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## Implementation of Novel Approaches in Bidirectional Model Transformation: A Systematic Literature Review

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### Abstract

In the past few years, software development has seen rapid growth, and developers have adopted different methods to provide efficient procedures in software development, thus reducing the overall bug counts and time delay. Bidirectional model transformation is one such technique that encompasses the development of the object code in both directions enabling an abstract view of the software to the developer; over the year's researchers, have been able to produce many approaches in bidirectional model transformations (bx), but the cost and best fir for effective model transformation, in particular, a quantities survey will be designed which will discuss the best possible apron in the bx. The methodology for this survey shall be made through SLR to identify around 20 different approaches proposed for bidirectional model transformation; these studies range from the year 2010 till date and are thus, rendered latest in the respective fields of our survey. The gathered results have been calculated on the specific set of parameters that are cost and time of usage time are the main aspects of these approaches, and that is the predicament that has made us produce a systematic literature review (SLR) on this very topic. Thus, this paper investigates different approaches based on their implementation cost and time delay and discusses their limitations, and the approach is implemented. Those approaches have been selected, which culminate in both of these respective parameters. The main objective of this SLR is to provide an insight into the different approaches and establish a well-balanced approach that can be used in bidirectional model transformation in software development.

**Keywords:** Handcrafted Features, Feature Ensembles Pedestrian Gender Recognition, and Visual Surveillance

### 1. Introduction

Bidirectional model transformation is one of the most efficient approaches to visu-

alize the abstract level of data and, thus, implement a professional approach to the source itself. The best available approaches in bidirectional model transformations (bx) are numerous, and in the past few years, many such approaches have been presented by rescuers that simulate many development problems and address their solutions to the development community. However, the fact is that these numerous approaches do not answer the fundamental issue of development: the implementation cost and time delay, along with discussing their limitations and the approach are the best fit for an effective model.

Transformation, in particular, these are the fundamental question that needs to be addressed, and that is the major aim of this paper. That is, to provide an in-depth survey of the different approaches that are presented in recent years and then establishing the approaches that are best suited for the bx development.

### 1.1.1 Research Methodology.

The systematic literature review is one of the most advanced research methodologies designed for approaching a problem to understand the key differences, using some of the approaches that may include data gathering and analyzing using some specific set of parameters. The first step in this was to gather data, which was done as per the following criteria.

### 1.1.2 Category/approach selection

In parts and parcel, the review part that we had selected was in more affectively be searched if we cater them to the approaches rather than categorize, which would base our research, therefore for the better review and thus, we evaluated our research-based approaches that were being used in this regard following approaches in bidirectional model transformation had been selected.

1. Approaches in bidirectional models using different tools
2. Estimating effects and cost of model transformations
3. Effectiveness of different approaches on software modeling
4. Enhancing feasibility and cross-platform implementation through Bx

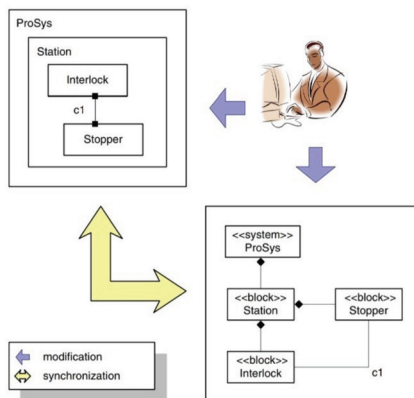


Fig. 1. Model of Synchronization

Figure 1 is obtained from (Malavolta, I., Muccini, H., Pelliccione, P., & Tamburri, D., 2010), representing a simple block diagram and a corresponding class diagram that results from a correct transformation.

Systems, blocks, and processes of a block diagram are transformed into classes with corresponding stereotypes.

## ***2. Research Questions***

The central part of any research is to establish some ground rules that define the research goals and on which the fundamental research will be based; in our paper, we have proposed 4 research questions that cater to the different aspects of our survey; these questions are as follows.

RQ1: What are different technologies and techniques available that implements efficient and practical model transformations?

RQ2: What are the effectiveness and limitations of different approaches or frameworks presented to manage the semantic issues of bidirectional model transformation?

RQ3: What are the tools available that support such transformations and the problems related to them?

RQ4: Which approaches best fit the criteria of effective model transformation?

