations incorporate updating mechanisms that can record invariance and change in target individuals (Codicil 3).

Finally, in sections 3 and 4, I propose an argument that lends support to the attentional flexibility hypothesis. It depends, namely, on two premises about the cross-domain functions of attention. First, section 3 explains how the heterogeneity of tracking sources is overcome by *multisensory synergies* that guide the orienting of perceptual attention, especially in synchronic multimodal tracking (i.e., tracking an individual through several modalities through a single encounter). Furthermore, section 4 suggests that the heterogeneity of tracking sources and methods may also be overcome through the performance of *cross-domain inferences* that take advantage of cognitive flexibility for acquiring reasons to believe empirical propositions about the target's location and identity, especially in diachronic integrated tracking (i.e., the tracking of an individual across temporally disjoint encounters) and expert integrated tracking.

1. The Empirical Tracking of Individuals (ETI) Theory

Humans can identify and locate persisting individuals across changes in their intrinsic or relational properties. What are the cognitive bases for this ability? A number of theories suggest that this kind of intentionality is tightly bound to processes aimed at *tracking* mind-independent material individuals and acquiring beliefs about their properties. The problem with this appeal to 'tracking' is that the meaning of this notion varies considerably across specialized disciplines.

In philosophy, a number of doctrines define *knowledge* as a form of true belief acquired through a reliable and non-accidental tracking process. For instance, you know that there is currently a cup on the table if you have acquired this belief through a reliable perceptual process (e.g., by looking at this very cup) and not by an accidental procedure (e.g., by randomly guessing that there is a cup). Thus, for a number of epistemologists, knowledge is identified with the activity of tracking the truth (Luper-Foy, 1987; Nozick, 1981; Roush, 2005) and science is identified with a tracking activity (Carruthers, 2006; Liebenberg, 1990). Here, philosophers use the term 'tracking' to analyze the flexible use of methods for acquiring and sustaining justified true beliefs.

In philosophical file semantics (Bach, 1987; Evans, 1982, 1985; Perry, 2001) and works on perceptual reference (Campbell, 2002, 2004; Clark, 2000, 2004; Matthen, 2004, 2005), the reference to individuals—so-called *singular reference*—is held to depend on the ability to single out and trace individuals through the use of a variety of perceptual and cognitive tracking systems. Related works in metaphysics study the ontology of singular intentionality. Prominently, in a tradition originating in Kant's *Critique of Pure Reason* (1781–1787/1929), Strawson (1956, 1959, 1997) argues that individuals which occupy a spatial location and gradually change over time are the basic entities that are traced and identified within our unified spatiotemporal conceptual scheme.

Cognitive science has also studied the different capacities and methods of tracking. There is empirical evidence indicating that the basic ability to perceptually track other objects and agents has its roots in the early stages of human cognitive development (Carey & Xu, 2001; Spelke, 1990). This perceptual tracking may be a basis for tasks routinely performed by adults, including interactive sensory-motor tasks (Ballard, Hayhoe, Pook, & Rao, 1997), such as visually tracking a tea pot while pouring water into it (Land, Mennie, & Rusted, 1999) or keeping track of multiple moving objects (multiple object tracking [MOT]: Cavanagh & Alvarez, 2005; Pylyshyn & Storm, 1988). Furthermore, neuropsychological research has documented syndromes which can include specialized dysfunctions in the perceptual ability to track familiar objects (e.g., visual agnosia: Farah, 2004), or familiar agents (e.g., Capgras delusion: Capgras & Reboul-Lachaux, 1923; Coltheart, 2007).

Besides perceptual tracking, methods of tracking using memory, categorization, language and technical instruments are also under investigation. For instance, research on memory systems (Burgess, Jeffery, & O'Keefe, 1999; McNamara, 2003; Moscovitch, Nadel, Winocur, Gilboa, & Rosenbaum, 2006; Nadel & Moscovitch, 1997) has provided insights into the frames of reference and trace-keeping systems humans use when tracking individuals and locations on the basis of memory. With regard to categorization, research on the acquisition of concepts has developed models based on the conceptual tracking of individuals (Barsalou, 1999; Barsalou, Huttenlocher, & Lamberts, 1998; Millikan, 1998). With respect to tracking methods aided by technology, the study of extended and distributed cognition has revealed that humans use an increasing number of prostheses (e.g., systems of 'Augmented Reality' in engineering, navigation or surgery; see Clark, 2003; Sutton, 2006) and external representations (e.g., diagrams and interactive maps) to track individuals via expanded perceptual and cognitive systems.

There is little research that attempts to investigate potential links between these different sources and methods of tracking and none that offer a unified taxonomy of human tracking procedures. However, the use by humans of such varied tracking-related procedures indicates that they can use and combine heterogeneous sources and methods of tracking to ground their ability to refer to individuals. This flexibility raises a critical problem: how do humans manage to keep track of a gradually changing individual as the same persisting entity despite the fact that the extraction of information about such an individual must often rely on heterogeneous information sources or heterogeneous tracking methods?

As an attempt to address this problem and account for the wealth of data specific to human tracking, this article develops a philosophical theory of integrated tracking termed the 'Empirical Tracking of Individuals (ETI) theory'. This theory hypothesizes that humans have acquired through natural and cultural evolution an integrated ability to keep track of individuals within a relatively unified spatiotemporal system. The key concept of this theory is 'integrated tracking', which can be characterized as follows: a mature human person performs—as a *tracker*—the *integrated tracking* of target individuals if this person (i) acquires and stores historical information on the identity and location of the targets with respect to a unified spatiotemporal system (i.e., acquires and correctly binds the 'which', 'when' and 'where' information about this individual) and (ii) updates this historical information about their location and identity. This process may take place as a function of varied tracking procedures (i.e., combination of sources, methods or strategies) and variable degrees of accuracy.

The qualification "with respect to a unified spatiotemporal system" refers to the fact, prominently analyzed by P. F. Strawson (1959, pp. 23–38), that human thinkers *qua* trackers can identify and locate individuals with respect to hierarchically organized frames of reference, which are eventually consistent with a spatio-temporal conceptual scheme in which human thinkers locate objects, persons, historical events and geographical entities.[2] This spatio-temporal framework manifests itself in the possibility that one has to translate one system of coordinates into another (e.g., when one translates an ego-centered frame of reference into an allocentric[3] frame of reference, or when one translates a date in a lunar calendar into the Gregorian calendar).

Integrated tracking might be specific to human beings because one can expect mature humans to routinely combine tracking sources and methods, as when they routinely translate the located identification of an individual from an ego-centered frame of reference into one which is carried out with respect to an allocentric frame of reference.[4] Of course, attributing this integrated ability to someone does not imply that this person is an omniscient tracker and can identify all the properties of the target or refer to all its positions in any frame of reference. Rather, it indicates that the tracker demonstrates the dynamic capacity to combine and update identification and location information about an individual, and to carry out basic translations between different frames of reference.

As a rudimentary taxonomy of the variable accuracy in integrated tracking, one can term *intuitive tracker* the person who does not rely on scientific expertise or instruments to guide their acts of integrated tracking. As an intuitive tracker, Mary performs the integrated tracking of her spouse George between t_1 and t_3 if she knows who George is, where he is located between t_1 and t_3 and if she can follow some of his successive locations with respect to a unified spatiotemporal system. For instance, this condition is fulfilled when she follows George first as briefly located in her left visual fields at t_1, then as a voice saying "goodbye" at t_2, and eventually as somebody who has arrived back after a day at work and can be perceived in a multimodal experience at t_3. Mary's tracking is integrative because, despite the fact that she gathers information about George from different sources and in different frames of reference, she demonstrates an understanding of George's sameness and consecutive allocentric positions. In contrast, a patient with Capgras syndrome (Capgras & Reboul-Lachaux, 1923; Edelstyn & Oyebode, 1999) may fail to perform the integrative tracking of their spouse due to a delusional belief that the person perceived at t_1 has been replaced by an impostor at t_3.

Mary's casual way of tracking remains intuitive because she does not deploy any scientific expertise or technical apparatuses to determine George's location between t_2 and t_3. For instance, she neither uses instruments and data recording to sharpen the accuracy of her tracking, nor hire a professional detective to trail George between t_2 and t_3. In contrast to her intuitive tracking, expert human trackers can cope with the cognitive limitations inherent to unaided tracking through the methodic use of technologies. Tracking techniques are extensively used, namely, in legal and scientific investigations.

