The Open Graph Archive: A Community-Driven Effort

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Abstract. In order to evaluate, compare, and tune graph algorithms, experiments on well designed benchmark sets have to be performed. Together with the goal of reproducibility of experimental results, this creates a demand for a public archive to gather and store graph instances. Such an archive would ideally allow annotation of instances or sets of graphs with additional information like graph properties and references to the respective experiments and results. Here we examine the requirements, and introduce a new community project with the aim of producing an easily accessible library of graphs. Through successful community involvement, it is expected that the archive will contain a representative selection of both real-world and generated graph instances, covering significant application areas as well as interesting classes of graphs.

1 Introduction

In its basic form a graph is a set of vertices and a set of edges connecting some of the vertices together. In this paper we use this term broadly: edges can be directed or weighted, there can be multiple edges between two vertices, and vertices and edges can be labeled. A graph can also have some metadata associated with it, answering who-, when-, how-, why-, and what-type of questions about its creation and existence. A database is an organized collection of data usually stored in digital form. A graphbase, a term coined by Knuth [10], is a database of graphs and computer programs that generate, analyze, manipulate, and visualize graphs. The terms graph library and graph archive are often used as synonyms for this term.

Our vision is to provide an infrastructure and quality standards for a public graphbase, named the Open Graph Archive, that is accessible to researchers and

* This work was initiated at Schloss Dagstuhl in seminar 11191 on “Graph Drawing with Algorithm Engineering Methods”.

other interested parties around the world via the worldwide web. This paper
describes the current work undertaken towards this goal; the paper is also intended
to be a call for participation since this will be a community-driven effort where
most of the content will be provided by users of the system.

Our motives for building this universal graphbase are similar to Knuth’s
motives for building the Stanford GraphBase [10]: we are just working on a larger
scale. First, we want to provide standard sets of graphs to enable repeatability of
experiments. We expect that the graphbase would be particularly interesting for
researchers working in the areas of algorithm engineering and graph drawing.
Second, we want to provide a single point of access for datasets relevant for
people working with graphs. By annotating the datasets with their origin and other
semantic information, we can help researchers to find publications relevant
for their work. Third, a graphbase that is accessible worldwide can stimulate
interesting theory development. As pointed out by Knuth [10], a graphbase can
bridge the gap between theoreticians and practitioners. Fourth, the programs
(and maybe also the datasets) available in a graphbase, if done well, can have a
significant educational value.

Many existing collections, like the graphs available in the Stanford Gra ph-
Base [10] and the well-known Rome graphs [3], are static and only cover a small
number of data sizes, types, and properties that may be relevant for the users.
In order to allow collection and exchange of interesting graphs, it is impor tant
to make the graphbase extendable. The needs of the community will certainly
change over time. Expandability has been recognized as an important goal by
other researchers as well (see, e.g., [11,2]), but the available data collections seem
to be relevant to a limited range of users only. Our goal is to support the use in
a wide variety of application areas.

This paper is organized as follows. Section 2 presents the results fr om a sur-
vey conducted among a small group of potential users (the partic ipants of the Da gstuhl seminar 11191) on their needs and requirements for a useful graphbase.
Section 3 reviews and compares existing graph collections. Section 4 describes
a prototype implementation developed at the University of Tübingen that shall
form the basis for further development. Section 5 concludes with a call for par-
ticipation encouraging community involvement in this endeavour.

2 User Needs and Requirements

In order to investigate the relevance of and the requirements for a universal
graphbase we conducted a survey among 30 participants of the Dagstuhl seminar
11191, coming from the graph drawing and algorithm engineering communities.
The survey solicited a variety of open-ended textual responses. In this section
we summarize the most interesting and commonly recurring feedback.

Describe two most important use cases for a graph archive. The most frequent
use cases were to search for graphs with specific properties, and to benchmark
and compare algorithms, both mentioned by 37% of the participants. Further
Of the multiple-choice question “Which services do you consider as critical for a graph archive?” answers were to share datasets (27%), and to replicate experiments and compare results (23%). Since these are fundamental aspects of experimental scientific processes, we can see that a graphbase would be an important tool for researchers of graph algorithms.

**What services do you expect?** We proposed nine services of which the survey participants could select those they considered important. As shown in Table 1, support for tags and arbitrary comments are the most crucial features. When asked for further important services, a handful of people wanted to know which publications refer to a specific graph or collection of graphs (17%).

**Which category tags and analysis properties may be useful?** Participants named 20 different application domains to categorize a graph or collection of graphs, e.g., biology, social networks, geography, software engineering. Furthermore, participants named 16 graph properties, most of which can be determined automatically. The most popular properties were connectivity (60%), including the number of k-connected components, and planarity (43%), including the best known crossing number for non-planar graphs.

