

NAVIGATION ALONG DATABASE RELATIONSHIPS

An Adaptive Framework for Presenting Database Contents as Object Graphs

Ahmet Atli, Katja Nau

Institute for Applied Computer Science, Karlsruhe Institute of Technology, P.O. box 3640, 76021 Karlsruhe, Germany

Andreas Schmidt

University of Applied Sciences Karlsruhe, P.O. box 2440, 76012 Karlsruhe, Germany

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Abstract: In this paper, we will present an approach to visualizing arbitrary relational database contents in the form of object graphs via the World Wide Web. The focus is on the relationships between the datasets rather than on the data itself. The tool allows definition of different node types representing the datasets and edges representing the foreign keys and relationship tables in the database schema. Each node type has a label, and optionally a short description and a user definable image associated with it. The information for these fields can be extracted 1 : 1 from the corresponding database tables or otherwise be aggregated from different tables. Along the edges, it is possible to navigate through the content of the database. At any time, exactly one node represents the center of the object graph. Starting from this graph, edges and other nodes down to a user-definable depth n are visualized. The depth n may vary along different node and edge types, so that it is possible to customize the representation of the object graph.

The graphical representation of arbitrary database contents has been of great help to us. In addition to using it in the initial application area, we intend to use it in some other areas we had left unconsidered. From these, we can infer a number of suggestions as to how to improve our tool and make it more universal.

1 INTRODUCTION

The starting point of the presented work is the requirement to develop a web portal for the broad public within the framework of the *DaNa* project (DaNa, 2010), funded by the German Federal Ministry of Education and Research (BMBF). *DaNa* (Acquisition, evaluation and public-oriented presentation of society-relevant data and findings relating to nanomaterials) is an umbrella project aiming at collecting and evaluating scientific results of various projects in the nanotechnology area along with data from literature for interested laymen.

Nanotechnology is a key technology of the 21st century. It makes use of the effects of very small structures in the range of a few nanometers. A nanometer is one billionth of a meter or one millionth of a millimeter and, hence, corresponds roughly to one fifty-thousandth of the thickness of a human hair. The success of this exciting technology is based on its versatility. On the nanolevel, both physical and che-

mical properties of materials change dramatically, i.e. color, electrical conductivity, and melting point. Gold, for example, becomes reddish, ceramics even transparent, and metals become semiconductors. In addition, nano-objects are much more reactive than conventional particles. These modified properties open up new technological possibilities. Therefore, nanotechnology is an interdisciplinary technology, which affects a number of new developments in all consumer applications.

However, many consumers miss reliable and understandable information on nanomaterials and aspects of nanotechnology. In an interdisciplinary approach, the objective *DaNa* project team will create this transparency and present research on nanomaterials and their effects on humans and the environment in a popular way.

1.1 Motivation

In a first version, the results of the different projects were condensed textually and were published via a content management system (CMS) on the website of the *DaNa* project.

Information about physico-chemical characteristics, properties, use, occurrence, and production of today's nanomaterials (e. g. titanium dioxide, zinc oxide as UV filters in suncreams or dyes) was compiled in an overview. In addition, detailed descriptions were presented of potential ways of exposure, uptake, behavior, and risks of nanomaterials to the human body and to the environment.

It was found, however, that this textual form of presenting toxicology data is not adequate for the target group (the broad public), because the public is more interested in applications of nanomaterials than in technical and chemical properties: Even more important are the relationships between nanomaterials in products and the potential risk of these products to human health and the environment.

The goal, thus, was to present toxicological information in a second version of the web page so that the relation between application and nanomaterials would be in the foreground instead of pure datasets themselves.

The main contribution of this paper is the design and development of a graphical navigation application for arbitrary relational contents. Although we found various great visualization applications (in (Steele and Iliinsky, 2010)) during our investigation, none of them seems flexible enough to handle arbitrary data. We will therefore formulate a number of requirements that such a tool has to fulfill and build a simple prototype. The outlook later on will discuss a number of further requirements to make our tool more adequate for different types of data.