In criminological and forensic practices, an institutional use of technologies for the integrated tracking of humans is found by the end of the nineteenth century in Alphonse Bertillon's systems of "anthropometric" identification (Bertillon, 1890, 1893) and in Francis Galton's introduction of fingerprints for identification (Galton, 1892). Bertillon, who was a clerk in the Paris Prefecture of Police, devised a system for trailing recidivist criminals, known as 'bertillonage', aimed at distinguishing individuals by talking physical measurements, recorded on cards along with a verbal description and, increasingly, photographs (and fingerprints in some cases). More recent developments in technologies for tracking persons include methods such as automated fingerprint identification system, genetic profiling (e.g., White & Greenwood, 1988), iris recognition, voice print, retinal scan and Global Positioning System or electronic bracelets for automated localization. Tracking data are often collected in networks of integrative databases (e.g., Shen & Tan, 1999; Wein & Baveja, 2005) such as the databases of the FBI National Crime Information Center (F.B.I., 2005), which include the Integrated Automated Fingerprint Identification System (IAFIS), or the Combined DNA Index System (CODIS). The latter store and update profiles of individuals convicted of crimes, DNA profiles developed from crime scene evidence, profiles of arrested persons and DNA profiles from missing persons.

Technologies for integrative tracking are also ubiquitous in scientific investigations and technologies developed for scientific purposes. For instance, research in astrophysics and aerospace engineering uses a wide range of instruments to identify and locate astronomical or orbiting objects. To cite a precise case, by 2006, more that 9000 Earth-orbiting man-made objects (e.g., pieces of old space ships and spent rockets) are tracked by the US Space Surveillance Network (Liou & Johnson, 2006), which is a network of military radar and telescopes located at two dozen sites around the planet. Similarly, marine biologists use satellite-based tracking systems to trace the located identity of tagged animals such as pelagic predators along with variables of their local environment (Block et al., 2005; Tremblay et al., 2006).

Although intuitive and expert tracking are clearly distinct form of cognition, one should note that they raise a common *cognitive* problem. In each case, the tracker must integrate information from different information sources, different frames of reference and different tracking methods. Unfortunately, to the best of my knowledge, no available theory provides an account for, and taxonomy of the varied procedures of integrated tracking. There is, however, much known about spatial cognition, and about how spatial cognition connects to language[5] or reasoning.[6]

Nevertheless, integrated tracking cannot be reduced to spatial cognition, or to the study of location cognition considered independently of the occupants of such locations. It is the dynamic ability to bind and update identity and location information about a referent, and to gain knowledge about a located identity. As a plea for research on this missing theory, I propose four basic philosophical principles for the ETI theory.

The first principle of the ETI theory is epistemological; it refers to the role of tracking for the formation of true beliefs and the guidance of action:

> **Principle 1** (of belief and power): The integrated tracking of individuals is a necessary condition of the ability to entertain true empirical beliefs about individuals, and to acquire the power to interact with them.

Support for the principle of belief and power is that the verification and the falsification of empirical beliefs about individuals require reliable integrated tracking of their targets. For instance, your ability to obtain true beliefs about the persons presently located in your house is dependent on your ability to directly perceptually track them or to indirectly track them when they are not within reach of your perceptual fields (*epistemic* tracking, based on reasoning, memory, communication or technical devices; see below the principle of cognitive flexibility). Perceptual tracking of somebody in your house can provide you with *evidence* or *reasons* to believe in observational propositions about this person, and thus about their identity and location.[7]

The epistemological thought linked with the principle of belief and power is that one cannot hunt for truths without hunting for individuals *qua* truth-makers. Truth-makers are the entities in virtue of which sentences or propositions are true.[8] From this thought, it derives that the epistemic ability to 'track the truth' in Nozick's sense—i.e., the acquisition and maintenance of non-accidental true beliefs—is, at the very least, partly dependent on the empirical tracking of individuals and their attributes.

Furthermore, knowledge obtained from tracking an individual can guide actions performed on that individual, and be grounds for acquiring the power to capture, control or influence that individual. Thus, strategies of tracking are often strategies for acquiring power. For instance, animal predators and human hunters (Liebenberg, 1990) are trackers who gain the power to kill their targets (prey) from identifying and locating information gained through stalking and trailing. In the social domain, the aforementioned instruments for legal identification and biometrics clearly provide social power to their users. Similarly, most weapons and military systems acquire power to neutralize or annihilate adversary targets through the integrated tracking of such targets.

The second principle refers to the intuitive or scientific classification of tracked targets:

> **Principle 2** (of ontological classification): Variations in tracking behavior must be accounted for by making the ways the tracker classifies its target(s) explicit—such ways are the tracker's ontological classifications or commitments according to domain-specific or expert knowledge.

This principle predicts that tracking is performed as a function of the tracker's classifications defining—for the tracker—the target's (purported) nature, or ontological status. Traditionally, the term *ontology* refers to the theory of *what there is*: the fundamental constituents or things that exist in the world.[9] Principle 2 uses the notion of purported ontological classification—the ontological commitment of a tracker—to refer to the tracker's intuitive or scientific classificatory representation of *what the target is*. For instance, an intuitive tracker ascribes a (purported) ontology to a biological organism if it expresses expectations or beliefs about the birth, persistence, survival and extinction conditions of this organism.

Classificatory processes inform trackers about the components of the world and about their workings. They organize sensory experience (Barsalou, 1999; Matthen, 2005), expedite new learning needed to trace instances of real kinds (Millikan, 1998), help predict the behavior of tracked items (individuals or kinds), allow efficient extrapolations and predictions from one set of circumstances to another (Barsalou, 1999; Barsalou et al., 1998; Millikan, 1998), and introduce an essential economy in the tracker's representation of the world. An effective classification system is one that sorts individuals and real kinds in the world into discreet categories according to criteria which make an individual's membership of any particular class a relevant datum for guiding tracking behavior and action.

In contrast to the scientific classifications underlying expert integrated tracking, which depend on the history of scientific culture and practices, human intuitive trackers may guide their procedures of integrated tracking with 'folk' or 'naïve' ontological classifications. The latter are sometimes described as grounded in the principles of 'folk' or intuitive physics (McCloskey, 1983), intuitive biology (Atran, 1998; Medin & Atran, 1999) and intuitive psychology (Bering, 2006; Boyer, 2000; Bullot, 2006). If evolutionary psychology (Cosmides & Tooby, 1994) is correct, such common sense classifications are to be specializations that have evolved in response to adaptive problems (Hirschfeld & Gelman, 1994; Mithen, 1996, 2005).

The principle of ontological classification pinpoints that, irrespective of whether an act of integrated tracking is intuitive or expert, it must classify its target in order to represent its ontological status. Although one might expect classifications made by humans to be conceptual representations, certain tracking mechanisms might possibly be independent of the influence of conceptual contents while still operating some implicit classification of their targets through non-conceptual ontological commitments (Pylyshyn, 2007).[10]

The third principle introduces the notion of flexibility and cognitive flexibility among heterogeneous sources, modules or methods of tracking:

> **Principle 3** (of cognitive flexibility): The integrated tracking of individuals depends on the flexible interplay—or *cognitive flexibility*—between (i) perceptual-motor tracking and (ii) epistemic tracking.

While continuous perceptual tracking is essential for the acquisition of perceptual knowledge, tracking through a single perceptual encounter cannot be the only ground for tracing the persisting identity of individuals. The most apparent reason for this is that, with regard to long-term periods and widely scattered distributions of individuals in space, human trackers cannot continuously observe all individuals at all times.[11] Human integrated tracking must therefore operate on the basis of temporally disconnected episodes of perceptual tracking (e.g., encountering a friend once per week). This requires trackers to bind perceptual tracking with other methods of tracking such as reasoning on the basis of memories (e.g., remembering what the friend was doing the previous week) or using devices that carry information about the located identity of the target (e.g., using the phone or a video system to inquire about somebody's activities and location).

Integrated tracking can thus use at least two basic kinds of tracking. The first is *perceptual and motor tracking* (e.g., using information acquired through vision and audition to track somebody).[12] This is the ability of a tracker to access and trace a target directly by means of a sensorimotor system (Adams, 1961) or visual attention (Campbell, 2002). In this case, the tracker directly perceives or manipulates the target and can locate it approximately, at least with respect to an ego-centered frame of reference. Most past and present experimental research on tracking explores this type of tracking in vision (e.g., Cavanagh & Alvarez, 2005; Pylyshyn, 2007; Pylyshyn & Storm, 1988).