### ***2.1. Inclusion/Exclusion Criteria***

Following are the six parameters based on which the relevant papers were selected

#### ***2.1.1. Subject relevance***

The first step that we took was to opt for those papers whose subject matter was related to our research; the undertaking this step was done on the extent to which the paper's subject was answering our research questions, and the approach was based on the bidirectional model transformation.

#### ***2.1.2. Time Line 2010-2017***

The selection of paper was made on the timeline, taken for the publishing year of 2010 till 2017, that makes the overall period of 7 years and which is sufficient to make the understanding of the subject understudy has the publication which is latest in the trends and are catering the new needs of the research work; thus this will enable that the papers that we have opted are in relevance with latest trends in our field.

#### ***2.1.3. Publishers***

The databases selected were as follows

- IEEE
- ACM
- Science Direct
- Elsevier
- Springer
- Taylor & Francis

Other than these databases, papers were not selected.

### 2.1.4. Crucial Effects

The results were the primary concern of the inclusion or exclusion of a particular paper from the SLR, these papers which presented results more positively, i.e., the techniques proposed in the selected papers are all implementable and can be manipulated for further advancements, and on these bases, the papers were selected in SLR

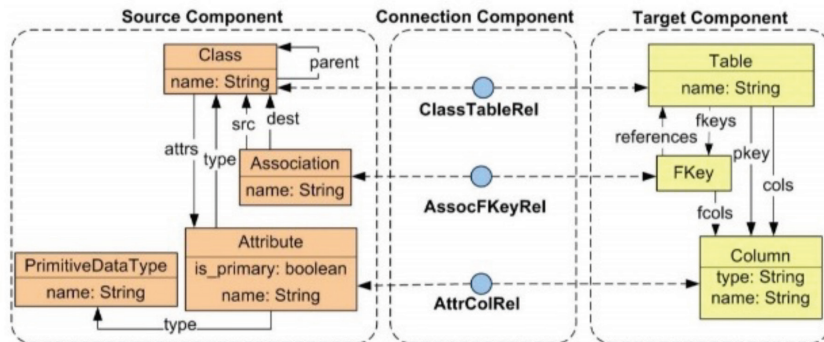


Fig. 2. Model Transformation-1

Figure.1 shows that three components are implemented in this approach 1) source component, which describes the complete details about the source used in this approach, 2) connection component, which describes all the details about connections and their implementation. Moreover, 3) Target Component, which describes the details about table and columns, is used.

### 2.1.5. Result Oriented

Those papers which had used strong validation methods such as testing their algorithms and approaches on the known test cases and presenting their results along with solid facts were selected; further, those papers which did not have the sufficient backing of solid facts in their results were canceled and dropped from the list.

### 2.1.6. Repetition

The other main aspect of the selection criteria was the repetition of the research work of the understudy; that is, most of the work related to one another on these grounds. Most of the papers were rejected a scheme was used in which the latest paper of a particular stream has opted, and the latter were discarded; also, the unique works were selected in this way.

## 2.2. Search Process

The search process in our paper has included the databases as prescribes to us, which included ACM, Elsevier, Springer, IEEE, Science Direct, and Taylor & Francis, along with inclusion and exclusion criteria also was taken into consideration thus, in this manner, we had been able to achieve our search. Following is the table showing the search process we had taken, which includes the search terms that we had opted for and the respective databases that had provided results for those key terms; also,

the Boolean operator used was AND operator mostly.

*Table 1: table showing the search process from keywords and related databases results*

Sr. #	Search Term	Operator	No. of Search Results				
			IEEE	SPRINGER	ELSEVIER	ACM	Taylor and Francis
1	“bidirectional model transformation architectures”	AND	856	596	203	589	0
2	“language in bidirectional model transformation”	AND	126	124	45	754	9
3	“design strategies in bidirectional model transformation”	AND	85	118	10	175	14
4	“functional levels in bidirectional model transformation”	AND	90	124	785	982	3
5	“bidirectional model transformation Tools”	AND	525	889	65	4599	0

### **2.3. Quality Assessment**

Our approach is to develop the quality benchmarks that can address the critical outputs or the results in general that were taken from the finalized list of researches that undergo our scrutiny. These resulting benchmarks have also catered for the authenticity of the factual data that had been selected from the finalized research papers and articles, along with their accurate conclusions.

