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The Psycho*Models* Database – Facilitating the Exchange of Formal Models

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Abstract: In this article, we address the fragmented landscape of formal model sharing in psychological science by introducing Psycho*Models*, an online repository for improving models' accessibility, reusability, and interoperability. Psychological research often relies on idiosyncratic approaches for model documentation and communication, which hampers transparency, limits reuse, and stifles collaborative growth. Inspired by successful repositories in other academic fields, Psycho*Models* aims to be a central platform where mathematical and computational models are stored, indexed, and described following FAIR principles (Findable, Accessible, Interoperable, Reusable). The platform will enable structured searches of models by discipline, framework, and language, thus enhancing discoverability by both novice and expert users. Moreover, Psycho*Models* can emphasize ease of use through detailed model annotations, implementation guidelines, and links to external resources, bridging the gap between theory and application. Through the stimulation of community-driven peer review and model-sharing standards, Psycho*Models* will aspire to enhance reproducibility and foster a collaborative ecosystem within psychological modelling. In this article, we explain the philosophy behind Psycho*Models*, demonstrate the application of the database's preliminary version, and present plans for future development.

Keywords: formal models, database, model sharing, open science

In recent years, there has been increasing interest in theory construction in psychological science (Borsboom et al., 2021; Forstmann et al., 2011). Theories in psychology usually take a verbal form, making it hard to draw clear and precise predictions from these theories. When it is ambiguous which predictions to draw from your theory, actual testing with the intent to falsify becomes harder as well. Post hoc explanations are easily found in verbal theories, especially in what they leave implicit. To explicate and test theories, it has been suggested to express them as formal models (Guest & Martin, 2021; Haslbeck et al., 2022; van Rooij & Baggio, 2021).

Some subdisciplines of psychology have a long tradition in formal accounts of psychological processes, such as mathematical psychology (cf. Navarro, 2021) and cognitive psychology (e.g., de Hollander et al., 2016). However, formal modelling is not an established practice in the wider psychological research community. In part as a result of this, psychology lacks systematic approaches to document and share formal models. As a consequence, modelling is an idiographic enterprise, with each practitioner having personal preferences regarding coding, annotating, storing, and communicating their models. Thus, formal models in psychology are seldom FAIR (Findable, Accessible, Interoperable, and Reproducible; van Lissa et al., 2025). Apart from the fact that idiosyncratic storage and sharing methods are not conducive to the scientific process itself, this situation also hinders the development of modelling skills among psychologists, as a psychological scientist who aims to develop such skills has few resources to access existing models.

We are not the first to signal these problems. Accordingly, in various subdisciplines of psychology, there have been efforts to create collections of models or theories that address the need for adequate storage and documentation. A prime example is catlearn, a collection of formal models of categorization and associative learning (Wills et al., 2017) implemented as an R package. The collection of models is curated, checked for reproducibility, and well-documented. A similar example is the ontology-based collection of behavior change theories by Hale et al. (2020), presenting a detailed overview of different theories and relating them based on ontological relations between their constructs. Beyond collections of models, there has been increasing effort to unify models and establish an account of empirical evidence, notably within working memory research (Oberauer et al., 2018). This project collected a series of well-established effects from working memory research to establish benchmarks for model development. The need for a theory/model databases has been pointed out by the editors of this topical issue before Glöckner et al. (2018).

However, despite these efforts, psychology lacks a central repository or collection of models across the full breadth of the discipline, as is common in several other disciplines. Examples of such databases include *PhysioNet* in the health sciences, *CoMSES* in the social sciences, and *BioModels* in biochemistry. For instance, *PhysioNet* (Goldberger et al., 2000) is a platform that curates datasets and analysis software for physiological signals, as well as offering expert guidance on the analysis of health data and physiological signals, ranging from basic to translational research. *CoMSES* (Janssen et al., 2008) presents an example of a structured approach of sharing computational, mostly agent-based models in a community for reuse and educational purposes. This database contains models described within the *ODD protocol* (Overview, Design concept, Details; Grimm et al., 2006), ensuring reproducibility and unified model entries; the database website also offers resources around relevant skills for software development, e.g., containerization and an educational forum for the community. Finally, *BioModels* (Malik-Sheriff et al., 2020) is a repository for computational models of biological and biomedical processes containing curated and noncurated models, with the former being thoroughly reviewed for reproducibility and adherence to the reported results in each associated paper. A notable feature of BioModels is their model indexing, based on e.g., the biological model parameters or the modelling approach.