The second basic kind is *epistemic tracking*, which occurs when the target individual cannot be adequately perceived, or cannot be perceived at all, but can be identified and located on the basis of indirect information, gathered by such sources as linguistic communication, reasoning, imagery, semantic and episodic[13] memory, or the mediation of technology. For instance, historians, paleontologists and archeologists are expert epistemic trackers because they routinely locate and identify extinct, invisible or hidden individuals on the basis of indirect evidence, such as archives or archeological vestiges (e.g., Jones, 2007). Experts in criminology and forensic science (see the discussion above) are epistemic trackers working with criminal traces and records and technical devices for finding and identifying suspects and retrieving evidence from a crime scene. Similarly, biologists who track animals via tags that transmit data to satellites and computer networks (e.g., Block et al., 2005; Tremblay et al., 2006) are expert epistemic trackers since they follow located individuals without directly perceiving them. Expert epistemic tracking often use communication, culture and technology in highly integrated and sophisticated fashion.

Identifying or locating a target without perceiving it, and thus simply on the basic of clues (e.g., when a detective trails a murderer through the examination of clues), is a case of *purely epistemic* tracking. As a distinct case, if the tracker reasons on the basis of information acquired from several temporally disjoint encounters, we can refer to this case as a form of *diachronic* integrated tracking that involves elements of epistemic tracking. The diachronic act is distinct from *synchronic* tracking understood as the tracking of an individual through the binding of information gathered from several modalities and epistemic resources during a single and possibly unique encounter (e.g., as in a unique multimodal encounter with somebody).

Both synchronic and diachronic integrated-epistemic tracking rely on the combination of heterogeneous sources of information and heterogeneous methods of tracking. Therefore, they are unlikely to be explained by the appeal to a single sensory module or a specialized cognitive system (see section 2). Integrated tracking must therefore primarily depend on the flexible combination of different sources of information and methods of tracking. I will term this ability to combine information sources and methods of tracking, and also to switch between frames of reference, the *cognitive flexibility* of a tracker's mind. Cognitive flexibility is an ability to exchange information flexibly between and among mental modules or domain-specific knowledge. Here this concept of cognitive flexibility is akin to what Stephen Mithen views as the 'cognitive fluidity' of the human mind (Arp, 2006; Carruthers, 2002, 2006; Mithen, 1996, 2005), which may account for the cultural innovations introduced by *Homo sapiens sapiens* during the Middle/Upper Palaeolithic transition.

It is not always simple to differentiate sensory-motor and epistemic/integrated tracking because the former type can be tightly linked to strategies of integrated tracking. A kind of sensory-motor tracking that does not seem to involve much epistemic process is illustrated by the individuation required for grasping a projectile such as a ball. The ball catcher's behavior is adapted to the currently perceived properties of the ball. However, the act of catching the ball does not require any sophisticated historical knowledge of *that* particular ball (e.g., knowing the ball's distinctive properties that make it different from any other ball). The navigation toward a ball may be controlled by optic flow and expansion of the ball's retinal projection in the visual field.[14] One may classify this as a basic case of *perceptual-motor individuation* in which the sameness of the individual is registered implicitly by the tracker's action, and the tracker's ontological commitments (see the principle of ontological classification) on the nature of the target may be minimal or null. At the polar opposite of the spectrum, one finds *complete perceptual-demonstrative identification*, in which the tracker possesses sufficient information and conceptual knowledge about the target for discriminating and re-identifying it as a token individual distinct from *any* other token (e.g., when Mary recognizes that *that* person is her mother, who is distinct from that of any other individual of the human kind).[15]

The fourth principle of the ETI theory, which addresses the problem of the heterogeneity of sources and methods in tracking, refers to the role of attention in integrated tracking:

> **Principle 4** (of attention files): The integrated tracking of individuals depends on procedures performed by attentional systems that can incrementally build singular representations (*viz.* records of individuals, or singular files) and guide singular actions (*viz.* actions directed at individuals).

Arguably, the role of attention in the flexible coordination of different forms of tracking is critical because attention links perceptual processes with cognitive operations based on memory, linguistic reference, communication and reasoning. Thus, the investigation of attention should provide grounds for understanding how, in integrated tracking, perceptual-motor tracking (e.g., in vision and audition) flexibly interact with various forms of epistemic tracking (e.g., based on memory and reasoning) (see the principle of cognitive flexibility).

According to an influential view,[16] attention systems are involved in the construction of representations of particular individuals because the focusing of attention on a target individual enhances the salience of all its current properties, reactivates its recent history (Kahneman et al., 1992, p. 176) and allows the tracker to form and entertain singular thoughts about this individual. In this tradition, the principle of attention files hypothesizes that human trackers refer to individuals through the performance of context-dependent evaluation procedures that link each target of perceptual tracking with predicates in singular representations termed *singular files*. The ETI theory suggests applying the concept of singular file from theories in perception and semantics to the analysis of the integrated tracking of object and agents (Bullot & Rysiew, 2007). A *singular file* is a mental record that can store and update information about a single individual on the basis of contextual inputs (e.g., audio-visual tracking, communication) or internal processes based on multimodal sources (e.g., reasoning). At least in perception, the construction of singular files through attentional procedure may be a basic ability whereby the tracker can assess beliefs about tracked individuals (through verifications performed by sensory-motor and attentional acts during the construction of each file). It follows from the ETI theory that the understanding of integrated tracking and reference (Campbell, 2002, 2004; Matthen, 2004, 2005) must be supplied by a procedural theory of attention, which describes the architecture, semantic, syntactic and pragmatic procedures used to construct singular files.

2. The Cross-Domain View of Integrated Tracking and the Attentional Flexibility Hypothesis

We can contrast two approaches to the problem of integrated tracking. A first one could be derived from the thought that integrated tracking is driven by a dominant sensory modality and its domain-specific knowledge. Consistently with this view, a number of theories propose that vision is a key to the understanding of tracking since the identification and localization of individuals is predominantly carried out by visual modules and routines.[17]

It is useful to consider this approach in the context of a comparison between vision and audition (Kubovy, 1988; Kubovy & Van Valkenburg, 2001; Matthen, 2005, in press). John Campbell and Mohan Matthen hold that, in contrast to auditory tracking, the visual or visuo-haptic tracking of an individual offers special access to this individual as a material object.[18] In contrast to the visual experience of material shapes, Matthen specifically proposes that the direct contents of audition are not material objects *qua* spatial shapes but temporal entities such as activities and events in which objects are involved (2005, pp. 282–289, in press).

Consider this example, which I adapt from John Campbell (2002, pp. 115–116): suppose that Matthew is curious about his new neighbor Mary, who has just moved in the house next door. For a period of several days, Matthew can only hear sounds coming from inside Mary's house. Call 'σ' the crowded space inside the house. On the basis of his auditory experience of the sounds produced by the sources located inside σ, Matthew hears the sound of a glass-breaking event and can speculate about the activities, location and identity of things in or around σ that are causally responsible for the glass-breaking sound. He might be able to test and confirm some of his audition-based hypotheses over several days of recurrent careful listening. Although Matthew can perform auditory epistemic procedures, the situation will become much different when he is invited, at last, to visit Mary's house and encounter objects and agents located inside σ and around the house. When the day finally arrives, what does this add to Matthew's knowledge?

According to Campbell's (2002, pp. 115–116) analysis, the contrast between the knowledge Matthew obtains on the basis of a look at the individuals located in σ and the knowledge he had before of the sound sources, is that Matthew is no longer tracking *types* of activity but is 'confronted by the individual substances themselves' (Campbell, 2002, p. 116) only when he sees the *token* individuals. On this view, Matthew's visual experience of such individuals provides him with the knowledge of the causal grounds of the activities and properties he earlier simply postulated. Matthew can confidently form demonstrative thoughts about tokens of located identities such as 'this broken glass window is very likely the sound source I heard beforehand'. He can use visual demonstratives to gather knowledge about causal interactions between the individuals located in σ. Hence, Campbell suggests that visual experience of an individual that results from its selection by visual attention can provide grounds for referring to it demonstratively and tracking its causal characteristics as a unique token.

Similarly, if Matthen (2005, pp. 282–289, in press) is correct in thinking that the direct objects of audition are not material objects but are activities or events in which objects are involved, the direct perception of the individuals inside σ can only occur when Matthew sees the individuals while exploring σ. Auditory experience may have only provided information for tracking types of activities without providing sufficient information for identifying and locating target in a manner consistent with their integrated tracking.