The remaining of the paper is organized as follows: After collecting all requirements, we assess the relevant existing tools, placing emphasis on stand-alone applications and on some frameworks, especially for the visual part. Lastly, we will introduce our concept based on our conclusion that there is no tool available that could completely fulfill our requirements. We will divide the problem into the two constitutive problems "mapping" and "visualization" before we take a closer look at the configuration space of our application and at some aspects of performance. Then, our present prototype is shortly introduced and we present a summary of our findings that is followed by a discussion of possible extensions and improvements to our current system.

2 REQUIREMENTS

To provide a broader basis for the application that we intend to develop, we have chosen not to realize any concrete solution for *DaNa* application but to rather build a universal tool for visualization of database contents on the World Wide Web. The targets formulated in the following thus are not only related to the concrete requirements that had been identified for *DaNa* application but to the more abstract and complex level of a tool for visualization of arbitrary database contents.

Target Platform. The content must be displayed inside an actual web browser¹ without the need to install additional plugins (Javascript is allowed).

Visualization. At every time an excerpt of the database should be displayed graphically. The focus lies on clarification of the relationships between datasets. Hence datasets are displayed by nodes, while relationships are represented by edges between the nodes. Nodes can be of different types (node types), representing different data types or concepts. Nodes have labels and optional images. Moreover, it must be ensured that information can be added along the edges (i.e. as tooltips).

Visualization Range. A limited extract of the database is always shown as an object net. In every situation, one node represents the center of the database extract. Starting from that point, all nodes reachable within a number of (configurable) edges should be displayed.

Node Types. Different node types must be definable. In addition, it must be possible to have different node types for the data in the same relational table, i.e. they must be distinguishable among the values of an attribute (i.e. normal employee, boss).

Navigation. By clicking on a concrete node, this item must be appear in the center of the object net. The previously centered node is brushed aside. Hence, by clicking on another than the centered one of the object-net, you can navigate in the database.

Internationalization. If supported by the database schema, the application should be able to handle different languages (according to a user's selection).

¹Firefox 3.5+, Internet Explorer 8, Opera 10.6, Google Chrome 5.

Support for All Types of Relationship. In addition to $1 : 1$ and $1 : n$, also $n : m$ relationships must be supported.

Aggregation. In the concrete *DaNa* application, the data of one node is derived from exactly one dataset in a concrete table (with the exception of multilingual text). Since, in general, this is not necessarily the case, we need a mechanism to aggregate data from different tables to appear in one node (as label or tooltip).

Context-sensitive Visualisation. Depending on the distance of the central node, the visual representation of a node should be configurable. This refers to, e.g., the number of information to be displayed as well as to the size of the node.

Search Functionality. In addition to the navigation functionality, there must be possibilities to search for concrete nodes. This could be supported, e.g., by a free text search that may be based on an auto-completion mechanism.

Callback Functions. In the case of a click (or right click) on a node/edge, it should be possible to additionally execute arbitrary definable functions. This functionality is, for example, useful to show additional information about the selected node inside another window (detail view) or trigger other actions in general.

3 STATE OF THE ART

In the context of the *DaNa* project, we started by looking at already existing applications fulfilling our requirements as mentioned in Section 2. First we take a look at complete applications that we can use and later, after we realized that none of the examined applications could fulfill our requirements, we take a look at already existing libraries we could probably use when building such a tool by ourselves.

3.1 Complete Applications

We examined a number of applications from which to them should shortly be described:

3.1.1 *PersonalBrain*

PersonalBrain is a Mind mapping software tool (Willis and Miertschin, 2006), which allows to organize text, pictures and URLs inside a Mind Map. It supports $1 : 1$, $1 : n$ and $n : m$ relationships and also allows a categorisation of the data (via meta-data). The visualization is done by a special viewer but

export to HTML with Javascript is also possible. A direct support to visualize data from databases is not available, so you have to write a mapping to the internal format (or supported input formats) by your own. The search functionality supports text search inside the node labels and the meta-tags.

PersonalBrain does not support multilinguality and also the visualization scope can only be defined coarse grained. Another important point that the tool misses is the support of calling user defined callback functions.

3.1.2 *Mind Manager*

MindManager is another mind mapping software. Like *PersonalBrain* it has a special viewer which does the visualization part. Beside this, you can export a static graphic or animated flash (Adobe Creative Team, 2008). Text search is available and also a complex search which supports search into meta-data and the position of a node inside the graph is available.