1. The data for the understudy had been extensively studied, and no ambiguity whatsoever has been left, i.e., no stone has been left unturned. We have followed extensive study made in this domain and are bolstered by strong valid proofs of the gathered data's authenticity

2. Before starting the research work, thorough learning, was made on the topic of our choice, and a complete study was thus, made which included understanding different case studies, survey reports, and books

3. The purpose of the research is to survey the different approaches that are being used in the bidirectional; model transformation techniques, and for that purpose, to

make this survey report much more authentic, the latest research trends had been looked upon for our work which included those papers that were published in the year 2010 and till date which has provided us with the latest trends in the field and also made the survey paper up to date with the latest trends for the understudy, a comparative histogram is shown in figure 1 which shows the percentage of papers from a specific year

5. As aforementioned, the research papers that had been selected are comprised from the databases which have overall impact factor much more significant and also they are globally accepted as a credible source of data sharing and gathering these included ACM, Elsevier, Springer, IEEE, Science Direct and Taylor & Francis

6. As per the point quality is concerned, the primary focus of our research is to provide a survey of the latest trends that are being used in the bidirectional model transformation and provide results based on the parameters (discussed earlier) as to which is the best approach in implementing bidirectional model transformation. Figure 5 is quoted from (Malavolta, I., Muccini, H., Pelliccione, P., & Tamburri, D., 2010), which shows the result of applying our rule to the block diagram. The rule was applied in two steps. In the first step, a match for the left-hand side of the rule was determined.

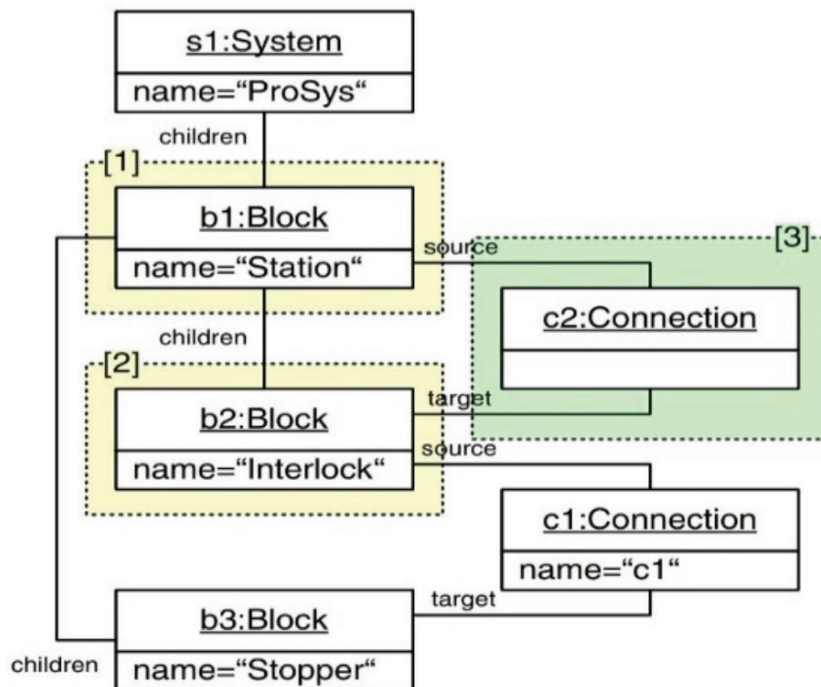


Fig. 3. Block Diagram

In our case, node x was bound to object b1 (shaded area 1), and node y was bound to object b2 (shaded area 2).