This kind of interpretation of Matthew's increase in knowledge is intuitively appealing because something important is added to his knowledge when he is in a position to visually track the sound sources he once heard. Nonetheless, although Campbell is convincing in his statement that attention is constitutive of demonstrative thoughts and tracking, I believe that his exclusive focus on visual attention is misleading. For it is incorrect to conclude from Matthew's example that 'pure'[19] vision is the dominant modality and knowledge system for performing integrated tracking and constructing singular knowledge through tracking.

The evident argument against focusing solely on vision is that vision is not the exclusive sensory modality used by human trackers to locate and identify individuals, despite the fact that it is likely to be the most efficient modality for recovering the shape and spatial layout of objects in sighted persons (Kubovy, 1988; Kubovy &

Van Valkenburg, 2001). Trackers must combine procedures carried out by different sensory and motor systems to perform actions aimed at the integrative tracking of a set of targets. Besides, human trackers can demonstrate significant success in identifying and locating objects on the basis of non-visual perceptual systems such as audition (e.g., Bregman, 1990; Handel, 1995; McAdams & Bigand, 1993; Wightman & Jenison, 1995) and the haptic system (Klatzky & Lederman, 1993, 1999, 2002).

In accordance with the principle of cognitive flexibility, we should thus recognize that, since integrated tracking is fundamentally dependent on multisensory and cross-domain abilities, no pure sensory modality can be said to grant *by itself* the ability to perform integrated tracking. The latter depends on transfers of information across sensory modalities, across cognitive systems (e.g., working memory and episodic memory) or domain-specific knowledge and across methods of tracking. Therefore, the explanation of integrated tracking should focus on the cognitive flexibility that permits a human tracker to integrate information across separate modalities or modules, across heterogenous sources of information and across methods of tracking. I will term such an approach the *cross-domain view* of integrated tracking.

A rationale for apprehending the increase in Matthew's knowledge in accordance with the cross-domain view is that multimodal perception and reasoning are necessary conditions of his experience. The increase in his knowledge that seem to result merely from visual tracking is, in fact, dependent on a multisensory perceptual tracking and an active exploration of the spatial layouts of the objects and agents present in Mary's house. As soon as the visit of the house begins, individuals in σ can be directly perceived, actively scrutinized by several sensory systems and subjected to reasoning procedures that serve integrative tracking (see the discussion of cross-domain inferences in section 4).

This exploratory opportunity contrasts, indeed, with Matthew's anterior experience restricted to hearing. For in the episodes of pure listening, only a restricted range of acoustic events produced by the individuals in σ could serve as cues for identifying and locating their intrinsic or relational properties. However, this contrast does not derive from the difference between pure vision and pure audition. Rather, it originates from the differences separating the case of a limited access to individuals present in σ and the case of a much more extended sensory and motor access to the individuals located in σ. Whereas Matthew can only evaluate and reason about auditory predicates (e.g., 'is loud', 'is high pitched' or 'has a male voice') in the listening phase, he can evaluate and reason about a much broader range of visual, haptic or auditory predicates while exploring the individuals located in σ. In the latter case, he is therefore in a better position to complete the integrated tracking of some such individuals.

The combination of the principle of attention files (Principle 4) and the cross-domain view suggests that attention should serve integrated tracking through the binding of heterogeneous sources of information and tracking methods. This thought can be specified through a series of codicils to the principle of attention files. The first is this hypothesis:

> **Principle 4**, *Codicil 1* (hypothesis of attentional flexibility): The cross-modal and cross-domain functions of attention are a necessary condition of the integrated tracking of individuals, and, therefore, of the cognitive flexibility between heterogeneous ways of tracking such as sensory-motor and epistemic tracking (see the principle of cognitive flexibility).

This first codicil is relevant for apprehending both synchronic and diachronic tracking. With regard to synchronic multimodal tracking (i.e., the integration of information during a single episode of multimodal tracking), the flexibility hypothesis suggests that when one is paying attention to a human individual such as Matthew, one must identify and locate Matthew through the combination of information delivered by different sensory and motor modalities. For example, in a situation in which Mary and George are listening to Matthew, who is talking to them, Mary and George can direct their joint attention at Matthew and his speech. This will provide them with the ability to reliably combine the visual tracking of his body and face with the auditory tracking of his voice and speech. They will crossmodally trace the movements of a visible body and the inflections of an audible voice as phenomena that originate from an internally connected causal source, which is a cause of some salient perceived phenomena—and who is a known, unique and traceable speaker. A faculty that does such auditory-visual combination is likely to relate to *attentional selection and control*. In this sense of attention *qua* selection driven by multisensory synergies, directing attention to an individual equates combining information from multiple sensory modalities to serve the reliable perception of this individual.

In the case of diachronic integrated tracking (e.g., reidentifying Matthew as the same Matthew each Monday morning), the faculty of attention may contribute to another kind of cross-domain ability. For instance, if Mary loses track of Matthew but wants to meet him again to communicate him a piece of news, she must shift to a strategy of epistemic tracking aimed at finding him at his new location (see the principle of cognitive flexibility). On the basis of her memory of a previous agreement on a place to meet, she may try to find the place which is the referent of their agreement. This strategy of epistemic tracking can be said to depend on attention *qua* faculty of combining information on the current status[20] and context of her tracking task with the episodic memory of a relevant piece of information. In this case, attention is the faculty that contributes to form *cross-domain inferences* based on the flexible interplay between episodic memory (e.g., the content of her talk and agreement with Matthew) and perceptual and situational awareness of the ongoing task and its context (see section 4).

Mary uses at least two distinct forms of attention: multisensory tracking in synchronic tracking versus memory-based cross-domain inferences in diachronic tracking. Each form serves integrated tracking because each contributes to the acquisition—criterion (i) of integrated tracking, in section 1—and updating—criterion (ii) of integrated tracking, in section 1—of historical information about Matthew's identity and current location. Moreover, as the two forms of attention serve the knowledge of a single individual, it is reasonable to further hypothesize that a crucial capacity required for integrated tracking is the ability to update a mental record about the individual to be tracked (e.g., Bullot & Rysiew, 2007; Kahneman et al., 1992; Perry, 2001; Pylyshyn, 2007). The perceptual and epistemic tracking strategies may both share the use and updating of an internal record that refers to Matthew understood as unique spatio-temporal individual. Such a record would underlie the assembling of thoughts and linguistic utterances referring to Matthew. Therefore, besides the role of language[21] for expressing cross-domain thoughts that partake in integrated tracking, each of the two forms of attention (i.e., multisensory integration and cross-domain inferences) may be involved in the construction of *representations of individuals* for integrated tracking through multimodal perception, action or reasoning. The principle of attention files terms these records *singular files*.

On this basis, a second codicil to the principle of attention files can be expressed as follows:

> **Principle 4**, *Codicil 2* (of the cross-domain construction of files): Attention is the faculty that controls cross-domain procedures required for constructing *singular mental files* that assemble information about target individuals so as to perform their integrated tracking, which depends on the cognitive flexibility between the sensory-motor and epistemic tracking of individuals.

Moreover, in order to construct a singular file for integrated tracking, a tracking system must be an *updating* system that can trace invariance and change in the target in different situations. This aspect derives from the fact that integrated tracking has to perform tracking over time in spite of varied spatio-temporal and intrinsic changes in both the target to be tracked and the agent performing tracking. Updating is the process that can incrementally record these changes while maintaining the possibility of referring to the same (moving, changing, growing) individual. Therefore, if cross-domain attention is to play a role in integrated tracking, it must encompass updating resources allowing the tracker to record invariance and change in the target individual.

This desideratum about cross-domain attention as updating mechanism can be expressed through this third codicil:

> **Principle 4**, *Codicil 3* (of invariance and change recording): Attention performs the dynamic identification and localization of individuals by means of *updating procedures* that allow trackers to record invariance and change in tracked individuals.

At this stage of the analysis, the attentional flexibility hypothesis and the other codicils remain conjectures. Moreover, they leave many problems about the concept of cross-domain attention unanswered, including the psychological problem of specifying the architecture and neurobiological bases of cross-domain attention. In an attempt to provide further justification of the cross-domain view of integrated tracking, the next section will propose an argument in support of the hypothesis of attentional flexibility and its related codicils.

