PRIMROSe
A Tool for Enterprise Architecture Analysis and Diagnosis

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Abstract: Enterprise Models are the central asset that supports Enterprise Architecture, as they embody enterprise and IT knowledge and decisions. Static analysis over this kind of models is made by inspecting certain properties and patterns, with the goal of gaining understanding and support decision making through evidence. However, this is not a straightforward process, as the model in its raw form is rarely suitable for analysis due to its complexity and size. As a consequence, current approaches focus on partial views and queries over this model, leading to partial assessments of the architecture. In this paper, we propose a different approach to EA analysis, which consists on the *incremental* assessment of the architecture based on the interaction of the user with visualizations of the whole model. We implemented our approach in a visual analysis tool, PRIMROSe, where analysts can rapidly prototype custom functions that operate on topological properties of the model, combine partial insights for sounder assessments, associate these findings to visual attributes, and interact with the model under several visualization techniques.

1 INTRODUCTION

Thirty years since its inception, Enterprise Architecture (EA) has evolved from a method for reconciling business and IT to a relatively mature discipline. Enterprise Modelling is one of the subjects where EA can deliver real value on the organization, and consists on the development of Enterprise Models (EMs), which are the embodiment of all the collected information about the enterprise under several perspectives. Building EMs typically comes with a high price tag that is payed for when they are analyzed, that is, when additional knowledge is created by processing and reworking previously defined facts (Buckl et al., 2010). The knowledge gained from analyzing EMs serves to support decision making processes in architectural and stakeholders boards, and to lower risk.

A very important concern with analysis is that it is far from being a trivial task. Most of the times, analyzing an EM involves the formulation and reformulation of hypotheses, as well as the composition of different insights in order to get to sound assessments. Furthermore, the scope of analysis processes is arbitrary and not necessarily known *a priori*. It may range from a full-fledged impact analysis over the entire model, to an in-depth analysis on a specific domain where issues were detected during the early stages of the analysis process. For instance, if an analyst needs to assess the business process architecture of an enterprise, he would use a pertinent and proven method (e.g. Flow Analysis) for this evaluation, which differs from say, a security (e.g. vulnerability) assessment. Furthermore, it would be a good idea to use a combination of several methods, in order to arrive to more powerful insights.

On top of that, the reasoning process behind an analysis is rarely expressed and documented because it heavily depends on the experience of the analyst. This lack of a traceability mechanism forces the analyst to guess the rationale behind past decisions.

Also, we have to take into account that EA modelling tools offer different features and thus restrict the kind of analysis that they support (Schekkerman, 2006). Some of the characteristics that result in limitations include **a)** the modelling approach, **b)** the metamodels supported, and **c)** their analytical capabilities, which range from model conformity checks to generation of pre-defined views and the possibility to query the model.

Given known and important characteristics of EMs, such as being large, complex, typed, and structural in nature (Naranjo et al., 2013), visualizations are becoming more and more used to support analysis methods. However, most modelling tools only pro-

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vide the capacity to visualize (by means of diagrams or views) partial models that are subsets of an EM. While there is the notion of an integration of these views to form an unified model, it is rarely possible to apply analysis techniques over the whole EM.

The problem with this, as evidence suggests, is that applying analysis without an overview of the whole model can possibly lead to information loss and reaching false conclusions (Naranjo et al., 2012). Furthermore, interactive exploration of the large volumes of data by visual means, appears to be "... useful when a person simply does not know what questions to ask about the data or when the person wants to ask better, more meaningful questions" (Fekete et al., 2008). This precisely reflects what precedes most ad-hoc analyses and explains why visualizations are progressively considered less as a product (diagrams) than a medium.