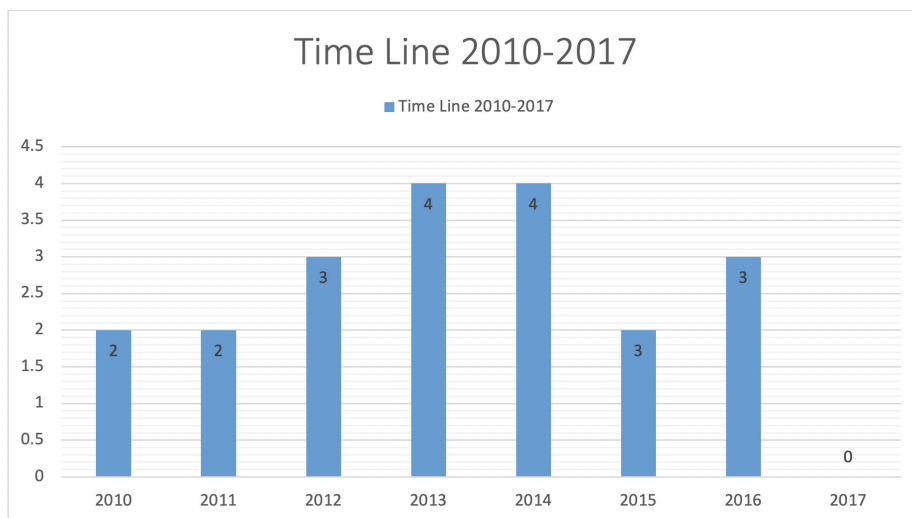


Fig. 4. distribution of the research papers based on their timeline

Table 2: showing data extraction

Sr. no.	Description	Details
1.	Bibliographic Information	Research papers from 2010-2017, Systematic Literature Review
Extraction of data		
2.	Overview	The basis of this research is to provide a survey paper on the latest approaches that are being used in the bidirectional model transformation software development approach.
3.	Results	we have been able to nominate several approaches that can be best suited for our bidirectional model transformation development model
4.	Data collection	Qualitative or Quantitative method used.
6.	Validation	We have done the research and verified it from different sources mentioned in a research paper.

*Bibliographic information*

Sr. #	Scientific Database	Type	Selected Research Works	No. of Researches
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1	IEEE	Journal	(Efrizoni, L., Wan-Kadir, W. M., & Mohamad, R., 2010, December)	1
		Conference	(Samimi-Dehkordi, L., Zamani, B., & Kolahdouz-Rahimi, S., 2016, October; Song, H., Huang, G., et al., 2011; Kramer, M. E., & Rakhman, K., 2016)	9
2	SPRINGER	Journal	(Wider, A., 2014, March)	1
		Conference	(Macedo, N., & Cunha, A., 2013, March; Eramo, R., Pierantonio, A., & Rosa, G., 2015, October; Xiong, Y., Song, H., Hu, Z., & Takeichi, M., 2013; Macedo, N., & Cunha, A., 2016)	4
3	ELSEVIER	Journal	(Malavolta, I., Muccini, H., Pelliccione, P., & Tamburri, D., 2010)	1
		Conference	(Klassen, L., & Wagner, R., 2012; Eramo, R., Pierantonio, A., & Rosa, G., 2014)	4
4	ACM	Journal	(Hidaka, S., Hu, Z., Inaba, K., Kato, H., & Nakano, K., 2011, November)	3
		Conference	(Buckl, S., Ernst, A. M., et al., 2015; Kim, D. K., Lu, L., & Lee, B., 2017; Song, H., Huang, G., et al., 2011)	3

### Results

RQ1: What are different technologies and techniques available that implements efficient and practical model transformations?

Techniques	Paper
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EVL+Trace, QVT-R, TGG and JTL	(Samimi-Dehkordi, L., Zamani, B., &Kolahdouz-Rahimi, S., 2016, October)
Scala as an iDSL	(Wider, A., 2014, March)
QVT-R bidirectional model transformations tool and UML class diagrams in Alloy	(Macedo, N., & Cunha, A., 2013, March)
Algorithm to implement Synchronization	(Xiong, Y., Song, H., Hu, Z., &Takeichi, M., 2013)
QVT-R tool and embedding of both QVTR transformations and UML class diagrams in Alloy	(Hu, Z., &Takeichi, M., 2013; Macedo, N., & Cunha, A., 2016)
A metamodel-independent approach for uncertainty and JTL engine proposal	(Eramo, R., Pierantonio, A., & Rosa, G., 2015, October)
Delta lens framework with an uncertainty mechanism	(Diskin, Z., Eramo, R., Pierantonio, A., &Czarnecki, K., 2016)
Bidirectional model transformations to synchronize architecture models and RSA	(Song, H., Huang, G., et al., 2011)
Mapping Automated Inversion Approach	(Kramer, M. E., &Rakhman, K., 2016)
A metamodel-independent approach for uncertainty	(Eramo, R., Pierantonio, A., & Rosa, G., 2014)

RQ2: What are the effectiveness and limitations of different approaches or frameworks presented to manage the semantic issues of bidirectional model transformation?

Paper	Approach	Effectiveness	Limitation
GRoundTram: An Integrated framework for developing well-behaved bidirectional model transformations	GRoundTram	Using this approach, systematic development of model transformation can be carried out in a compositional model. It has precise semantics for bidirectional model transformation and can be efficiently implemented.	In this paper relation between the rule-based approach and the algebraic and functional approach is not studied. They can be made more powerful for bidirectional model transformation.