3. Multisensory Synergies in Synchronic Perceptual Tracking

On the basis of the concepts analyzed in the previous sections, we are now in a position to formulate an argument to support to the attentional flexibility hypothesis. The argument incorporates the distinction between the two functions of attention discussed in the former section and, thus, proceeds as follows:

> **Premise 1**: The (exogenous or endogenous) attention of a tracker must select a perceived target individual, or update a file referring to a not-currently-perceived individual,
>
> (*1a*) to initiate and sustain the tracker's synchronic perceptual tracking of such an individual through multisensory synergies (rationale provided hereafter, section 3), and/or 2
>
> (*1b*) to allow the tracker's diachronic epistemic tracking of this individual via cross-domain inferences—grounded in the memory of, and reasoning about certain of its properties (rationale provided in section 4).
>
> **Premise 2**: Cognitive flexibility between (i) synchronic perceptual tracking and (ii) diachronic tracking through cross-domain inferences allows the tracker to complete the integrated tracking of such an individual (see the principle of cognitive flexibility).

If Premises 1 and 2 are warranted, they would support the hypothesis of attentional flexibility because they imply that attention and files are an essential condition of integrated tracking. Specifically, attention and files would be a necessary condition of the flexible interplay between heterogeneous methods of perceptual and epistemic tracking. In the remainder of this article, I will consider further how Premises 1a and 1b of this argument can be justified.

What are the arguments that can lend support to Premise 1a? In the first place, one can appeal to a phenomenological argument. Its rationale is that a careful examination of the phenomenology of attentive multisensory experience indicates that, in circumstances in which one tracks an individual through synchronic deliverances from distinct sensory modalities, one does not experience conflicts between the different sensory inputs. Our brain does perform subtle adjustments to combine information across sensory modalities into coherent spatio-temporal representations. For example, it recalibrates[22] signals to compensate temporal discrepancies between auditory and visual information. Such adjustments, however, are not usually explicit in the content of our multisensory experience. The mundane experience of completing multisensory tracking of an individual reveals the properties of the tracked individual instead of the putative discrepancies among distinct sensory qualities.

In contemporary philosophical theorizing, the direct access to the properties of the objects of perceptual experience is described in terms of 'transparency'. The *transparency of experience* is the phenomenological observation that when we, human perceivers, try to attend to our perceptual experience itself, we usually find ourselves attending to the objects around us instead of anything intrinsically subjective or internal.[23] This observation does not necessarily imply that mature human trackers are never in a position to introspect their experience independently of attending to external objects. However, it suggests that when one reflects on one's perceptual experience, one does so most naturally by attending to the individuals that our experience purportedly presents and tracks. Although conclusions drawn from this observation remain controversial (see Gendler & Hawthorne, 2006), the observation of transparency seems particularly relevant to label the point I have just noted, which could be termed 'multimodal or multisensory transparency'. In this sense, the *multimodal transparency of perceptual experience* refers to the phenomenological fact that the attentive and conscious perceptual tracking of individuals seems to immediately reveal the properties of the tracked individuals instead of those which are specific to separate sensory signals used in the tracking process.

For instance, when Matthew is crossmodally directing his attention at Mary while she is speaking, the usual experience of multimodally perceiving Mary does not call his attention to discrepancies between audition and vision. While attending to the speech, he experiences Mary's voice and visual appearance as belonging to her and not as belonging to two of his sensory systems. Similarly, when perceiving and tracking a lover with whom one is having an erotic encounter, while one's erotic and sexual acts might significantly affect most sensory modalities, one's attentive experience is not one of having to reflect on heterogeneous streams of sensory qualities to retrieve the identity and location of one's partner. Arguably, one's perceptual experience is a unified experience of the carnal properties of the partner's externally located and unique body, and of the emotions it communicates.

What does the phenomenon of multimodal transparency of experience reveal? First, it suggests that a perceptual experience of crossmodal synchronic tracking depends on multisensory synergies that serve the tracking of an individual as a *distal* or *externalized* entity (Dretske, 1981; Matthen, 2005). Instead of directly tracking proximal stimuli, proximal stimuli relative to sensor-centered or body-centered frames of reference are used to track the external bodies that are presented in experience.

Second, a perceptual experience of multimodal synchronic tracking accesses the distal target *qua* internally connected causal source.[24] The perception of the target's unity depends on the ability to perceive the causal connection among its parts and their causal role in the generation of specific contents of one's perceptual experience. The multimodal transparency of perceiving Mathew as a speaker is an experience in which the tracker sees moving parts of the Matthew's face (his lips) as being causally linked to the experience of the speech which is heard. In the eventuality in which audition and vision were in conflict, crossmodal synergies may contribute to rectifying conflicting commitments for providing coherent information about the target as a causally interconnected individual that possesses a set of invariant properties despite noticeable changes.

Third, such a multimodal access to the target's distal and internal connection may be used in the genesis or updating of a mental record for the tracked individual (e.g., a mental file in the sense defined by the principle of attention files and its codicils), which can subsequently be used in the formation of true singular beliefs (see the principle of belief and power) about the location of tracked individual relative to a variety of frames of reference.

Premise 1a and the multimodal transparency of experience might be supported by complementary empirical arguments (Calvert et al., 2004; Spence & Driver, 2004). Although such empirical arguments do not directly corroborate the principle of the cross-domain construction of singular files (Codicil 2 of Principle 4), they seem nonetheless to indicate that the multisensory synergies cited in Premise 1a contribute to the flexibility and robustness of perceptual tracking. Support for such a role for multisensory synergies is suggested by findings about endogenous or exogenous[25] attention along with crossmodal identification (Calvert, Brammer, & Iversen, 1998; Greene, Easton, & LaShell, 2001).

Consider the *endogenous* attention directed at a speaker. It has been shown that visual lip-reading improves our auditory capacity to recover linguistic information from the acoustic medium, and subsequently makes it easier to grasp the content of the perceived speech (Calvert et al., 1998; Reisberg, 1978). This improvement of perception of speech by lip-reading partakes in the perception of the speaker as a connected causal source, of which causal connectedness is retrieved despite differences in the visual and auditory signals.

Think now the phenomenon of dynamic attentional capture. The notion of *exogenous capture* of attention is an apparent truncation of a voluntary attentional search due to the presence of a distinctive attractor element (e.g., abrupt onset, new object) which 'pulls' attention to a specified individual or location. Thus, capture relates to an involuntary access to events or individuals that deserve attentional analysis due to their contextual saliency. Support for Premise 1a is that exogenous capture correlates with multisensory synergies and crossmodal spatio-temporal access (Calvert et al., 1998; Driver & Spence, 2004). Capture by one individual in one sensory modality is likely to facilitate overt and covert cognitive access to the same enduring individual in other modalities, and thus might facilitate the opening of a cross-domain singular file for tracking it.

Take the case of publicly observable bodily movements that usually follow attentional capture, which can be described as a form of *overt* attentional capture. If a heavy book falls from a table, it will collide with the flooring. The collision will cause an abrupt impact sound that operates as an alerting signal for any perceiver present in the surroundings of the impact. Typically, the dynamic acoustic event (bang, collision, explosion etc.) will elicit overt and multimodal orienting acts of attention. Those around will direct their attention to the location of the set of sound sources, through, for instance, saccadic eye movements (Findlay & Gilchrist, 2003), bodily orientation (Gibson, 1966; Van Opstal & Munoz, 2004), and they may perform defensive multimodal movements (Graziano, Gross, Taylor, &

Moore, 2004). Hence, certain salient events and individuals cause tracking responses guided by multisensory synergies.

This observation seems underpinned by experimental findings about the *covert* outcomes of exogenous capture. Experimental works with the *orthogonal cueing* paradigm developed by Driver and Spence (1998a, 1998b, 2004) indicate that multisensory priming and crossmodal links in exogenous spatial attention seem to occur even before any overt bodily motion, in a covert manner. Spatially non-predictive cues in one modality appear to attract covert attention towards its location in other sensory fields, not solely within the cued modality (e.g., Driver & Noesselt, 2008; Driver & Spence, 1998a, p. 255). For instance, abrupt sounds seem to 'attract' visual and tactile attention, rather than merely auditory attention. Although the relation of such crossmodal effects with attention remains debated (Calvert & Thesen, 2004; McDonald, Teder-Sälejärvi, & Ward, 2001), the evidence suggests that the capture of auditory attention in a given region of space facilitates the detection within the same particular region of space of events or individuals by other sensory modalities. Since the properties of each material individual are usually co-localized, this kind of crossmodal capacity is likely to facilitate the synchronic tracking of individuals across distinct sensory fields. Hence, this crossmodal effect is consistent with Premise 1a, and deserves to be discussed in connection with the problem of explaining how tracker overcome the heterogeneity of sources and methods in tracking.