Taking into account the issues discussed above, we consider that a platform that enables structural analysis of EMs, and is supported by its visual exploration and interaction, can facilitate the tasks of an analyst. Thus, we can formulate our research question as follows: *How can we provide an useful and flexible method for inspecting facts on an Enterprise Model, and what is the architecture behind an analysis tool that supports the visualization of the whole model, displaying these facts incrementally?*

The goal of this paper is to present a conceptual framework –and a tool that implements it– that addresses these issues. This framework supports the formulation of analytical functions that enrich the model, and allows their visualization through an extensible set of visualization techniques. This work is based on the usage of overview visualizations that display the underlying topology of an Enterprise Model and help the analyst to incrementally find new structural properties and patterns. This conceptual framework was implemented in PRIMROSe, an advanced platform for the analysis of metamodel-independent EMs, which provides feedback continuously as new insights are generated during an analysis process.

The structure of this paper is as follows: First, in Section 2 we will provide a literature review of similar approaches. Section 3 offers an overview of our approach, followed by Section 4, which describes the conceptual framework and the architecture of PRIMROSe. Then, Section 5 will describe in depth the analysis component of the tool, and Section 6 will explain how to map analysis results into visualizations. Finally, Section 7 will discuss results and future steps.

2 RELATED WORK

In general, Visual Analysis of Enterprise Architectures is grounded in the wide array of previous work in Software Visualization. The contribution of (Panas et al., 2005) is a framework and an architecture that supports the configuration of model-to-view and view-to-scene transformations, under a graph-based approach.

Based on the relation between visual attributes and views, the authors start from a model graph, which is translated almost directly to a view graph, filtering unused properties from the model. Visual Metaphors are a collection of common Visual Representations, i.e. families of visual objects fitting together, and are used to visualize properties of a model under a given visualization, such as graphs, trees, or more complex 3D representations (e.g. city maps).

However, this architecture does not support the differentiation of edges, an important requirement on EA Analysis (Naranjo et al., 2013). Moreover, as the framework deals just with the visual mapping, so the platform requires a pre-processing of the model that is left to the user. Finally, it is not clear how to travel the way back from visualization to further analysis, i.e. the representation is static.

(Chan et al., 2010) describe a Visual Analysis tool for bottom-up enterprise analysis, based on the incremental reconstruction of hierarchical data. Analysis is made by the exploration of the model, starting with an initial view of an entity, and adding elements to a graph visualization by selecting concepts and relations in the metamodel. This is complemented with a set of filtering, searching, and abstraction methods.

This bottom-up exploration is useful to manage the complexity of models, and can be a complement to top-down analysis. However, this approach assumes that the analyst knows where to start, which is a problem in models of thousands to millions of elements. Moreover, previous processing and analysis is again a prerequisite, and custom views have to be coded a priori, as there is no integration with graphical frameworks. Finally, EMs are semi-hierarchical (Naranjo et al., 2013), which means that non-hierarchical edges are eliminated.

In the field of Model Driven Engineering, Zest (The Eclipse Foundation, 2013), based on the work of (Bull, 2008), amplifies visual capabilities of modelling editors based on the Graphical Editing Framework with Spring, Tree, Radial and Grid layout algorithms, or in general, families of graph visualizations.

The framework allows the processing of the model graph, e.g. to search for paths, operating in terms of the attributes of the model elements. Also, it is possible to selectively highlight elements and relations, developing view operations that modify visual attributes. However, each view must be developed from scratch, and while the authors focus on an easily to program framework, there is no explicit way to compose and process independent view operations. Also, despite there is an effort to provide custom visualizations, and support for other graph formats has been recently added (such as the DOT format of the Graphviz library), visualization is bounded to the techniques offered by their visualization toolkit.

Recent approaches on the Visual Analysis of EA focus on view-based modelling and analysis. (Buckl et al., 2007; Schaub et al., 2012) describe the conceptual framework and requirements behind the generation of domain independent interactive visualizations that comply to pre-defined stakeholder Viewpoints, linking an abstract View Model with the EA Information Model.

With a focus on non-technological stakeholders, the authors provide a tool (Hauder et al., 2013) that allows the design of ad hoc visualizations that filter the model taking into account aspects such as access rights of a stakeholder to the information.

In (Roth et al., 2013), the authors further enhance this framework with a pattern matching algorithm that supports the mapping of information and view models, based on the information demand and offering. The tool provides a set of configurable visualization techniques, such as a Gantt Charts, Matrices, Bubble Charts, and Cluster Maps.