On the other side it is not possible to connect to a relational database and also multilinguality is not supported. $n : m$ relations are also not supported by this tool.

3.2 Libraries

After finding out that no tool fulfills our requirements in visualizing arbitrary relational data, we take a look at a number of libraries for representing graphs. In the following section, we present *processing.js* and *InfoVis*.

3.2.1 *processing.js*

processing.js (Fry, 2007) is a library for creating animations and graphics. It is based on a own language called *Processing* which can be included inside a HTML page. The Javascript library *processing.js* converts the *Processing*-code to Javascript and visualize it inside a HTML5 canvas element.

It offers a rich set of functions for drawing geometric elements, building animations and react to user actions.

On the downside, the library is missing a layout algorithm for positioning the nodes.

3.2.2 *Javascript InfoVis Toolkit – JIT*

InfoVis (Belmonte, 2010) developed by Nicolas Belmonte is another Javascript library which uses the HTML5 canvas element. In contrast to *processing.js* it already contains a number of predefined elements to visualize data. Especially it has support to visualize

graphs (i.e. forced-directed placement (Fruchterman and Reingold, 1991)). The input to the visualization core is JSON (JSON, 2010) and it has wide configuration possibilities.

4 CONCEPT

After having studied the present state of the art and having found out that none of the available applications or frameworks will fulfill our requirements, we decided to develop an application by ourselves.

The application is divided into two main parts: The first one is responsible for extracting the relevant information from the database while the second one is responsible for the graphical representation in a browser. The overall architecture is shown in Figure 1.

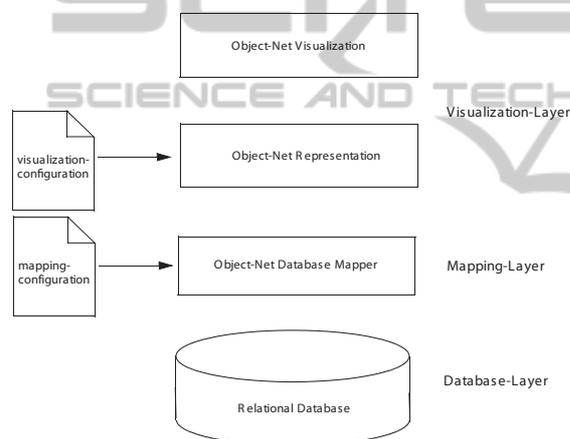


Figure 1: General architecture.

The overall application is realized as a classical multilayer architecture whose core component consists of a mapping layer which, similar to an object-relational mapping tool (i.e. Hibernate (Bauer and King, 2006)), creates a map between the relational database and an object net.

This information is transformed by the layer above into a suitable graphical representation (an object net). This upper layer may be responsible for visualization which, however, may as well be performed by a separate structure.

4.1 Mapper

Wanting to build a tool that can visualize the content of arbitrary database schemata, we need to configure which information should be displayed.

We must build a configurable mapper between a relational database schema and an object representation consisting of nodes of different types and edges between the nodes representing the relationships expressed by foreign keys or relationship tables. This task is comparable to what is done by an object-relational mapper, which maps a relational database to an object-oriented representation with different classes and relationships between them. A possible configuration is discussed in Section 4.4. In contrast to an OR mapper, which normally does a 1 : 1 mapping between database column and instance variable of a class, we only need a short label and a slightly more informative description (i.e. tooltip). However, the latter obtain their information from a number of fields from probably different tables.

For the mapping itself, there are two possibilities of implementation:

1. Implementation as an interpreter: The mapper reads the configuration at runtime, extracts the specified information from the database and forwards it to the visual component.
2. Usage of a code generator: A generator tool reads the configuration at build time (configuration time) and generates the source code for the concrete mapping. In the case of a compiled language like Java, another additional compiler step is necessary; in case of an interpreted language like Python or PHP, the generated source can be used immediately.