The previous discussion suggests that endogeneous and exogeneous orienting of attention to a target place a tracker in a position to benefit from multisensory synergies, which in turn contribute to the tracker's cognitive access to the target's uniqueness, current spatio-temporal path and causally connectedness properties. Thus, multisensory synergies might ground the experience of continuity attached to the phenomenology of multimodal tracking—the multimodal transparency of perceptual experience.

Note that this analysis does not rule out that perceptual tracking could in some cases antedate, or run independently of conscious awareness. The multimodal transparency of experience is merely intended to describe a phenomenological fact, which is the conscious tracking of an individual that stimulate different modalities (e.g., a speaker, a lover or an artifact simultaneously touched, seen and heard). However, this phenomenological given does not exclude the psychological reality of pre-attentive tracking routines in sensory-motor systems, which could track an individual in absence of the perceiver's awareness of such tracking. For example, the exogenous capture of visual attention due to the auditory detection of a salient acoustic event depends on routines that track acoustic events and weight their saliency prior to any perceptual awareness of such events. Similarly, the normal control of human eye fixations requires that the gaze control system possesses short-term or long-term episodic information relative to the identity and location of the targets that must be fixated to complete the ongoing task (Henderson, 2003). If the gaze control system were capable of learning and using this episodic information in absence of conscious awareness of its use (Land et al., 1999), this would be evidence of a non-conscious form of tracking.

4. Attention, Cross-Domain Inferences, and Integrated Tracking

This section will focus on Premise 1b in support of the attentional flexibility hypothesis, which holds that a human tracker can use cross-domain inferences to track an individual. I will present (i) an argument from the blanks in unimodal perceptual information and (ii) an argument from the assembling function of conscious attention.

As for the first argument, the epistemic and learning power of cross-domain inferences is revealed by the way it contrasts to the limitations of sensory modalities considered in isolation from one another. I will develop this argument with regard to the specific case of audition, although it should apply to the analysis of other sensory modalities equally well.

Material objects and agents have physical or organic characteristics that determine their natural modes of vibration and, thereby, the acoustic patterns they radiate when placed in a situation to generate vibrations. The acoustic structure of a vibrating individual is potentially informative, therefore, of the individual's properties. If the information contained in the radiating acoustic waveforms can be detected and perceptually analyzed, then a listener can, in principle, hear and track properties of this individual.

Specifically, through listening, it is known that human auditory attention can pick up information on varied audible properties of material things.[26] Audition contributes to the identification and localization of sound sources and there is evidence indicating that the auditory cortex may be divided in a 'what' and 'where' systems specialized in identification and localization, respectively.[27] Audition localization can pick up spatial characteristics of the sound sources such as direction with respect to the listener's body and perhaps gross geometric[28] properties. Human auditory recognition can also extract information about material composition, mechanical activities and events,[29] and, when listened targets are human persons, audition can inform about voice, gender and linguistic phrases. Nearly everyone would therefore agree that audition can contribute to procedures of integrated tracking, and that some of our true beliefs depend on perceptual verifications performed by the means of attentive auditory tracking (see the principle of belief and power).

An eminent example of auditory tracking is found in medical practice. Through auscultation, physicians have routinely formed true beliefs about the diseases of their patients. Introduced by R. T. H. Laënnec (1819), the method of *indirect auscultation*, or '*auscultation médiate*', uses the stethoscope applied on the patient's chest for listening to different kinds of sounds associated with the activity of their voice, heart and lungs. Laënnec discovered the stethoscope and has written a seminal book (Laënnec, 1819) to describe the *inferences* and diagnostics that can be drawn from this method for tracking sound sources in patients' chest. Together with meticulously conducted anatomo-pathologic correlations, his method has changed the history of medicine by increasing the cognitive access to (invisible) functional components of the *living* human chest. Such a cognitive access has permitted better assessment of the health status of the heart and lungs and more insight into how illness might evolve (Duffin, 1998; Lachmund, 1999; Reynolds, 2004).

In accordance with the principle of belief and power (Principle 1), in a case of successful auscultation, the physician's true beliefs about the patient's diseases depend on strategies of auditory tracking of internal parts of the patient's body. However, the knowledge made explicit by the beliefs associated with the medical diagnostic is *not* purely auditory. Rather, as stated in the principle of cognitive flexibility (Principle 3), the medical diagnostic concludes a clinical investigation that relies on the cognitive flexibility between, namely, (1) the multisensory synchronic and cross-domain tracking of an individual (the patient), (2) the auditory tracking of organic activities internal to the patient's body, and (3) the epistemic and integrated tracking of causal relations among parts that explain the investigated pathology. Hence, the physician's auditory attention partakes in cross-domain and causal inferences about the patient's health status based on the coordination of the auditory tracking of organic sounds in the patient's chest and the cross-domain inferences. In harmony with the principle of attention files (Principle 4), it is plausible that such flexibility between heterogeneous information sources and tracking methods serve the integrated tracking of the patient and depends on the physician's ability to direct their cross-domain *attention* (Codicil 1, hypothesis of attentional flexibility) at the patient and update their mental *file* (Codicils 2 and 3) about the patient as a function of increase in causal knowledge.

The gap between integrated tracking of an individual as in clinical auscultation and pure auditory tracking is striking. In contrast to the cases in which cognitive flexibility between heterogeneous sources and methods is possible, pure audition would exhibit information blanks precluding the auditory tracker from performing integrated tracking. By *blanks* in available perceptual information, I refer to a set of non-specified variables or characteristics that are missing for completing integrated tracking because their absence renders the conveyed information incomplete or ambiguous.

Specifically, pure audition would present at least three fundamental information blanks. As a first limitation, pure auditory localization is frequently incomplete with respect to allocentric (environment-centered) frames of reference. Audition informs about source directions in ideal condition (anechoic chamber). However, perceiving directions with respect to an ego-centered frame of reference cannot be equated with perceiving source locations in environment-centered frames of reference. For directional information may lack distance information and this may prevent the perceiver from translating ego-centered information into an allocentric frame of reference. Moreover, estimation of the source location can be rendered difficult in environmental contexts by echoes and reverberations (Kubovy & Van Valkenburg, 2001) and the lack of information about surrounding silent (non-vibrating) material individuals. Second, while vision provides the tracker with cognitive access to individuals' located boundaries and surfaces, audition provides essentially dynamical information about the activities of sources and cannot directly inform about the precise location of objects' boundaries and surfaces (Kubovy & Van Valkenburg, 2001). Third, pure audition cannot guarantee access to evidence of the target's continued existence because an individual that ceases to vibrate and emit sounds tend to become 'absent' to the auditory sense. From these limitations, it results that the deliverances of pure auditory tracking are likely to present 'blanks' in auditory information relative to its targets unless this information is combined with information provided by complementary sensory modalities and cognitive resources.

In contrast to the conundrum of perceptually tracking an individual with a modality that presents information blanks (as in Matthew's mere auditory tracking of Mary's house in section 2), it becomes easier to understand the foundations of *integrated* tracking once the attentional flexibility hypothesis is adopted together with other codicils to the principle of attention files (Principle 4). The cross-domain explanation is that integrated tracking is highly dependent on *cross-domain inferences*, which result from the combination of information from multisensory perception or action, memory and tracking methods (e.g., indirect auscultation, procedures based on technologies). The power of cross-domain inferences is to supplement the presence of blanks in perceptual information through the use of information sources and tracking methods that can *reach beyond* present sensory information and trace invisible individuals or variables.

This can be illustrated, once again, with the example discussed in section 2: Matthew is conducting a phase of pure auditory tracking of sound events happening in the house next door, hears events such as a glass-breaking, and is then given a chance to visit and explore the house. On the basis of his multimodal experience combined with his episodic memory, Matthew can produce cross-domain inferences expressed by demonstrative identifications such as: 'this broken glass window is very likely the sound source I heard beforehand'. Multisensory synergies between the synchronic visual and auditory tracking of the window (considered independently of semantic and episodic memory) are not sufficient to explain Matthew's identification and causal understanding. This is because of the long temporal lag between the relevant auditory and the visual information deliverances. The explanation of his causal understanding is that he can search for the targets while keeping the descriptive features conveyed by the initial heard event in singular files and episodic memory. When he sees an individual that satisfies the descriptive features kept in his memory, he can then produce the cross-domain inference that the seen individual is likely to be the *same individual* as that which was heard in the initial sound event.