<p>Model-based M2M transformations based on drag-and-drop actions: Approach and implementation</p>	<p>Model-based M2M transformations based on drag-and-drop actions</p>	<p>The model-driven development and customization approach of M2M transformations increases the flexibility, extensibility, and usability features of this capability when used in a CASE tool environment. This approach comes with relatively simple and intuitive visual transformation modeling language, which, while being conceptually simple, can be used to design powerful transformations composed of tuples of related/contained model elements.</p>	<p>Transformations of metamodel and DSL engine bring more flexibility and usability features to the development and application of the transformation.</p>
<p>(Samimi-Dehkordi, L., Zamani, B., &amp;Kolahdouz-Rahimi, S., 2016, October)</p>	<p>EVL+Trace, QVT-R, TGG and JTL</p>	<p>EVL+Trace can contain the information update from any user, and it also accommodates the reconciliation factor.</p>	<p>It is also prone to more errors since it does not meet the language standards.</p>
<p>(Wider, A., 2014, March)</p>	<p>Scala as an iDSL</p>	<p>The implementing bx language in Scala proved very effective results in terms of expressiveness and static analysis.</p>	<p>Application to other bx languages</p>
<p>(Macedo, N., &amp; Cunha, A., 2013, March)</p>	<p>QVT-R bidirectional model transformations tool and UML class diagrams in Alloy</p>	<p>It follows the principle of least change and maintains the consistency between models.</p>	<p>Limited performance</p>

(Xiong, Y., Song, H., Hu, Z., &Takeichi, M., 2013)	Algorithm to implement Synchronization	It is capable of supporting concurrent updates in bidirectional model transformation.	Absence of Conflict resolution
(Hu, Z., &Takeichi, M., 2013; Macedo, N., & Cunha, A., 2016)	QVT-R tool and embedding of both QVTR transformations and UML class diagrams in Alloy	It helps in maintaining consistency among these models in case of any updates.	Limited performance
(Eramo, R., Pierantonio, A., & Rosa, G., 2015, October)	A metamodel-independent approach for uncertainty and JTL engine proposal	This approach resulted in the fact that the uncertainty became a first-class priority represented by multiple models, and they are more scalable.	Usability and application to a set of different models
(Diskin, Z., Eramo, R., Pierantonio, A., &Czarnecki, K., 2016)	Delta lens framework with an uncertainty mechanism	The delta-lenses framework is extended so that it helps in the process of consistency preservation.	Representation with tools and visualization
(Kramer, M. E., &Rakhman, K., 2016)	Mapping Automated Inversion Approach	Both forward and backward transformations could easily change the attribute values based on the assumption that instances of both Metaclasses are already generated.	It is only applicable to those expressions With one source Attribute.

RQ3: What are the tools available that support such transformations and the problems related to them?

Tools	Paper
Darwin/FSP ADL and to a UML2.0	Providing Architectural Languages and Tools Interoperability through Model Transformation Technologies
EMorF	EMorF - A tool for model transformations

SoCaTool	Generating Visualizations of Enterprise Architectures using Model Transformations
a generative tool-set	Supporting runtime software architecture: A bidirectional-transformation-based Approach
Eclipse development tool, MoTE3, EMoflon5, QVT-R tool	(Efrizoni, L., Wan-Kadir, W. M., & Mohamad, R., 2010, December)
QVT-R tool	(Macedo, N., & Cunha, A., 2013, March)
JTL	(Eramo, R., Pierantonio, A., & Rosa, G., 2015, October)
QVT-R, UML	(Hu, Z., & Takeichi, M., 2013; Macedo, N., & Cunha, A., 2016)
TGGs	(Kramer, M. E., & Rakhman, K., 2016)

There are different techniques and tools available that support efficient implementation and practice of model transformation. To specify and execute the model transformation, (Klassen, L., & Wagner, R., 2012) presented a model transformation to EMorF for EMF. EMorF is an open-source model transformation tool for the Eclipse Modeling Framework (EMF). In place, model transformations are specified graphically by graph rewriting rules, and model-to-model transformations are specified by triple graph grammars [Sch94]. The main advantage of triple graph grammars is that they allow executing a model-to-model transformation in both directions.

RQ4: Which approaches best fit the criteria of effective model transformation?

