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System dynamics simulations for data-intensive applications

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ABSTRACT

Simulation modeling is increasingly perceived as a methodological asset to the field of data science. Nonetheless, adequate graphical database interfaces are missing especially for most System Dynamics (SD) simulation tools. SimSyn is freely available middleware used to link together models developed in VENSIM with a PostgreSQL database for spanning SD models over geographic or multi-dimensional parameter space. The capabilities of SimSyn are demonstrated by simulating terrestrial carbon storage for 10,000 years on a 5 arc-min raster mesh with 278,115 grid cells. Results indicated the reasonable performance of data-linked simulations (7, 500 to 10,000 runs per 15 min) and a considerable increase of computational overheads associated with additional time series inputs. Apart from increasing performance, the incorporation of SD interoperability standards is a key objective for the further development of SimSyn.

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Software availability

Name of software: SimSyn
Developer: Christian Neuwirth
Download: https://github.com/simsynser/SimSyn
Year first available: 2017
Software required: Vensim PLE, PostgreSQL, Windows OS
Program language: Python
Program size: 216 MB (executable file)
Availability and cost: Open source

1. Introduction

Ideally, sophisticated simulation tools should be able to handle the inputting of large datasets of different type. The need for such functionality is growing due to a *"massive increase in the availability of informative social science data* (King, 2011)" and environmental data (Lokers et al., 2016). While traditional techniques of data analysis are largely confined to variants of statistical summary, categorization and inference; data analysts may seek to add simulation techniques to their toolbox as the field of data science matures (Houghton and Siegel, 2015). In the traditionally 'data-poor' discipline of System Dynamics (SD) modeling (Pruyt et al., 2014), specialized tools have yet to be developed. The key objective of this ongoing work is to extend the set of data categories and scales exploitable by traditional SD process simulations.

Essential data categories include time series, lookups and subscripts. The use of subscripts refers to the assignment of model parameter values to configure different model parameterizations. This approach is typically used to show many alternative futures, to span uncertainty space (Pruyt et al., 2014) or for spatial replication of model structures.

The coupling of simulation tools to specialized database software for sophisticated digital archiving, querying and analysis of input and output data is a highly plausible approach for running this type of simulation. Up to now, this is not entirely supported by appropriate database interfaces in standard SD software. Whereas the input of time series or lookups is enabled by ODBC in the proprietary DSS version of VENSIM (Ventana Systems, 2016) or by csv-files transfer in STELLA (Pierson, 2011), subscripting types are not well-established.

In VENSIM, for instance, subscripts need to be typed in manually which limits large scale applications. Unlike Vensim, software such as SIMILE or NOVA provide more sophisticated forms of model disaggregation (Muetzelfeldt and Massheder, 2003; Salter, 2013). Moreover, SIMILE has functionality for loading spreadsheet and image data as one- or multidimensional array. Also the future integration of features for collecting inputs from geographical information systems is announced by NOVA (Salter, 2013). Yet, the implementation of database connectivity features didn't receive as much attention as methods of data import from files. On the

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contrary, simulation software like AnyLogic or Powersim support database connectivity. Nevertheless, the creation of model instances from database data is not supported by built-in functions. Alternatively, libraries like EMA Workbench for Python (see Kwakkel and Pruyt, 2015) in conjunction with specialist database APIs can be used to get control over traditional SD and database software. Also Software like StellaR is capable of translating conceptual SD diagrams into a more flexible scripting environment (Naimi and Voinov, 2012). Nonetheless, the high efforts associated with script development and editing to tightly couple simulation and database systems constitute a major drawback of this approach.

SimSyn is a freely available graphical user interface (GUI), which links VENSIM to a PostgreSQL database. This enables an efficient subscripting of VENSIM models, while removing the need for time-intensive coding. Possible applications are local process simulations - i.e. models are parameterized with values at spatial locations (lateral interaction and flow is neglected in this type of model), comprehensive scenario testing, model calibration or sensitivity and uncertainty analyses.