**Name two file formats you use most.** The most frequently mentioned formats were GraphML (43%) and GML (33%). Since a total of 13 different formats were named, it is evident that a universal graphbase should not rely on one specific format, but offer support for several formats, preferably even converting automatically between formats.

**Existing archives and collections.** Responses for existing archives showed that GraphArchive [6] from the University of Tübingen and the datasets from the DIMACS implementation challenges [5] were both known by a handful of people (20% and 13%, respectively). These numbers are quite low and might also be biased towards the archives used by the researchers that participated in the seminar. They also suggest that there is currently no commonly used and accepted graph archive service. Regarding graph collections, participants mostly

| Service                                           | Percentage |
|---------------------------------------------------|------------|
| Add categorization tags                           | 80%        |
| Add comments, links, or further information       | 77%        |
| Search for specific tags                          | 77%        |
| Automatic conversion of file formats              | 70%        |
| Search for specific properties                    | 60%        |
| Add information on how graphs were created        | 60%        |
| Add images (drawings of the graphs)               | 50%        |
| Automatic analysis of graph properties             | 47%        |
| Programmatic web service                          | 23%        |

Table 1. Result of the multiple-choice question “Which services do you consider as critical for a graph archive?”
worked with randomly generated graphs, as well as with the popular Rome and AT&T graphs.

Community contributions. Several participants of the survey declared that they would be willing to provide human resources (students, testing and development time), a hardware platform, or even money. This reaffirms that there is definite interest and enthusiasm for such a system, and also that the project should take advantage of this through involvement of the community.

Technical and service requirements. The survey results and subsequent community discussions indicate that potential users agree on a core set of important features, as well as a larger list of desirable functionality. However, several questions regarding the interface, architecture, and content remain open. Below we list the most relevant issues that need to be discussed or dealt with.

Storage. Graphs must be stored persistently under a unique ID for identification and access. Should graphs be stored in their original submission format, or converted by the system or the user into a unique storage format? In file conversions it is important that as much information as possible is preserved.

Metadata. There is a variety of metadata that can be stored with a graph, e.g., creator, description of the underlying data or the generator, additional keywords, and links to corresponding experiments or publications. Some of this data should be defined as mandatory properties, whereas other parts may be added as generic text properties. Useful keywords/tags for categorization need to be defined. Some tags could be attributes for graphs or collections of graphs, and some could list their structural and semantic properties.

Searching. Based on the survey results and our own experience, we assume that a graphbase should allow the user to search using both graph properties (number of nodes, etc.) and annotations (categories, origin, etc.).

Data analysis. Automatic analysis of basic graph properties must be possible. However, we are not sure if there should be a restriction on the computational complexity of the analysis or on the size of the analyzed graphs, or if users should be allowed to upload that information, e.g., the crossing number of a graph.

Programs. In addition to datasets, it must be possible to store programs like graph generators, analyzers, or visualizers. If the graphbase contains randomly generated collections of graphs with certain attributes, it would be useful to provide access to the programs used for their generation.

Ownership and copyright. The ownership of uploaded graphs must be clear from the outset. The content should be as freely usable as possible with fair attribution to the original authors. Contributors will need to take responsibility for their submitted graphs and collections of graphs.

Existing collections. Existing popular collections should be made identifiable and accessible via the system.
Possible extensions. Further useful extensions may include the following:

- Automatic file conversion could be provided as an additional service and the programs providing these conversions could also be made available.
- A series of drawings (layouts) for submitted graphs could be provided, or even automatic layout on demand, and the programs used for drawing the graphs could be made publicly available.
- Special support for browsing collections of graphs could be provided. For this purpose a hierarchical classification system can be useful.
- Structure-based searching could be supported, e.g., find graphs containing a clique of a specific size.
- Versioning of individual graphs as well as the possibility to store a series of dynamic graphs could be supported.
- A web-service API could be provided to allow interrogation of the database by computer programs, rather than via a web browser.

3 Related Work

In this section we examine the features of existing systems in more depth. Based on the survey responses, we selected the most relevant existing archives and checked their capabilities with respect to the desired features. Not all of these archives are designated graph or even graph-drawing archives; several are dedicated to either specific experimental goals (e.g., [5]) or to matrices (e.g., [2]), and the interfaces are designed accordingly. Table 2 lists the most desired features from the survey and evaluates existing systems accordingly.

Together with a large number of customized benchmark sets, several widely used graph collections have become de-facto standards for benchmarking in graph drawing. Note that the following list does not lay claim to completeness. Rather, it is a selection of graph collections commonly used within the graph-drawing community. Other popular collections are the GD contest graphs [7], the test suite from GDToolkit [8], the Hachul graphs [9], and the graphs in the Stanford GraphBase [10].