Taking inspiration from these databases in other fields, we introduce a database to store and share psychological models: Psycho*Models*. Psycho*Models* is an online database that allows users to find mathematical and computational models created for psychological research and theory construction. A simple model ontology ensures an organizational structure that makes the database easily parsable by laypeople. Finally, educational material attached to the database should enable any interested psychologists to use these models irrespective of their modelling experience. The general aim of Psycho*Models* is to improve the usability of formal models in psychological science through FAIR indexing with automatic metadata, minimal descriptive information for formal models in psychology, and community engagement in populating the database. To this end, the database will include model descriptions, links to publications and code repositories, details on implementation such as software versions, and a peer-review system to discuss the model entries. In addition, we aim to unify existing approaches in our database by indexing existing model collections such as catlearn in our database, incorporating a similar approach to Hale et al. (2020) in how we represent our models, and including empirical evidence similar to the benchmarks in Oberauer et al. (2018) in an extension of our database.

In this article, we explain the philosophy behind Psycho*Models*, describe the features of the current but preliminary version, and demonstrate an existing use case. We conclude the article with a discussion of future development of Psycho*Models*.

Introducing Psycho*Models*

With Psycho*Models*, we aim to introduce a platform that facilitates access to and communication about formal models in psychological science. Psychological science has a rich tradition of empirical research and data analysis. In this age of collaborative and open science, it is regarded that scientific data should follow the FAIR principles (Wilkinson et al., 2016): data must be (a) findable, (b) accessible, (c) interoperable, and (d) reusable. These guidelines set standards for data stewardship. In psychological science, these principles currently pertain to data from empirical research, where adherence to the principles has been incorporated into the broader endeavor of scientific reform toward more transparent and reproducible research. However, theoretical and methodological practice is currently excluded. There is a growing interest in theory development (Borsboom et al., 2021; Forstmann et al., 2011) and specifying theories as mathematical or computational models (Guest & Martin, 2021; Haslbeck et al., 2022; van Rooij & Baggio, 2021).

Furthermore, (cognitive) modelling in general is currently somewhat excluded from the open science movement (cf. Lee et al., 2019; Szollosi et al., 2020). Other fields have a stronger tradition of sharing models and fostering a common language for expressing and communicating models (e.g., theoretical ecology, economy). In psychological science, there are a plethora of models and areas with rich modelling traditions (e.g., mathematical psychology, psychometrics). We, and the people we came into contact with during this project, believe that the theoretical and measurement models—developed to support empirical research and explain its findings—should also be made to adhere to the FAIR principles. To make this a reality, we have created the Psycho*Models* database.

Psycho*Models* Philosophy: Making Models FAIR

In the following, we will present the design ideals for our database, then introduce the current online version, and finally sketch out the next steps for further development.

Findability

Similarly to existing publication databases (e.g., Google Scholar) and data repositories (see the American Psychological Association's Links to data sets and repositories), we intend to create a database where models would be easily findable. Currently, models are part of published research output, meaning a researcher would have to go through full research records. A dedicated database will make specific models easier to access, while allowing for indexing of relevant aspects, such as discipline, modelling framework, or programming language.

Accessibility

Psycho*Models* addresses accessibility as the entries contain an overview of the purpose of the model, the substantive context of a model, such as the empirical variables that are captured, and methodological details of the implementation. This allows for fine-grained navigation of particular models and provides a general overview of modelling practices in particular research areas. More detailed information as well as repositories that contain e.g., code or data can then be found under the link to the original publication.