Of course, such a cross-domain inference is not immune to errors through misidentification or mislocation. However, based on the tracker's episodic memory of perceived individuals and events, this kind of cross-domain inference can allow an epistemic tracker to *supplement blanks* in perceptual information and to *re-construct* via reasoning *unperceived* properties, spatio-temporal paths and invisible causal histories of the targets. Hence, in accord with the principle of the cross-domain construction of files (Codicil 2 to Principle 4), cross-domain inferences should contribute to the updating of singular files and knowledge, and constitute the diachronic integrated tracking of the target individual. Moreover, in accord with the principle of invariance and change recording (Codicil 3), these inferences might allow the epistemic tracker to obtain information about the *invariant* causal properties of the target, detect *changes* in it and test predictions about its observable behavior. Overall, cross-domain inferences provide the tracker with *reasons* for believing true propositions relative to evidence and reasons for identifying and locating a target in a specific way (see the principle of belief and power), and therefore to make progress in strategies of integrated tracking.

As for the second argument, support for the use of cross-domain inferences in integrated tracking (Premise 1b) can also be found in research on consciousness. For cross-domain inferences may primarily depend on explicit procedures performed by conscious attention. For conscious awareness, alongside perhaps the possession of language (Carruthers, 2002; Mithen, 1996, 2005), seems to be required by tasks—such as integrated tracking—that demand durable information maintenance in a multimodal format necessary to novel and reflective combinations of contents. Specifically, the combinatorial and metacognitive (or metarepresentational) functions of conscious states can be hypothesized as required by cross-domain inferences.

A rationale for this view derives from the role of conscious states in cognitive or global access to information. It relates to *access consciousness* or conscious attention understood as a faculty of combining information available from different sensory modalities and mental resources.[30] As formerly discussed (section 2), a typical cross-domain inference in integrated tracking depends on strategies that assemble awareness of the current status of the tracking task with memorized information about the target. If the tracker's access consciousness has the function to bind awareness about the current status of the tracking task with information stored in different forms of memory, then it is likely to contribute to the performance of cross-domain inferences (and, subsequently, of integrated tracking).

This integrative approach to access consciousness is widely followed in the research on consciousness. The reason is that it seems difficult to account for the conscious mind merely in terms of modular and domain-specific processing. Conscious awareness is associated with executive attention and controlled procedures for acquiring information about individuals and acting upon them. Numerous theories share the hypothesis that controlled attentional procedures requires a specific functional architecture which goes beyond modularity and can establish flexible and reflective links among existing informational resources or inputs to control behavior (see the principle of cognitive flexibility).[31]

For instance, according to Dehaene and co-workers, conscious awareness is a *global workspace* understood as follows: "besides specialized processors, the architecture of the human brain also comprises a distributed neural system or 'workspace' with long-distance connectivity that can potentially interconnect multiple specialized brain areas in a coordinated, though variable manner"

(Dehaene & Naccache, 2001, p. 13). They suggest that the global workspace provides a large potential for the combination of multiple inputs, outputs, and internal systems. They suggest that at least different categories of systems must participate in the workspace such as perceptual circuits that inform about the present state of the environment, long term memory circuits, evaluation circuits, and attentional or top-down circuits that selectively determine the focus of interest.

The systems of attention seem to have a crucial role in the functioning of this notion of integrative consciousness since attention can be understood as the faculty that control the access of information in consciousness understood as a global workspace.[32] In this executive conception of attention, attention is required for information to enter consciousness *qua* global workspace.

Even if the consciousness *qua* integrative structure or global workspace is a necessary condition to cross-domain inferences, this fact is not sufficient to explain the workings of such inferences. To the best of my knowledge, cross-domain inferences have not been directly investigated *as such* in philosophy and cognitive science and, as a result, we do not have a systematic theory of their workings. However, as a suggestion for future research, such an understanding may be provided by a theory of working memory.

A hypothesis that deserves investigation is that cross-domain inferences serving integrated tracking are performed through the temporary combination of task-relevant information and meta-cognitive evaluation in working memory. This binding can be described by different models of working memory, whose relation to long-term memory remain debated (Baddeley, 2003; Ruchkin, Grafman, Cameron, & Berndt, 2003).

In the four-component model of working memory developed by Alan Baddeley (1986, 2000), the (newly added to the model) episodic buffer is relevant to account for cross-domain inferences.[33] The *episodic buffer* is a limited capacity system that provides temporary storage for information 'held in a multimodal code' (Baddeley, 2000, p. 421), which is capable of binding information from the subsidiary systems, and from long term memory, into a unitary episodic representation. Conscious awareness is assumed to be the principal 'mode of retrieval' from the episodic buffer. The buffer is therefore a functional structure that can carry out the multimodal assemblage required by cross-domain inferences, in order to update records of individuals (plausibly, singular files in the sense defined by Principle 4) that encode the identification and location information about the targets of integrated tracking. Baddeley even holds that 'the buffer is episodic in the sense that it holds episodes whereby information is integrated across space and potentially extended across time' (2000, p. 421).

Holding such episodes across space and over time seems to be a key, necessary condition to cross-domain inference for integrated tracking. It cannot be a sufficient condition because cross-domain inferences require meta-cognitive states that could account for the reflective evaluation of the epistemic value for integrated tracking of memorized content and awareness of the current action. The latter may be accounted for in procedural-executive accounts of meta-cognitive attention and working memory, such as in Shimamura's (2000) proposal, in which meta-cognitive control depends on the selection, maintenance, updating and rerouting of information.[34]

5. Caveats and Conclusion

One of the aims this article was to demonstrate the importance of studying *integrated* tracking. In addition to its intrinsic interest for understanding the human mind, the study of integrated tracking is critical as a bridge between the cognitive and social sciences because of the social and ethical issues attached to the integrated tracking of human persons. The specific aim of the article was to address the epistemological problem of heterogeneity of information sources and methods in integrated tracking. It has proposed the ETI theory in order to analyze integrated tracking in accordance with four epistemological and taxonomical principles, which develop a cross-domain view and formulate the hypothesis of attentional flexibility. An argument has been advanced to lend support to the hypothesis, which holds that at least two kinds of attentional systems are involved in integrated tracking: the guidance of attention by multisensory synergies and the engagement of conscious attention in cross-domain inferences. Even if the hypothesis of attentional flexibility is correct, further research remains to be carried out on tracking to specify the roles of culture, language and reasoning in integrated tracking, to determine whether integrated tracking is a uniquely human cognitive ability, and to develop a comprehensive taxonomy of tracking abilities and procedures in human and animal cognition.

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Notes

[1] In this formulation of the problem, the term *heterogeneous* refers to differences between *genera* of (1) specialized cognitive systems (or information sources) such as perceptual modules (Carruthers, 2006; Coltheart, 1999; Fodor, 1983), sensory-motor systems or memory systems (Schacter & Tulving, 1994); (2) domain-specific knowledge (Hirschfeld & Gelman, 1994) and (3) information provided by the use of distinct methods of tracking. The concept of *tracking method* refers to orderly procedures of identification and localization grounded in learned expertise, the application of scientific knowledge or of technological instruments. For instance, legal identification through Bertillon's system or Galton's system of fingerprints (see below, section 1), biometrical procedures of identification (see below,

section 1), localization through radar and satellite systems (see below, section 1) or auscultation (see section 4) are specific tracking methods.

[2] In a Kantian tradition, Strawson (1959) has notoriously described this unified scheme as follows: "I have suggested that the fact that material bodies are the basic particulars in our scheme can be deduced from the fact that our scheme is of a certain kind, viz. the scheme of a unified spatio-temporal system of one temporal and three spatial dimensions" (p. 62). The characteristics of the unified spatio-temporal system are also discussed, namely, by Campbell (1993), Evans (1982), and Quinton (1973, pp. 57–80, 1979).

[3] In the text, the term *allocentric* refers to a kind of spatial representation that locates places in a framework external to, and independent of, the position of the observer. On the distinction between ego-centered and allocentric spatial representation, see Bloom, Peterson, Nadel, and Garrett (1996), Newcombe and Huttenlocher (2000) and McNamara (2003), O'Keefe and Nadel (1978), and Paillard (1991).

[4] For a philosophical discussion of this point, see Evans (1982) and the debate between McDowell (1990) and Peacocke (1983, 1991); for empirical evidence on this kind of flexibility in human spatial cognition, see, e.g., Hermer-Vazquez, Spelke, and Katsnelson (1999).