4.2 Visualization

As mentioned in the Requirements (Section 2), the output device should be a common browser, without additional plugins. Hence, there are two possibilities for visualization:

1. We can generate the visual representation on the server side and send it to the browser which is responsible for the representation. This can be done with the help of a clickable image map. To generate the object net, we can use a number of existing libraries (i.e. Graphviz (GVS, 2010)).
2. Another possibility is to create the visual representation on the client side (the browser). A number of libraries like *raphael* (Sencha, 2010), *processings.js*, *ProtoVis* (ProtoVis, 2010) and *InfoVis* exist, that can represent structural information as diagrams, especially object nets. Section 3.2 gives a more detailed description of some of the mentioned libraries.

When the client is responsible for the representation of the object net, the extracted informa-

tion from the mapper must be sent to the client (the browser). This can be done in the form of (a)synchronous HTTP-requests. Popular data formats are XML (AJAX (Crane et al., 2005)) or JSON (JSON, 2010).

4.3 Loading-mechanism

In the browser, small excerpts of the database are displayed. Clicking on an object, the object selected is placed in the center of the displayed area. As a rule, this requires loading of information about further nodes and edges. The “visualization range” requirement discussed in Section 2 implies that all nodes that can be reached from a central node be visualized down to a depth n at any time. The respective depth is determined by the number of relationships to be passed through starting from the central element. Since, as is evident, the data needed cannot simply be loaded at one go, one has to navigate along the object net which, depending on the level of embedding, leads to an exponential increase in individual database requests. Although the respective amounts of data to be loaded are relatively small, each request is afflicted with a constant latency that affects performance.

This performance bottleneck can be avoided through a number of solutions discussed below.

4.3.1 Client-cache

The browser is required to visualize a certain number of objects and edges. Clicking on a node, the node selected will move into the center of the displayed area. By loading additional nodes that are reachable from the outer nodes, subsequent clicks for reloading can be neglected and it suffices to display the respective nodes only visually. After the object net has been built up and visualized in the browser, nodes and edges that are connected with the outer nodes of the object net can be reloaded asynchronously by means of AJAX (Crane et al., 2005). In doing so, the number of nodes to be reloaded in a user interaction can be reduced or avoided. An adequate cache (least recently used (LRU), minimal distance strategy) must be implemented within the client in support of this.

4.3.2 Mapper-cache

Just like the client cache, the server-side mapper that is in charge of various client requests can profit from a cache. The cache can be realized as a simple LRU cache or, in line with the client cache, may be sophisticated enough to load datasets in the “vicinity” of those already loaded.

Any node or edge request that cannot be satisfied

by a new request from the database. As mentioned above, several requests are as a rule required. In the case of databases with a higher latency, large numbers of small requests may be annoying. Different solution strategies are introduced below:

Complete Loading of Database. Applying this brute-force method, all the relevant information is simply loaded from the database into the mapper. Since all requests can be satisfied from out of the mapper cache, reloading can be neglected. This approach is appropriate when the database content to be visualized can be completely stored in the RAM.

Generating a Complex SQL Statement. To avoid multiple sequential reloading, a complex SQL statement which down to the desired depth n contains all the datasets needed may be generated from the configuration alternatively. This, however, requires developing a corresponding adequate SQL generator.

Application of Stored Procedures. Direct relocation of the loading logics from the mapper to the database has the advantage that a parameterized request suffices for the mapper to obtain all required data from the database. Since the information obtained comes from different types of nodes, a generic data structure must be provided for the node and edge information.

The advantage of applying stored procedures lies in an increased performance as compared to the successive loading through the mapping layer.

This solution has the major drawback that the stored procedures, unlike DML statements, are not standardized and that, hence, different implementations must be realized for different database systems.

There are two alternatives to implementing stored procedures:

Stored Procedure as Interpreter. The stored procedure has access to the mapping configuration. Based on the latter and on information about the central node, the further nodes and edges are identified down to the specified depth n .

Generated Stored Procedure. This approach is similar to that of generating a complex SQL statement but instead of generating an SQL statement one generates the code of a stored procedure. Unlike the previous interpretative solution, this stored procedure is optimized toward the concrete data schema and, thus, has a higher performance.