The Rome library [3] consists of 11528 small undirected connected graphs with 10 to 100 vertices with a limited variation of structures and properties. They are derived from a small set (112 instances) of (outdated) real-world graphs from software-engineering and database applications. The original collection with 11582 instances contains some corrupted files and duplicates. The 112 core instances were extended by executing multiple rounds of random sequences of five primitive operations including vertex/edge removal and insertion. After each iteration the graphs were filtered by testing their suitability, e.g., by visual inspection of structural similarity. The probability of each primitive operation was varied after each round.

The AT&T library [4] contains 389 undirected and 5114 directed real-world graphs with 3–1104 vertices and 1–7602 edges, respectively. The latter set
contains the North DAGs, which are 1277 acyclic connected graphs with 10 to 100 vertices. The graphs were collected by Stephen North at the AT&T Bell Labs by running two years an e-mail graph-drawing service. The graphs came from very heterogeneous sources, mainly representing different phases of various software-engineering projects. As a result, the densities of graphs with more or less the same number of vertices vary from very sparse to extremely dense, i.e., the relative densities are not uniformly distributed over the different numbers of vertices of the graphs. When verifying asymptotic running times with these graphs it is more appropriate to compare the run-times with the number of edges rather than the number of vertices. The North DAGs were processed such that for each isomorphism class (detected over identical vertex labels) only one representative graph was kept. Where necessary, minimal sets of edges were randomly added to make the graphs connected. Finally, some edges were heuristically inverted to eliminate cycles.

The DIMACS challenge graphs [5] are a large collection (about 20 GB) of graphs forming the testbed for the DIMACS implementation challenges, which started in 1990 and explore questions of determining realistic algorithm performances and comparing them to theoretical bounds. The addressed problems include graph partitioning and clustering, shortest paths, TSP, semidefinite optimization, and nearest neighbor searches. The instances are real-world graphs (e.g., co-author and citation graphs, street networks) and randomly generated graphs (e.g., Delaunay graphs, geometric graphs, uniformly drawn Erdős-Rényi graphs). It includes Walshaw’s graph partitioning archive [12] and a small subset of the Florida sparse-matrix collection.

The Florida sparse-matrix collection [2] is a large, growing set of sparse matrices that arise in real-world applications. The collection is widely used for performance analysis by the numerical linear-algebra community. This set of mostly very large instances originates from a wide spectrum of domains, including structural engineering, electromagnetics, semiconductor devices, thermodynamics, optimization, circuit simulation, and financial modeling. The collection currently contains 2541 matrices and the largest matrix has a dimension (maximum of the number of rows and columns) of more than 100 million. The library includes nearly every matrix from the matrix-market collection [1], which additionally includes matrix generators.

Evaluation. An evident weakness of the mentioned libraries is the lack of a significant number of real-world instances for a wide variety of applications, as well as the useful contextual information this would provide, i.e., where the data stems from, the original use, as well as detailed type or semantic information. Even though many of the available graphs are—or are derived from—real-world graphs, they only cover a small set of applications. Noticeably absent are the important application areas of biology and social sciences. Some of the datasets are also quite old, which means that the graphs do not necessarily represent

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7 See web-search interface at [http://www2.research.att.com/~yifanhu/GALLERY/GRAPHS/search.html](http://www2.research.att.com/~yifanhu/GALLERY/GRAPHS/search.html), accessed August 2011.
typical characteristics or sizes of current real-world data. A lack of real-world examples may be attributed to an inability or unwillingness of practitioners to share their data, a situation which may be improved by addressing issues of ownership and copyright. The heavy use of randomly generated graphs is also apparent. Random graphs play an important role in algorithm evaluation and engineering, and should therefore also be a part of the graphbase, possibly along with the corresponding generator code.

4 A Working Prototype: GraphArchive

In this section we give an overview of GraphArchive, a platform for exchanging and archiving graphs meant as a prototype for the Open Graph Archive. It is developed at the University of Tübingen and was designed as a successor to GraphDB, a now discontinued first attempt at creating a web-based graphbase. GraphArchive is an interactive online system built with modern web technologies. Below we list the main features of the existing prototype, followed by a short description of its software architecture. For more details, we refer to [6].

The working system can be accessed online at

http://graphdrawing.org/grapharchive/.