Thus, Psycho*Models* serves as a repository that provides both a quick substantive overview and links to full records of the models' implementations.

Interoperability

Due to its complexity, a higher degree of interoperability is currently not feasible. What Psycho*Models* does offer is a helpful step forward. In the current version, entries show software requirements indicating how users and software applications can use models in the database. Currently, disclosing a model's software requirements is not the default in journal publications, putting them at risk with every software update.

We aim for this central database to facilitate moving toward common standards in this regard. We encourage peer review on entries in the database and invite an open conversation on sharing principles to converge to interoperability standards that can be crystallized within the database at a later stage. Further considerations are discussed in the "Conclusion" section.

Search Interface and Its Features

Psycho*Models* can be found at https://psychomodels.org, and readers are encouraged to check out all present functionality. There are two central pages of the current database: the model search page and the model details page for each entry. The search page can be found under the menu item "Explore the Models." Here, users find an overview of the model entries and can browse the database through filters and search queries.

Figure 1 shows a screenshot of the interface, which has three important parts to it.

The search bar on top enables full-text search over the entire database and presents all matching search results (Box 2). For specific in-/exclusion of particular categories, the filters on the left allow users to specify criteria the models should adhere to (Box 1).

Centrally on the page, the search results are presented either as tiles that show a short summary of the model or a table (Box 3).

When users click on one of the models, they move to that model's page where it is presented in detail. We will be using the "Computational Model of Panic Disorder (Robinaugh et al., 2019) as an example in the following section. The user may find this model either on the front page or through using the "Explore the models" tab.

Model Details — Computational Model of Panic Disorder

We present the Model Details page by demonstrating an existing use case. The model of choice is the *Computational Model of Panic Disorder* by Robinaugh et al. (2019), a system of differential equations that aims to formalize existing theoretical models on anxiety and panic responses (e.g., Barlow, 2002; Clark, 1986). A screenshot of the entry on the website can be seen in Figure 2. On the Model Details page, the user sees a short summary at the top. This gives users a short overview of the purpose the model serves and the context in which it operates (akin to an abstract of a research paper). In the case of the Computational Model of Panic Disorder, this description includes the type of model, an introduction to panic attacks, and several key elements the model explains. The database provides headers to help users out, but an actual formal template of how to describe your model is not given. We may guide users, but we believe that model description are also something that needs to grow naturally. Users may