[5] On spatial representation, see Eilan, McCarth, and Brewer (1993), Newcombe and Huttenlocher (2000), and O'Keefe and Nadel (1978); on spatial representation and language, see Bloom et al. (1996), Hermer-Vazquez, Moffet, and Munkholm (2001), Hermer-Vazquez et al. (1999), and Landau and Jackendoff (1993).

[6] See, e.g., Gattis (2001).

[7] For epistemological analyses of the conditions in which perception may provide *reasons* to believe, see, namely, Brewer (1999), Dretske (1969, 1995, 2000), Markie (2005, 2006).

[8] On the notion of truth makers, see Mulligan, Simons, and Smith (1984).

[9] On philosophical ontology or metaphysics, see, e.g., Gaifman (1975), Quine (1960, 1969), or Strawson (1959).

[10] Pylyshyn (2007) holds that the capacity to individuate and track several independently moving things is accomplished by a mechanism in the early vision module that he calls FINSTs (for "FINgers of INSTantiation"), which functions to track 'visual objects' or 'FINGS'. Pylyshyn holds that FINSTs 'attach to' 'FINGS' through a non-conceptual and causal link but admit that cognitive science has not already completed the task of specifying the ontology of FINGS (see Pylyshyn, 2007, pp. 94–98). If his analysis is correct in the terms of Principle 2, it means that visual FINSTs have a non-conceptual 'ontological commitment', which is to select and refer to FINGS.

[11] See Bullot and Droulez (2008), Ganea, Shutts, Spelke, and DeLoache (2007), and Strawson (1959).

[12] Perceptual-motor tracking is studied namely in experimental psychology (e.g., Adams, 1961; Cavanagh & Alvarez, 2005; Craik, 1947; Poulton, 1952; Pylyshyn & Storm, 1988) and the philosophy of demonstrative identification (e.g., Evans, 1982; McDowell, 1990; Peacocke, 1991).

[13] I use the concept of episodic memory in Tulving's sense (Schacter & Tulving, 1994; Tulving, 2002).

[14] See, e.g., Gibson (1979) or Warren, Kay, Zosh, Duchon, and Sahuc (2001).

[15] This ability to perceive and locate one individual as the same (and distinct from all other individuals) is a form of demonstrative identification in Gareth Evans' sense (1982, pp. 143–203). In his analysis, demonstrative identification depends on the perceptual and conceptual grasp of the properties that distinguish the target object from all other objects of the same kind. This is what Evans (1982, p. 107) terms the *fundamental ground of difference* of that particular individual, which is reminiscent of Leibniz's Principle of the Identity of Indiscernibles (Hacking, 1975; Leibniz, 1764/1916). A *fundamental identification* in Evans' sense is that which correctly attributes a fundamental ground of difference to an individual.

A fundamental identification of a material individual (e.g., a perceptual-demonstrative identification) is a form of *integrated tracking* of an individual because it combines perceptual with epistemic tracking (e.g., deploying the recognitional concept that this individual is your mother and connecting her with a memorized history and some expected future).

[16] This argument for this view has its origin in the psychology of vision (Kahneman, Treisman, & Gibbs, 1992; Pylyshyn, 2007; Treisman, 1988, 1996); it is adopted in distinct versions by several philosophers (Campbell, 2002; Clark, 2000, 2004; Matthen, 2005).

[17] The view that the human brain is predominantly visual may be found, under different guises, in Kosslyn (1994), Milner and Goodale (1995), Posner (1994), Pylyshyn (2007) along related philosophical works by Campbell (2002), Dretske (1969), Gendler and Hawthorne (2006), Jacob and Jeannerod (2003), and Matthen (2005).

[18] This view is expressed by Campbell (2002, pp. 63–64, 115–116) and Matthen (2005, pp. 282–289, in press); other authors, such as Quinton (1979), hold similar views.

[19] In the present text, I use the adjective 'pure' as a qualification of a particular sensory modality (i.e., a presumed uni-modal perceptual system) to indicate that the sensory modality is conceived of in isolation of other sensory modalities, for instance because it is conceived of as a domain-specific module (Coltheart, 1999; Fodor, 1983). The concept of a pure sensory system is problematic and the notions of 'sense' or 'sensory modality' are especially difficult to characterize. This difficulty has been a long-lasting concern for philosophers (e.g., Keeley, 2002; Nelkin, 1990; Roxbee-Cox, 1970), psychologists (Driver & Spence, 1998b; Gibson, 1966; Shimojo & Shams, 2001; Stoffregen & Bardy, 2001) and neuroscientists (Calvert, Spence, & Stein, 2004; Churchland, Ramachandran, & Sejnowski, 1994).

[20] For an experimental study of a task of epistemic tracking of invisible individuals in which subjects must ascribe and update current status predicates, see Bullot and Droulez (2008).

[21] As a cognitive function of the faculty of language may be to endow a tracker with cross-domain thinking and cognitive flexibility (Carruthers, 2002; Hauser, Chomsky, & Fitch, 2002; Hermer-Vazquez et al., 1999; Mithen, 1996), the possession of language may determine the capacity to perform the integrative tracking of individuals. This hypothesis could justify the intuition that sophisticated forms of integrated tracking are uniquely human. I cannot assess this issue in the limited space of the present article, which focus on the role of attention in integrated tracking.

[22] Here *recalibrate* refers to adjustments performed by the brain to compensate for delays or discrepancies among inputs of distinct sensory modalities and, subsequently, to track the spatio-temporal congruency of physical events or individuals. For instance, detecting the simultaneity of two events across separate sensory channels is a challenge for the brain in audiovisual integration because the temporal congruency at the source of an audiovisual event is polluted by delays in the physical and neural transmission of signals. See, e.g., Fujisaki, Shimojo, Kashino, and Nishida (2004); Vroomen, Keetels, and De Gelder (2004).

[23] Introductions to the philosophical debates about transparency are found, namely, in Campbell (2002), Gendler and Hawthorne (2006), Harman (1990), and Martin (2002).

[24] Campbell (1993, 1995) has proposed to analyze objects or persons as individuals possessing causal connectedness; see also Cassam (1997) for a discussion of Campbell's proposal.

[25] It has long been described by phenomenological analyses that attention can undergo voluntary and involuntary shifts (see Hatfield, 1998, p. 10, for an historical overview). This has led to the distinction between (i) automatic or reflex and (ii) voluntary attention within various lexical idioms. See James (1890, pp. 416–417), Titchener (1899), or Wundt (1896/1897, pp. 217–218). Experimental cognitive sciences also bring this distinction into play, but use the phrases *exogenous attention* and *endogenous attention* respectively (e.g., Driver & Spence, 1998a, 2004, p. 189; Jones, 2001; Spence, 2001).

[26] See Bregman (1990), Handel (1995), McAdams (2000), McAdams and Bigand (1993).

[27] Alain, Arnott, Hevenor, Graham, and Grady (2001), Arnott, Binns, Grady, and Alain (2004), Clarke et al. (2002), Kubovy and Van Valkenburg (2001).

[28] Kunkler-Peck and Turvey (2000), Lakatos, McAdams, and Caussé (1997).

[29] Audition can inform on events such as vibrations between solids (e.g., scraping, rolling), motions of gases (e.g., exploding balloons, wind), and impacts involving liquids (e.g., splashing or pouring).

[30] The argument is thus about what Block (1995, 2001) and others term *access consciousness* in contrast to *phenomenal consciousness*; the argument presented in the text is neutral with regard to the debates about *phenomenal consciousness*, and focuses on access consciousness (supra-modal and global accessibility) and reflective consciousness (a special kind of access in which a conscious mental state—e.g., a state of episodic memory—is the object of another state).

[31] Posner (1994), Schneider and Shiffrin (1977), Shallice (1988).

[32] The workspace model of consciousness has been introduced by Baars (1988)—see also Baars (1997) and Baars, Banks, and Newman (2003)—and is currently developed by Dehaene and his colleagues (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Dehaene & Naccache, 2001, p. 14). Numerous theories are compatible with the hypothesis of consciousness as an integrative structure; see, namely, Damasio (2000), Dennett (1991), LaBerge (1997), Lycan (1995), Singer (2001), or Tulving (1985).

[33] Another reference includes Abeles and Morton (2000).

[34] For similar approaches to metacognition, see also Fernandez-Duque, Baird, and Posner (2000), Metcalfe and Shimamura (1994), and Proust (2007).

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