While this allows the analysis of the Enterprise Model by non-technical business experts, it makes difficult to provide flexible and specialized analysis to architects. As described in Section 1, the generation of these views deal with the communication of the architecture.

In summary, there are some aspects that current research is not addressing, leaving a gap in the field of Enterprise Model Analysis:

- We could not find approaches that allow the composition/combination of different analysis methods, i.e. incremental processing of the model by operating on previous analysis routines.
- Approaches seldom provide a clear division between analysis and visualization, the latter commonly being just a product of the analysis, e.g. diagrams, instead of a medium for interactive analysis.
- Support for ad-hoc analysis is limited, and often implies the development of tailored analysis tools from scratch.
- We could not find approaches that take full advantage of the several topological properties of Enterprise Models seen as networks/graphs, such as the differentiation of relations between elements, discovery of paths, clusters, or graph metrics.
- Current approaches are often tied to a concrete graphical library/framework, offering a limited set of visualization techniques. Moreover, the composition of several techniques on the same representation is not possible.

3 VISUAL ANALYSIS OF EA MODELS

Visual Analysis takes advantage of the ability of people to discover patterns easily, and revolves around giving shape - or *Finding the Gestalt* (Buja et al., 1996)- of information, in order to uncover outliers, bad smells, and interesting or unusual groups/clusters. In this aspect, the human visual system is one of the most sophisticated in nature, and shape is one of the most important visual attributes to characterize objects (Backes et al., 2009).

On the other hand, the complexity of Enterprise Models demands new methods for inspecting their properties and finding interesting facts about them. Thus, Visual Analysis appears as a valuable field with several ideas that we can take advantage of.

This section will describe the Visual Analysis process that starts with an Enterprise Model and ends with the results of analysis that derive on assessments about the architecture. This kind of analysis is incremental, and it is guided by the interaction of the analyst with the model.

3.1 Visual Exploration and Interaction

In their study about the interactive nature of visualizations, (Chi and Riedl, 1998) provide a conceptual model and a classification of interactive tasks. They propose the notion of operators that transform a data model under a series of stages in a *Visualization Pipeline* (see Fig. 1). This results on a *view* of the data, mediated by *Analytical* and *Visualization* models.

(Wickham et al., 2009) take this idea further, asserting that any visualization technique has the (often implicit) notion of a pipeline. However, they also mention the fact that this pipeline metaphor breaks down when user interaction is considered: on each transformation stage of the process, user interaction (e.g., grouping, collapsing, zooming) can take the visualization to another transformation step. Thus, in-

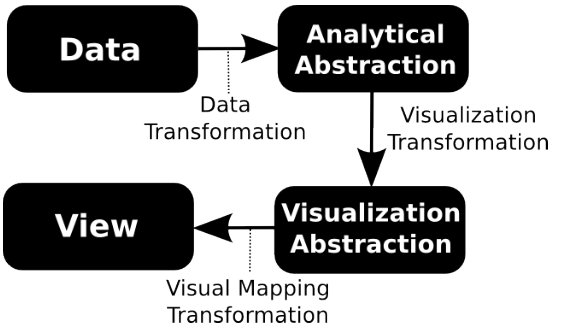


Figure 1: Visualization Pipeline from (Chi and Riedl, 1998).

stead of being sequential, the Visual Analysis processes operate in a *sense-making loop*, or dialog, between the user and the data in a visual form.

In the context of EA, (Schaub et al., 2012) describe a conceptual framework with requirements for interactive visualizations of EA models. In particular, the interaction type is selected depending on the type of analysis required. For example, in order to perform 'what-if' analyses, it provides the means to generate dynamic views conformant to a viewpoint metamodel aligned to the concerns of a stakeholder, and his access to information.

3.2 A Process for EA Visual Analysis

At this point we want to make a parallel with the field of Visual Analytics, which can be regarded as the transformation from data to insights by a concatenation of several sub processes, such as visualizing data sets and generating hypothetical models from them.