Effective model approaches in terms of	Description
Approach	GRoundTram: An Integrated framework for developing well-behaved bidirectional model transformations
Technique	EVL+Trace, QVT-R, TGG and JTL
Tools	Darwin/FSP ADL and to a UML2.0

### *Paper Summary*

S.No	Paper Title	Reference	Summary
1.	Providing Architectural Languages and Tools Interoperability through	(Malavolta, I., Muccini, H., Pelliccione, P., & Tamburri, D., 2010)	DUALLY is an automated framework that allows architectural languages and tools interoperability. It is implemented as an Eclipse plug-in. Putting it in practice, the DUALLY approach is applied to the Darwin/FSP ADL and a UML2.0 profile for software architectures. UML software

	Model Transformation Technologies		architecture is transformed by using an industrial complex system, and some verifications were made by using LTSA, and it also reflects changes required by the verifications back to the UML specification.
2.	EMorF - A tool for model transformations	(Klassen, L., & Wagner, R., 2012)	EMorF - a model transformation tool was proposed for EMF. EMorF supports the specification and execution of in-place model transformations as well as model-to-model transformations. The graphical though the formal specification is based on (triple-) graph grammars executed by an interpreter system.
3.	GRoundTram: An Integrated framework for developing well-behaved bidirectional model transformations	(Hidaka, S., Hu, Z., Inaba, K., Kato, H., & Nakano, K., 2011, November)	GroundTram is intended and implemented for compositional development of well-behaved and efficient bidirectional model transformations. It is implemented on the bidirectional framework and is equipped with a user-friendly language for coding bidirectional model transformation. The other notable feature of this approach includes an optimizing mechanism for improving efficiency, a powerful debugging environment for testing bidirectional behavior, and a novel tool for validating both models and transformations.
4.	Generating Visualizations of Enterprise Architectures using Model Transformations	(Buckl, S., Ernst, A. M., et al., 2015)	We identify issues in visualization handling that we came across during an extensive survey of existing tools for EA management. We then point to the fundamental principles of software cartography, an approach for EA modeling, including a method for the automatic creation of visualizations based on EA models. This approach is based on model transformations, which link the data to be visualized and their graphical representation, thereby circumventing the error-prone and time-consuming task of manual creation of the visual models. A brief overview of a prototypic implementation of this approach illustrates the practical applicability for visual modeling and documenting EA.

5.	Feature-based classification of bidirectional transformation Approaches	(Hidaka, S., Tisi, M., Cabot, J., & Hu, Z., 2016)	This paper tries to clarify and visualize the space of design choices for bidirectional transformations from an MDE point of view, in the form of a feature model. The selected list of existing approaches is characterized by mapping them to the feature model. Then, the feature model is used to highlight some unexplored research lines in bidirectional transformations.
6.	Model-based M2M transformations based on drag-and-drop actions: Approach and implementation	(Skersys, T., Danenas, P., & Butleris, R., 2016)	In this paper, we present our approach for an incremental model transformation that supports model synchronization. Our approach employs the visual, formal, and bidirectional transformation technique of triple graph grammars. Using this declarative specification formalism, we focus on the efficient execution of the transformation rules and how to achieve an incremental model transformation for synchronization purposes. We present an evaluation of our approach and demonstrate that even larger models can be tackled due to the incremental processing speed in the average case.
7.	Reactive model transformation with ATL	(Martínez, S., Tisi, M., & Douence, R., 2017)	This paper proposes a reactive paradigm for programming model transformations, and we implement a reactive model transformation engine. We argue that this paradigm facilitates autonomous model-driven systems that react to update and request events from the host application by identifying and performing only the needed computation. We implement such an approach by providing a reactive engine for the ATL transformation language. We evaluate the usage scenarios that this paradigm supports, and we experimentally measure its ability to reduce computation time in transformation-based applications.
8.	Design Pattern-Based Mode	(Kim, D. K., Lu, L.,	This work presents an approach for transforming an application model using

