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A Navigation Analysis Tool (NAT) to assess spatial behavior in open-field and structured mazes

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HIGHLIGHTS

- Novel analysis tool probing spatial behavior in open-field and structured mazes.
- Multi-parametric analysis of goal-oriented navigation and decision making policy.
- Wide range of protocols and data managed within the same relational database.
- Unified view through observations from multiple spatial navigation paradigms.
- Results on the ability of mice to learn the Morris watermaze and the starmaze tasks.

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ABSTRACT

Spatial navigation calls upon mnemonic capabilities (e.g. remembering the location of a rewarding site) as well as adaptive motor control (e.g. fine tuning of the trajectory according to the ongoing sensory context). To study this complex process by means of behavioral measurements it is necessary to quantify a large set of meaningful parameters on multiple time scales (from milliseconds to several minutes), and to compare them across different paradigms. Moreover, the issue of automating the behavioral analysis is critical to cope with the consequent computational load and the sophistication of the measurements. We developed a general purpose Navigation Analysis Tool (NAT) that provides an integrated architecture consisting of a data management system (implemented in MySQL), a core analysis toolbox (in MATLAB), and a graphical user interface (in JAVA). Its extensive characterization of trajectories over time, from exploratory behavior to goal-oriented navigation with decision points using a wide range of parameters, makes NAT a powerful analysis tool. In particular, NAT supplies a new set of specific measurements assessing performances in multiple intersection mazes and allowing navigation strategies to be discriminated (e.g. in the starmaze). Its user interface enables easy use while its modular organization provides many opportunities of extension and customization. Importantly, the portability of NAT to any type of maze and environment extends its exploitation far beyond the field of spatial navigation.

1. Introduction

Spatial navigation is a manifold process whose dynamics depend on a wide range of competitive and/or cooperative mechanisms (see Arleo and Rondi-Reig, 2007, for a review). Dissecting spatial behavior into its elementary components is instrumental, for instance, to correlate single neuron activity to specific behavioral patterns (e.g. Whitlock et al., 2012), and then to infer novel anatomo-functional properties based on causal animal–environment interactions. Analyzing spatial behavior can also help to elucidate the link between specific neuronal adaptation deficits (e.g. lack of synaptic plasticity in transgenic animals) and subtle goal-oriented navigation impairments (e.g. Rondi-Reig et al., 2001; Burguière et al., 2005; Rochefort et al., 2011).

Meaningful accounts of spatial behavior require multi-parameter analysis of large experimental datasets. Also, the ability to bind observations across multiple spatial learning tasks (which produce heterogeneous data in terms of performance indicators, protocols, maze shapes, and task complexity) is a necessary condition toward a unified view of the mechanisms underpinning spatial cognition. During the last decades, these considerations have given rise to a substantial effort to conceive automated analysis tools

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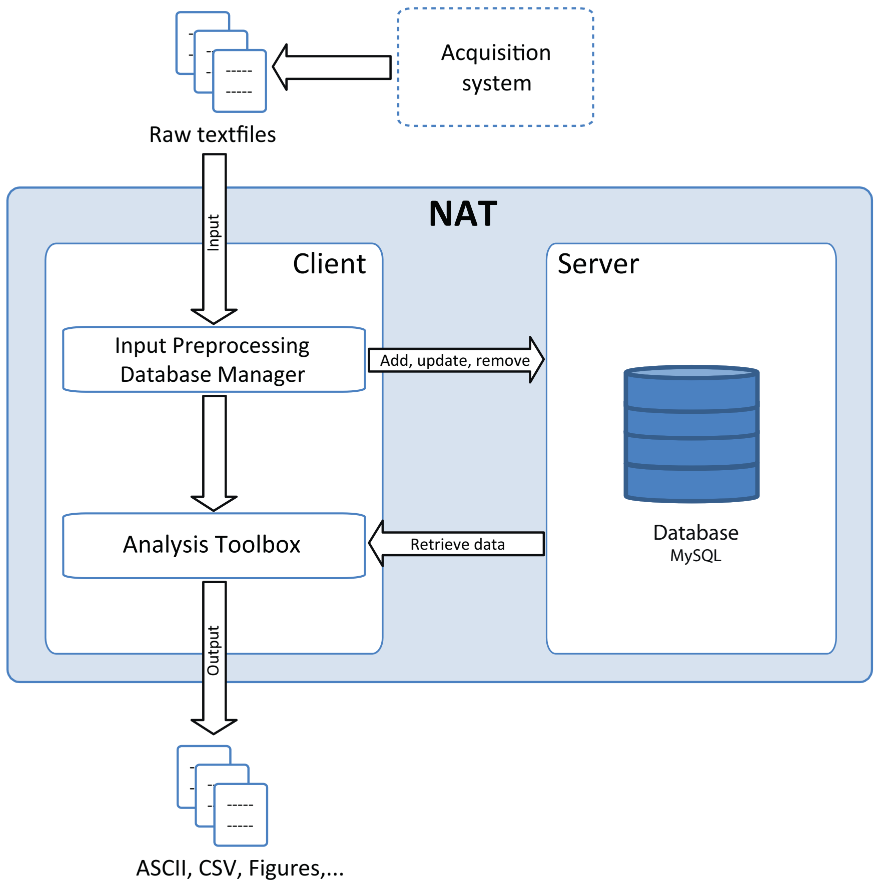