Table 2. Functionality of existing systems

| Services                  | Tübingen | Dortmund | Stanford | Matrix market | DIMACS | Florida |
|---------------------------|----------|----------|----------|---------------|--------|---------|
| Categorization tags       | Y        | Y        | Y        | Y             | Y      | Y       |
| Further info / comments   | Y        | N        | Y        | N             | N      | Y       |
| Search for tags           | Y        | Y        | N        | Y             | Y      | Y       |
| Conversion to file formats| Y        | Y        | N        | N             | N      | Y       |
| Search for properties     | Y        | Y        | N        | N             | Y      | Y       |
| Creation method           | N        | N        | Y        | N             | N      | Y       |
| Support for images / layout| N    | N        | Y        | N             | Y      | Y       |
| Autom. analysis of properties| Y    | Y        | N        | N             | N      | N       |
| Support for web services  | N        | N        | N        | N             | N      | N       |
| References to publications| Y        | Y        | Y        | Y             | Y      | Y       |
| Forum                     | N        | N        | Y        | Y             | Y      | Y       |
| Availability of generators| N        | N        | Y        | Y             | N      | N       |

* implemented but not yet available for the user
** search possible only for matrix properties
*** possible as a future extension
Main features. The features of GraphArchive, as listed below, have been chosen to support the goal of providing an open and easily accessible system.

Web-based user interface. The user interface is provided via a browser. A web portal offers all functionality that is needed to handle graphs, including uploading datasets, inspection and management of existing graphs, searching for specific graphs, and downloading datasets. Registration is performed online using a registration form, which is processed automatically. Standard techniques are used to prevent registration by spam bots.

Minimal permission management. There are no groups of users that define rights for small circles of users. Licenses for graphs limiting their usage are not encouraged in our open approach. However, if necessary, a license can be attached to a selected graph. After confirming registration by going through the opt-in e-mail process, a user has access to all graphs and can initiate queries without restrictions.

Categorization of graphs. For search queries, graphs can be assigned to the field(s) of application that they originate from. This enables researchers from different fields to use GraphArchive as a common platform.

Automatic graph analysis. After upload, graphs (with \(< 100,000\) vertices) are automatically analyzed in order to provide consistent data. Consistency is very important for queries on graph properties.

Multi-criterion search. Queries can be performed on multiple parameters, specifying graph properties, categories, author, name, and upload date. Also, parameters can be added later to further narrow down the result set.

Graph visualization. An image of a graph is valuable if a user wants to visually inspect the properties of a graph. Layouts are computed automatically in the background and can also be changed after upload.

Unique links to graphs. A URI associated with each graph allows for a permanent reference to be used in publications. By giving the URI, the user can quickly jump to a particular dataset. Reference annotations can be assigned to a graph in order to highlight publications and/or websites that refer to or make use of the graph.

Visual comparison of multiple graphs. For a quick comparison of graphs, we support simultaneous presentation of multiple graphs. Properties are displayed for all graphs. Boolean properties, e.g., directed/undirected, are presented visually on a scale (properties can be shared by (a) no graph, (b) a subset of the displayed graphs, or (c) all graphs).

Several file formats. When supporting many application domains it is impossible to dictate the file format used. Therefore, we aim at supporting as many formats as possible. The system is extendable and allows for addition of further formats in the future. For downloading graphs, a user can choose the format that fits best to his or her work environment. We provide cross conversion between different formats (the users can select any supported format and the system performs the conversion automatically).

Import/export of multiple graphs. We allow upload/download of several graphs simultaneously in zip-compressed form. In an upload process, each
file in a compressed archive can be optionally processed individually (for property analysis and layout computation).

**Guest access for non-registered users.** If a user wants to check a specific graph, he or she can access a detailed view of the graph using its URI. All properties and attributes of that graph are made visible via a guest account.

**Software architecture.** GraphArchive is built with common web technologies. The application is written in PHP and uses Apache for online presentation. For graph analysis and layout computation, we use the Java library yFiles; these computations are handled in the background via PHP/Java bridge. Data storage is managed by PostgreSQL database management system.

More details and a descriptive walk-through showing a typical use case of the system can be found in [6]. For more news and information on the system and its current development status, please consult the system website.

## 5 Conclusion and Outlook

We advocated the need for an open, worldwide graphbase to collect and distribute graphs and programs for their generation, analysis, manipulation, and drawing. Our recommendations for the supported features of such a system stem from the discussions and experiences within the graph-drawing community and the results of a survey conducted at Schloss Dagstuhl. The specification of reasonable features can be viewed only as a preliminary wish list—it is expected to change and grow along with community adoption of the system. Growth of the content and evolution of the system will be driven both by the demands of the users and their willingness to contribute material. We described a working prototype and propose that it will be extended and used to build the Open Graph Archive. The prototype already supports many of the recommended features and fully satisfies the minimum requirements.

Our hope is to stimulate discussion on the initial system proposal and trigger community growth around the Open Graph Archive. The success of this project requires a passionate and enthusiastic community. We urge you to step up and participate by critiquing the existing system, helping the development effort, or contributing material to the graphbase.

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