# BiGGer: A Model Transformation Tool written in Java for Bigraph Rewriting in GrGen.NET

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Summary

Graphs are well-studied mathematical structures that have diverse applications in fields such as computer science, chemistry, biology and social sciences. In this respect, graph rewriting is a powerful technique that allows for the manipulation of graph structures through the application of so-called *graph transformation rules*.[1] In other words, graph rewriting techniques elevate static graphs to the concept of time-varying graphs.

BiGGer is a Java library that implements a novel approach to graph rewriting for *bigraphs*, as devised by Robin Milner (Milner, 2009), using the graph transformation tool *GrGen.NET* (Geiß et al., 2006).[2] Bigraphs provide a compositional framework to model graph structures with two semantic dimensions that can be reconfigured by rules.

With regard to BiGGer, bigraphs are specified using a meta-modeling approach (Grzelak, 2023; Kehrer et al., 2016) that is based on the EMOF standard (ISO/IEC 19508:2014, 2014), which is common in the software engineering sciences, where this library is most useful. Grounding bigraphs on metamodels facilitate its construction via a universal and platform-agnostic language.

Ultimately, this library transforms EMOF-complaint bigraphs into multigraphs that GrGen.NET can visualize and execute. Furthermore, BiGGer is also shipped as a command-line tool for using the functionality via the terminal for experimentation. The most challenging aspect was the accurate translation of bigraphical rules to SPO-based rules, given that bigraphs and GrGen.NET employ distinct approaches regarding graph rewriting.[3]

Statement of Need

Primary Purpose

The tool is built upon the formal principles of bigraphs, allowing for the intuitive and expressive representation of dynamic graph structures equipped with two semantic dimensions. In the domain of bigraph rewriting, the Java library and command-line utility BiGGer provide a highly efficient solution by streamlining the intricacies linked to model conversions and system simulation when bigraphs and GrGen.NET are utilized in conjunction. The fundamental objective of BiGGer is to establish an alternative and resilient setting for bigraph matching and rewriting. This will enable the simulation of state transitions in software applications, models, and systems, as well as in any other field where graph-structured data possesses inherent advantages over simple data structures such as scalars, lists, or pointers.

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[1]The terms graph rewriting and graph transformation are used interchangeably.
[2]https://grgen.de/
[3]For an analysis of the interrelated aspects of these approaches, refer to (Ehrig, 2004; Milner, 2005).

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37 **Efficiency**

38 When considering the manipulation of bigraphs through rules, the central elements that require
39 implementation are bigraph matching and rewriting. This issue is mathematically known as
40 the *subgraph isomorphism problem*, a general variant of the graph isomorphism problem. Until
41 now, it is unknown whether the test for graph isomorphism can be solved in polynomial time
42 or whether it is NP-complete. Subgraph isomorphism is computationally more complex than
43 graph isomorphism and is known to be NP-complete due to the combinatorial nature of finding
44 subpatterns in graphs. Thus, graph rewriting is NP-complete (Bacci et al., 2014).

45 However, bigraphs require the matching and rewriting of two substructures. Specifically, one
46 substructure of a bigraph is a *forest*, which is relevant to the problem of locating forests in trees
47 (Bacci et al., 2014), while the other substructure is a *hypergraph*, which is associated with the
48 subhypergraph matching problem. To date, practical bigraph matching primarily exists as a
49 CSP implementation (Miculan & Peressotti, 2014), or SAT-based algorithm (Sevegnani et al.,
50 2010) in the literature.

51 GrGen.NET provides a universal framework written in C# implementing the so-called Single-
52 Pushout (SPO) approach of graph rewriting for multigraphs (see, for example, (Ehrig et al.,
53 2006; Jakumeit et al., 2023)). The choice to use GrGen.NET instead of other common graph
54 rewrite systems in the software domain (e.g., AGG, PROGRES, FUJABA) is its execution
55 performance with respect to matching and rewriting (refer to the benchmark described in (Geiß
56 & Kroll, 2007), which was introduced in (Varro et al., 2005) first). Specifically, GrGen.NET's
57 pattern matching engine employs some techniques that increase the practical execution
58 performance of subgraph matching, which is an NP-complete problem but is at least one order
59 of magnitude faster than comparable candidates (Jakumeit et al., 2023).

60 ## Key Features

61 The tool implements a unidirectional transformation from bigraph models to GrGen.NET
62 models, and generates several files that GrGen.NET can execute and visualize. These include
63 GrGen.NET's graph metamodel (`*.gm`), the graph model conforming to the metamodel (`*.grs`),
64 rules (`*.grg`), and a script that configures the initial graph state and defines a simple rule
65 execution strategy (`*.grs`). In turn this means that BiGGer is able to process the signature,
66 bigraph, rules and tracking maps specified in the Eclipse EMF Ecore format (Steinberg et
67 al., 2008), which implements the EMOF standard (ISO/IEC 19508:2014, 2014). Refer to
68 www.bigraphs.org on how to model EMOF-compliant bigraphs in Java, visually or via the
69 dedicated domain-specific language (Grzelak, 2021).

70 The functionality of BiGGer is offered via different interfaces suited for users of different
71 backgrounds: programmatically in Java via the API, or by using the command-line tool.
72 Developers and students benefit from the integration of BiGGer with other software systems
73 relying on bigraph rewriting via an object-oriented API. BiGGer supports the efficient execution
74 of transformation rules on large bigraphs currently available in the literature.

75 Moreover, BiGGer is shipped with sample bigraphs and rules and detailed instructions, which
76 are essential in facilitating a better understanding of BiGGer's capabilities and usage.

77 ## State of the Field

78 There are few practical solutions concerned with the bigraph matching problem for various
79 kinds of bigraphs; a non-exhaustive presentation is the following. For *binding bigraphs* (i.e.,
80 links have local scopes) by an inductive characterization of matching (Birkedal et al., 2007;
81 Damgaard et al., 2013); for *directed bigraphs* (which subsume *pure bigraphs*) (Bacci et al.,
82 2009); for *bigraphs with sharing* (i.e., the place graph is a directed acyclic graph) by using a
83 SAT-based algorithm (Sevegnani & Calder, 2016); for the pure case by (Miculan & Peressotti,

2014) as a CSP, and further an adapted reduction of the problem for directed bigraphs to a CSP (Chiapperini et al., 2020); and the work in (Gassara et al., 2019), which proposes a toolchain for bigraph matching that is conceptually most similar to our approach but not actively developed anymore and not as efficient as GrGen.NET.

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