Fig. 1. NAT overview. NAT consists of a client/server architecture. On the client side, a first module allows the experimenter to preprocess and import recorded data, whereas a second module (in MATLAB) implements the behavioral parametric analysis. On the server side, a MySQL relational database allows large sets of behavioral recordings to be stored and managed. A graphical user interface (in JAVA) assists the experimenter throughout the entire database managing and analysis process.

and data management systems (e.g. Bradley et al., 2005; Drai and Golani, 2001; Wolfer and Lipp, 1992; see Section 4 for a Discussion on existing solutions).

This paper presents a Navigation Analysis Tool (NAT) that was explicitly designed to cope with large behavioral datasets, and to draw coherent interpretations across multiple spatial learning tasks (e.g. involving both open-field and structured mazes). NAT provides an extended parameter space to characterize spatial behavior quantitatively, with a focus on goal-directed navigation and decision point analysis. It offers a flexible and easy-to-use tool aimed at benchmarking the analysis of spatial navigation data. The rationale behind the development of NAT is indeed to provide a standardized analysis framework to study learning and memory in the case of spatial navigation. NAT is released as open source software under the CeCILL license (compatible with GNU GPL), and it can be downloaded from the Plume web site www.projet-plume.org/en (see also the Supplementary User Guide).

In the following, we first describe the main features of NAT, which include information processing and management, and statistical behavioral analysis. We then provide a series of results obtained by applying NAT to quantify the spatial behavior of mice in two navigation tasks, namely the watermaze (Morris et al., 1982; Morris, 1981) and the starmaze (Rondi-Reig et al., 2006).

2. Materials and methods

NAT has a modular environment based on a client/server architecture (Fig. 1). On the client side, a graphical user interface (implemented in JAVA) helps the experimenter throughout the entire analysis process, which is mediated by two primary modules. First, the 'Input preprocessing and database manager' module allows behavioral recordings from an acquisition system to be preprocessed and imported into NAT (Section 2.1). Second, the 'Statistical analysis toolbox' (implemented in MATLAB) allows the experimenter to execute a set of parametric measurements to characterize spatial navigation performance (Section 2.2). The results of these parametric measures form the output of NAT (Fig. 1), which can be used for additional analyses (e.g. statistical significance). On the server side, a relational database (implemented in MySQL) provides an information management solution for storing large ensembles of behavioral data. It also allows specialized analysis software (e.g. MATLAB) to easily connect to and interact with the NAT base of knowledge.

2.1. Input preprocessing and database manager

For each experimental trial, NAT expects a text file containing (i) a time series of the positions visited by the animal $\{t, x(t), y(t)\}$ (where $x(t), y(t)$ denote the Cartesian coordinates of the barycenter of the body), and (ii) a numerical identifier for the subject. The format of the input data stream processed by NAT is described in the Supplementary User Guide, Sec. 2b.

2.1.1. Preprocessing and artifact correction

Video tracking systems can occasionally produce spurious data that lead to incongruent measures of the spatial coordinates of the animal over time. These artifacts can ultimately bias the evaluation