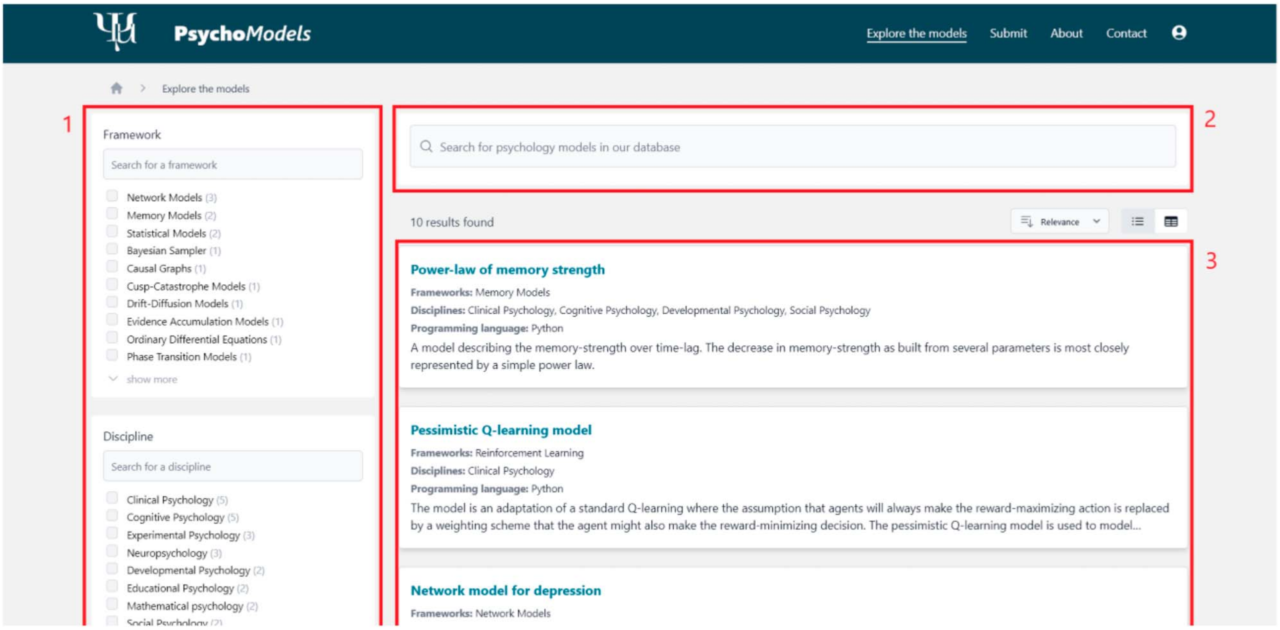

Figure 1. This screenshot shows the model search page of PsychoModels, highlighting the three components that are categorical filters (Box 1), a free-text search bar (Box 2), and the overview of fitting search results (Box 3).

latch onto other entries that they like and copy the style in their own entries.

Below the summary, the user finds several methodological details on the model implementation: First, several modelling frameworks (Figure 2, block 2) to which the model belongs. The model frameworks are an ontological feature of our database that captures the general methodological class or family of a model. Frameworks as a concept may capture either a general methodological approach (e.g., differential equation, agent-based modelling) as well as a certain model tradition (e.g., evidence accumulation models, Lotka–Volterra type models). Frameworks can be nested (e.g., the Ising model is a framework nested in network models, as it is a particular type of network model) and models can be part of more than one framework. For the panic model, we have three entries here: (a) most general, a network model as the model treats the symptoms as interrelated components; (b) more specifically a causal graph (which is a child framework of the network model) because we assume a specific causal influence between the symptoms; and (c) a differential equations model, as the causal influences are expressed in the form of differential equations.

Below the frameworks, a text box outlines how the model works (Block 3 of Figure 2). Here, the operation of the model is described in as much detail as is necessary to understand how the model operates and how to replicate it. The submission system allows the user to express this in verbal terms, mathematical equations (LaTeX format), or (pseudo-)code blocks that describe an algorithmic process. In the case of the Panic model, all differential equations used to run the model are presented.

Near the bottom of the page, the variables of the model are presented (Block 4 of Figure 2). We use a definition of "variable" that deviates slightly from its conventional use. We see variables as the components (objects) of a model that relate to what is (potentially) measurable or observable in empirical research (behavior, physiological responses, diagnostic outcomes, self-report items, etc.) and would thus be expressed as a variable in a dataset of such research. Thus, these variables do not necessarily have to vary or be variable in the model. Under our definition, parameters in the model with a fixed value could also be identified as a variable. For the panic model, the variables are arousal, avoidance behavior, escape behavior, perceived threat, arousal schema, and escape schema, as well as context features. Each variable is assigned a name, a short description, and a label, which indicates how it is identified in the model.

Variables can be present in more than one model, for instance, the same symptoms of depression can be present in two or more models concerning this or another mental illness. Between these models, the labels of the variable (how they are identified/coded in the model) might be different, but their names and descriptions are the same. In this way, variables can span as topical networks throughout models in the database. In this sense, they can also be used as characteristics on which