4.4 Configuration

Configuration serves to define the different node types and relationships to be displayed. In addition to the label and an optional brief description, the following information is specified for each node type:

- The data that the node type is constituted of: The source may be a single dataset or parts of it but node instances may as well obtain their data from several tables.
- The maximum distance between the central node and the displayed related nodes: This distance can be defined for each node type individually.
- The types and depths of relationships to be visualized.
- Optionally, an alternative graphical representation can be determined for each node type or instance. It is possible to define as a function of the distance of the node instance from the origin whether there is only one type of representation for all instances of a node type or whether each instance has a representation of its own.

```
Country:
table: mondial.country
id: country(code)
label: ${country_name}+' (Area: ' + ${country_area}+' km^2)
tooltip: 'Population: ' + ${country_population}
image: http://localhost/mondial/images.pl?type=country

source: select code as country_id,
           name as country_name,
           population as country_population,
           area as country_area
         from mondial.country country
         where code in (select country
                       from mondial.encompass
                       where continent='Europe')

City:
table: mondial.city
id: city(country, province, name)
label: city.name

source: select name
         from mondial.city
         where population > (select avg(population)
                             from mondial.country c
                             where c.code=city.country)
```

Figure 2: Configuration of node types *country* and *city*.

Figure 2 shows an example of configuring the node types *country* and *city* with the properties *label*, *tooltip*, and *image* specifying the representation in the object net.

The properties *label* and *tooltip* can be built out of variable contents² and strings by means of a simple syntax.

Image is optional and specifies an alternative graphical representation. *Source* specifies the SQL statement that the node type is based on. Since this

²The alias names specified in the `select` clause enable to access the contents (syntax: `$(columnname)`).

statement may be of any complexity, the data may be composed of several tables.

Figure 3 shows the definition of the relationships between the two node types. The maximum distance from the original node (`max_distance`) and the join condition in SQL syntax are specified. *Self-joins* in addition require alias names.

```
Relation: Country-City (is_in):
max_distance: 1
condition:
mondial.country.code=mondial.city.country and
mondial.country.capital!=mondial.city.name

Relation: Country-City (is_capital_from):
max_distance: 2
condition:
mondial.country.code=mondial.city.country and
mondial.country.capprov=mondial.city.province and
mondial.country.capital=mondial.city.name

Relation: Country-Country(neighbor):
max_distance: 2
condition: (alias: country other_country)
(mondial.other_country.code=mondial.border.country1 and
mondial.country.code=mondial.border.country2)
or
(mondial.other_country.code=mondial.border.country2 and
mondial.country.code=mondial.border.country1)
```

Figure 3: Configuration of edges between *country* and *city*.

5 IMPLEMENTATION

A first version of restricted functionality has been developed already within the *DaNa* project. Due to the limited amount of data, a version loading all data into the cache of the mapping tier at the beginning was implemented. The implementation of the object net in the browser was realized by means of the library Javascript InfoVis Toolkit (Section 3.2.2). In addition, the jQuery Library (Bibeault and Katz, 2008) is used on the client side.

Figure 4 shows a screenshot of the implemented *DaNa* scenario.

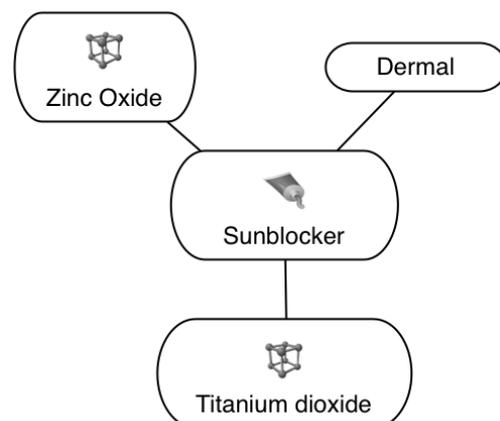


Figure 4: *DaNa* Screenshot

The communication between client and mapping tier is based on asynchronous Javascript requests with the exchange format being JSON. APIs were developed for both the client and the mapping tier sides of communication. These APIs can support functions for loading of all supported node types, loading of all “neighbors” of a node, and loading of all nodes within a defined distance to an original node. Alternative loading strategies like the ones discussed in Section 4.3 are not yet supported by the update version.

6 CONCLUSIONS AND FURTHER WORK

The present paper discusses a concept for visualization of contents from relational databases placing emphasis on an adequate solution for representing the relationships within the database rather than on visualization of the data themselves.

Future concepts will demand that not only nodes but also edges be placed in the center of the object net. This requirement evolved from another project focusing on analyzing correlated project steps.