The following section describes the functionality of SimSyn in more detail. Subsequently, an application of SimSyn is demonstrated through simulating the effects of prehistoric anthropogenic land cover changes on terrestrial carbon storage. This is followed by the presentation of simulation results and results of performance testing. The article concludes with a summary and outlook to future improvements of performance, interoperability and usability.

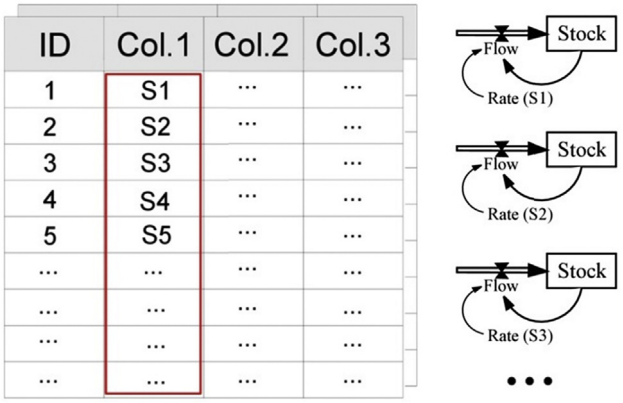

Fig. 3. Subscripting data link between table column 'Col.1' and model parameter 'Rate': Database values S1 to Sx are individually assigned to model parameter 'Rate' to create alternative model configurations.

2. The SimSyn middleware

SimSyn coordinates the interaction of VENSIM and PostgreSQL by means of a tight coupling approach (see Fig. 1). While commands from PostgreSQL are invoked in code through the psycopg2 database adapter for Python, VENSIM PLE models are translated and encapsulated in Python classes using PySD (see Houghton and Siegel, 2015).

Fig. 1. Schematic representation of system design.

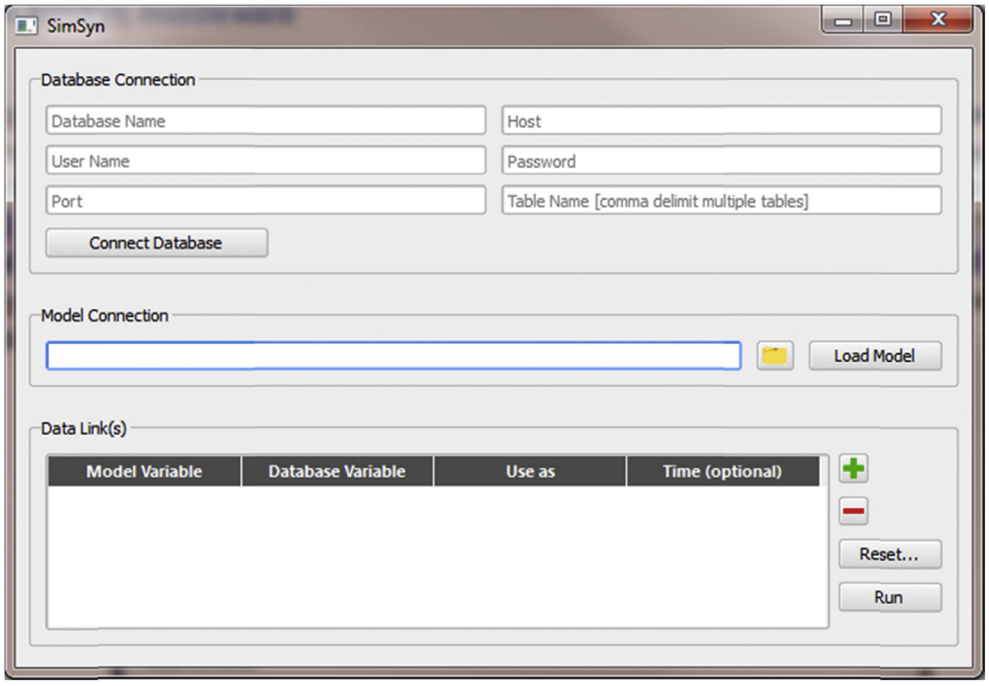

Fig. 2. SimSyn interface.

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