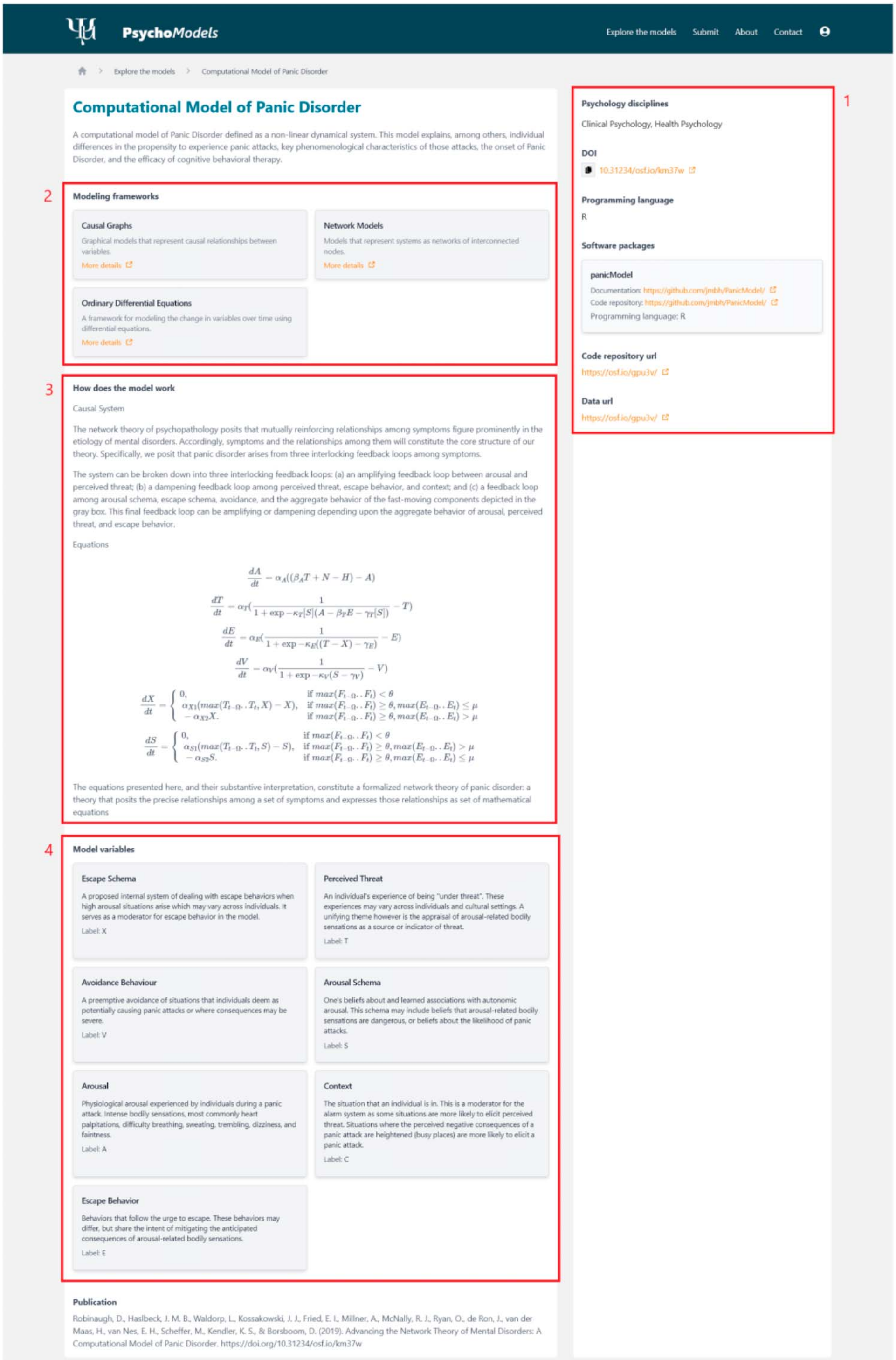

Figure 2. Screenshot showing an example of a model detail page, using the Computational Model of Panic Disorder (Robinaugh et al., 2019). The Boxes highlight different features: (Box 1) external resources, (Box 2) the modelling frameworks, (Box 3) a detailed description of how the model works, and (Box 4) the psychological variables pertaining to the model.

models can be searched and filtered. For instance, users could search for all models that contain avoidance behavior as a variable. If a variable is added to a model, it will contain model-specific details on how it is referred to or used in the context of this model. As such, every variable has two identifications, a general *name* and a model-specific label. In our example, each variable is assigned a name that makes it identifiable across models and a label with which each variable is referenced in the equations, as well as the descriptions of the variables as they are present in the model publication (Robinaugh et al., 2019).