The next version, moreover, will allow switching on/off certain node/relationship types interactively by means of a menu.

A similar suggestion is to formulate conditions that determine or decide whether relationships are to be displayed or are not displayed. This allows providing more relevant information without losing track on account of the complexity of the object net. As against the previous update, this version allows visualizing nodes/relationships based on certain data values instead of on types of nodes/relationships alone.

In addition, the intended implementation of generalizations via relationships is expected to allow combining several relationships and display them by one edge which will increase clarity within the object net.

Still another option consists in using the tool discussed for interactive similarity search: Problems can be approached by developing and using similarity measures based on the relationship structures of the different complex data structures that have been considered.

Looking for a technical solution, one considers realizing mapping of a relational database onto the object net by means of an object-relational mapping tool. In doing so, a broad cross-sectional functionality (configuration of the representation, performance features such as different caching mechanisms) can be made use of and the procedure can be reduced to mapping of the objects and relationships onto the nodes and edges of the object net. Since the map-

ping information required by the OR mapper contains only a subset of all configurations to be specified, it is worth discussing whether it makes sense to divide the configuration into two subareas (OR mapping information, special configurations for graphical visualization) or whether configuration should be made a central process followed by a transformation to the format of the OR mapper.

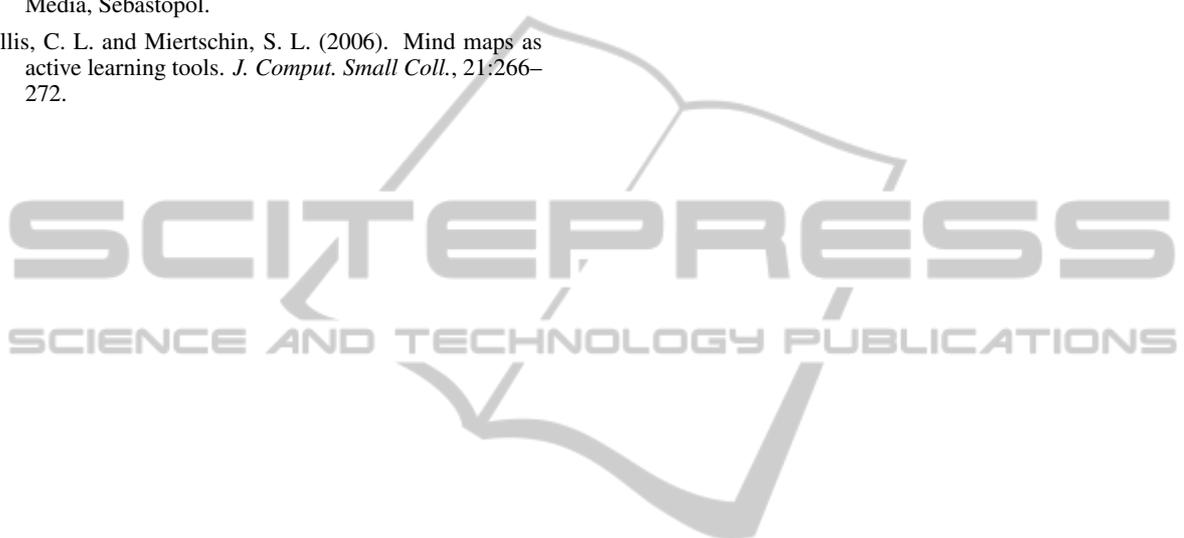
Another idea is to differentiate the appearance of a node depending on the distance to the center node. Considering the above example of displaying information about countries and their neighbors, the country in the center and the adjoining countries around should be represented by a graphic, displaying the contours of the countries. Countries which are still displayed but are no direct neighbors of the central country should only have a small graphic associated with them that identifies them as being countries (in contrast to other displayed node types like, e.g., cities.).

The Mondial scenario (May, 1999) (countries, regions, cities, rivers, mountains, ...) applied to evaluate the prototype has shown that it may make sense to control the positioning of the objects: Since Switzerland is expected to be positioned south of Germany, hence is shown to be below Germany on conventional maps, it was, for instance, found to be confusing to see the node of Switzerland being displayed directly above that of Germany.

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