	I Transformation Supported by QVT	& Lee, B., 2017)	both the structural and behavioral properties of a design pattern defined in terms of the problem and solution domain and its implementation using Query/View/Transformation (QVT). In the approach, we define pattern consistency for structural and behavioral pattern properties and pattern conformance for pattern applicability before transformation solution conformance after transformation. We demonstrate the approach using the Observer pattern applied to a graph application. Besides the Observer pattern, we also define transformation rules for the Visitor and Adapter patterns
9.	Supporting runtime software architecture: A bi-directional-transformation-based Approach	(Song, H., Huang, G., et al., 2011)	The study of synchronization mechanism between architecture configurations and system states for maintaining the causal connections. Four required properties for such synchronization were identified, and a generic solution was provided.  Bidirectional The transformation was used to bridge the abstraction gap between architecture and system, and an algorithm was designed based on it, which addresses issues such as conflicts between architecture and system changes and exceptions of system manipulations. A generative tool-set was used to implement this approach on a wide class of systems.
10.	A Systematic Literature Review to Identify the Issues in Bidirectional Model Transformation	(Efrizoni, L., Wan-Kadir, W. M., & Mohamad, R., 2010, December)	This paper aims to analyze and explore the current issues on BMT by using a systematic literature review (SLR). Based on the results of the SLR, seven issues related to BMT were identified, and two main approaches in solving the inherent BMT problem were discovered and reviewed. These results will be helpful as input in designing a better framework of BMT in the future.
11	Bidirectional model transformation approaches	(Samimi-Dehkordi, L., Zamani,	Bidirectional model transformation is an efficient way of maintaining consistency between different models in model-driven

	a comparative study.	B., &Kolah-douz-Rahimi, S., 2016, October)	<p>applications. Different bx approaches are evaluated in this paper, including EVL+trace, QVT-R, TGG, and JTL.</p> <p>These bx approaches are then evaluated based on the PL evaluation guideline and bidirectional features. A comparison is conducted between all the above bidirectional approaches based on the proposed criteria. The result shows that these approaches have a state-based change representation with bidirectional definition directionality that supports offline change in the input. EVL+Trace is able to contain the information update from any user, and it also accommodates the reconciliation factor. It is also prone to more errors since it does not meet the language standards. However, QVT-R is not able to provide the preservation and reconciliation feature. TGG is also not capable of supporting the preservation, reconciliation, and hippocraticness factors. JTL conforms to the language paradigms, but it does not accommodate the preservation and reconciliation features.</p>
12	Implementing a Bidirectional Model Transformation Language as an Internal DSL in Scala	(Wider, A., 2014, March)	<p>In bidirectional transformation languages, the creation of good tooling is an important and tedious task. The tooling must be compatible with other tools available in software development. In this paper, the concept of internal DSL is evaluated that a bidirectional language can be executed in Scala as an iDSL. Scala programs are generally similar to that of java. The scala concepts explored are implicit conversions and type members. The data mode implemented allows implementing original tree lenses without any change in the semantics for model transformations. The paper further explores the conversion between a model element to a typed term, the tree with cross-references, and maintaining the integrity during the conversion. Implementing bx language in scala showed</p>



			that a great measure of expressiveness and static analysis could be accomplished.
13	Implementing QVT-R Bidirectional Model Transformations using Alloy	(Macedo, N., & Cunha, A., 2013, March)	In model-driven engineering, different models are used to encompass various views of a particular system. The main idea is to maintain consistency between all these different models somehow so that making any change or updates in one model should be promulgated to all the others models consistently. In this paper, a QVT-R bidirectional model transformation tool is proposed to solve the issues in bidirectional transformation. It follows the principle of least change and maintains the consistency between models. In this paper, for clarity, the transformation between two Meta models is being considered. The check-before-enforce policy is adopted during the transformations. The two models are checked if they are consistent, and the transformation causing the change in a source model is consistently propagated to a target model. Further in this paper, the embedding of QVT-R in Alloy, a formal specification language, is proposed to ensure the correctness of specification and minimize run time errors.
14	Managing uncertainty in bidirectional model transformations	(Eramo, R., Pierantonio, A., & Rosa, G., 2015, October)	A model is proposed in this paper for uncertainty in bidirectional transformations, and further, the technique is applied to JTL to show the outcome of the suggested proposal. JTL is a language for bidirectional model transformation. The designer cannot implement deterministic transformation due to the unknown uncertainty at the time of design, and it is then converted into known uncertainty in the output. It is complicated for the designer to inspect models manually as the number of changes increases and more errors are likely to occur.