On the right side of the page, in Block 1, the user sees the meta-information of the model. It contains a link to the original publication, software details on the programming language and central software packages used, and links to code and data repositories. The left side of the page concerns the mechanics of the model, and the right side of the page provides the user with the sources to (re)use the model. For the panic model, there is a custom library for the R programming language, links to the code repository, and its documentation are both provided.

Finally, at the bottom of the page, the full reference to the original publication is added. It is often difficult to demarcate models as distinct from each other instead of different versions of the same model. We follow the practice of BioModels where a model is characterized by a unique publication identifier (Le Novère, 2006; Le Novère et al., 2005).

Conclusion

Psycho*Models* is a database that encourages sharing, reusing, and extending computational implementations of formal models in psychology. Through creating a platform designed for the exchange of models and their supporting empirical evidence, placing it within the context-related work, mathematical and computational modelling can follow the FAIR principles (Wilkinson et al., 2016): (a) findable, (b) accessible, (c) interoperable, and (d) reusable. Thus promoting the nurturing and further development of modelling practices in psychological science.

We envision five avenues for future developments of Psycho*Models*. The first is to directly improve the usability of the site. As the database is currently still under development, some key aspects are to be developed in the near future. We aim for a community-driven database in which peer review is used to see which models are interesting, while inclusion on the website is very open. At this stage, however, the developers serve as moderators for new models that are uploaded. This mostly entails common-sense checks. Additionally, the intended peer-review system on the database will aid with checking whether FAIR-principles are met. Reviewers may comment, for example, on the reusability of code, the correctness of mathematical descriptions, or the interpretability of model descriptions.

The second is to collaborate on codifying model-sharing standards for psychology that bring more clarity to the research community. Creating a concrete protocol will aid the further development of the platform, potentially resulting in a custom file format that encodes metadata in a machine-readable way. We could provide templates for this or, alternatively, an advanced interface could be developed to enable the direct creation of new models on Psycho*Models*.

Third, our objective is to facilitate community building around Psycho*Models* by implementing features that enable direct communication, collaboration, and possibly using the platform for model development. This could include a wiki-like collaboration tool, allowing users to contribute and refine existing models in the database. If there is interest from the community, we are also open to developing an API to further support integration with the platform.

Fourth, we would like to explore the possibilities of an online integrated environment where users can develop, experiment, and test models without having to install the required software on their own computer. Numerous online integrated development environments for general programming tasks already provide the tools to write, run, debug, and collaborate on code directly in a web browser. Examples of these are "Replit" and "JSfiddle." Having a similar tool for Psycho*Models* would greatly simplify developing, trying out, and collaborating on models. As mentioned earlier in the section on Interoperability, ensuring software runs seamlessly across platforms is challenging.

However, recent advancements in containerization are making this increasingly manageable. While it may not be feasible to create a fully comprehensive solution, we can begin by focusing on the most commonly used programming platforms, such as Python and R.

Finally, our goal is to develop and integrate related platforms for other areas of formal research processes (cf. the *Theory Construction Methodology*, Borsboom et al., 2021), such as collecting established psychological phenomena (Psycho*Facts*), as well as existing verbal theories that can be formalized in models (Psycho*Theories*). These platforms should also connect modelers with more empirically inclined researchers with deep domain expertise.

In conclusion, Psycho*Models*, when more widely adopted and developed, has the potential to nurture modeling practices, augment traditional publication formats, supplement open-source practices, and reduce communication thresholds between theoretical and empirical psychologists.

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