			<p>This paper deals with the uncertainty factor in a group of models executed after non-deterministic transformations. A meta-model independent approach is being presented, which would help generate a solution in terms of the uncertainty of the model. The uncertainty factor should not be ignored; instead, it is better to consider it a first-class concern during design. This approach resulted in the fact that the uncertainty became a first-class priority represented by multiple models. Further in this paper, it is explored how JTL will generate a model with uncertainty. The designer can then decide all the possible alternatives once a model with uncertainty is generated.</p>
15	Synchronizing concurrent model updates based on a bidirectional transformation	(Xiong, Y., Song, H., Hu, Z., &Takeichi, M., 2013)	<p>In bidirectional model transformation, when two models are being updated simultaneously, the consistency suffers. In this paper, an approach is presented to apply concurrent updates in model transformation. The main requirement for synchronizing concurrent updates such as consistency, stability, and preservation are identified. An algorithm is then proposed which is capable of supporting concurrent updates in bidirectional model transformation. This algorithm is implemented to an application that presents the outcome that could be used for some particular scenarios, and typically for medium-sized models, the performance is better.</p>
16	Least-change bidirectional model transformation with QVT-R and ATL	(Hu, Z., &Takeichi, M., 2013; Macedo, N., & Cunha, A., 2016)	<p>In this paper, a QVT-R tool has been proposed, incorporating the principle of least change. In model-driven engineering, a particular system might have different models which provide different decisions. The idea of maintaining consistency among these models in case of any update is important. The principle of “check-before-enforce” must be applied a it is also an essential factor of model transformation.</p>

			<p>The property of determinism should be fulfilled to make the outcomes more predictable. This is generally not applicable because it limits the expressiveness of a language by making the relations only mapped one to one. The embedding of QVT-R in alloy specification language is also discussed in the paper. The models on which the transformation is based contain UML class diagrams with OCL constraints. The consistency is checked for some concrete models. The tool immediately notifies the user if the models are at a minimum distance and presents some different alternatives. The tool is also updated to support the bi-directionalization of ATL transformations. The major disadvantage is reduced performance.</p>
17	Incorporating Uncertainty into Bidirectional Model Transformations and their Delta-Lens Formalization	(Diskin, Z., Eramo, R., Pierantonio, A., & Czarnecki, K., 2016)	<p>In bidirectional transformations, one of the main issues is that consistency relation between different modes could be of many types; maintaining consistency between them an indefinite process. In case of any change on one side that violates the consistency, there would need multiple updates on the other side to restore consistency. In this paper, the delta-lenses framework is extended so that it helps in the process of consistency preservation. Uncertainty management is a crucial process in model transformation. The approach presented will benefit the delta lenses framework based on the uncertainty criteria such that the problem of incompleteness would be managed within the algebra of single-valued operations.</p>
18	Supporting runtime software architecture: A bi-directional-transformation-based approach	(Song, H., Huang, G., et al., 2011)	<p>In this paper, synchronization among different architecture models is discussed, and a general approach is presented to address the issue of rum time systems. The bidirectional transformation is being used to explore changes between</p>

			<p>system and architecture. A two-phase execution criterion is applied to eliminate any conflicting changes. A validating read is also added after system modifications so that a consistent architecture model is constructed. The management APIs are considered for example. The algorithm fulfills the criteria of effective reconfiguration, consistency, and stability.</p>
19	Automated Inversion of Attribute Mappings in Bi-directional Model Transformations.	(Kramer, M. E., & Ra-khman, K., 2016)	<p>Bidirectional model transformation follows the concept that a single transformation specification can be executed in both forward and backward directions. Triple graph grammars are successfully used to define many computations in bidirectional mode. This paper presents an approach for the automated inversion of attribute mappings in forwarding specifications of bidirectional transformations. The approach is based on the languages such as Essential Meta Object Facility (EMOF). The GetPut and PutGet laws are used for bidirectional transformation in this paper. The inversion approach gets an assignment expression that consists of attributes from two different metaclasses as an input of the forward transformation direction and outputs an inverse assignment expression for the backward transformation direction. In this case, the attribute values could be easily changed by both forward and backward transformations based on the assumption that instances of both Metaclasses are already generated.</p>
20	Representing Uncertainty in Bi-directional Transformations	(Eramo, R., Pierantonio, A., & Rosa, G., 2014)	<p>In this paper, the uncertainty factor that exists in bidirectional transformations is being addressed. The issue of non-determinism in bidirectional transformations relevant to the uncertainty factor is discussed. The management of different models is complex and poses many threats.</p>

		<p>The transformation decisions are crucial and, if not done accurately, might result in different solutions, each representing different views. The lack of information during design time would lead to non-deterministic transformations, creating uncertainty in the solution. A meta model-independent approach is presented in the paper for uncertainty representation. The ambiguities in the model transformation must be encoded to get various design approaches for selection among them.</p>
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**Submitted: 20.06.2020**

**Accepted: 24.05.2021**