Visualization is a semi-automated analytical process, where humans and systems cooperate using their respective distinct capabilities for the most effective results (Kohlhammer et al., 2009). The user modifies visualization parameters repeatedly (Jankun-Kelly et al., 2007), allowing the analyst to gain insights by directly interacting with the data, and coming up with new hypotheses that can be validated, again with visual interaction (Keim, 2002).

This process is based on the economic model of visualization proposed by van Wijk (van Wijk, 2005; Fekete et al., 2008), where a visualization is a time-dependent image (instead of a static one), and a gain in knowledge is based on the perception of the image and knowledge acquired from previous interactions.

Inspired by this model, we define EA Visual Analysis as an iterative process between an Analyst and a VA System, where hypotheses are generated and refined by the means of interaction with visualizations.

This process (described in Fig. 2) begins with an

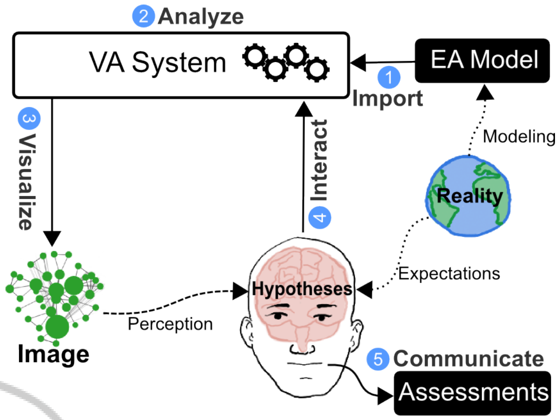


Figure 2: The EA Visual Analysis process.

initial **Import** of the Enterprise Model, which is transformed into a graph structure (part of the Analytical Abstraction - see Fig. 1). This model can be **Analyzed**, i.e. processed under a series of functions that operate in terms of its structure, adding new information. For the first iteration of the process, this stage will be a lightweight processing, as our priority is to visualize and explore the model in its totality.

Posterior to this processing, the analyst is able to **Visualize** the model structure with several Visualization Techniques. We use these visual representations as a memory aid to amplify cognition - that means, we transform data into images to derive insights, using pattern recognition from the human visual system to process visual information.

As the analyst starts to **Interact** with visualizations of the model, Hypotheses (which start as expectations, i.e. weak formulations) get refined over time. This interaction modifies the parameters of a visualization, both with view and data operators. These last operators parametrize and activate Analytical Functions for further processing of the model.

Within each iteration, these formulations are confirmed or denied, as the analyst starts to associate visual patterns with EA patterns (Buckl et al., 2008) that are present from knowledge and experience. Finally, when the Analyst has acquired sound insights on the model, he is able to **Communicate** results from the analysis in terms of Assessments of the architecture. **This last stage is out of the scope of this paper.**

3.3 Requirements for Visual EA Analysis

The complexity of depicting large models has been largely examined, and two key concerns that surface in their visualization are: a) the use of algorithms for the automatic placement of elements of the model to

Table 1: EA Analysis Requirements (Naranjo et al., 2012).

Category	Description
Identify and Relate Domains	Differentiate architecture domains/perspectives, and show the dependencies between them.
Emphasize Key Elements	Selectively give emphasis to certain elements based on key concepts of the metamodel or other criteria.
Offer a Focus of Interest	Create groups of interesting elements, in order to define a focus/scope for the analysis.
	Navigate the model under various levels of abstraction.
Support Structural Diagnosis	Display different visual patterns to discover critical elements, structural anomalies and outliers.
Display Semantic Characteristics	Take into account the different relation types of the metamodel,as their meaning is valuable information.
Uncover Architectural Qualities	Provide a continuous visual representation to offer assessments in terms of the whole architecture.

minimize visual complexity (Fruchterman and Reingold, 1991), and b) the need of automated abstraction mechanisms that reduce information overload (Egyed, 2002).

With these issues in mind, (Naranjo et al., 2012) defined a collection of requirements from the Visual and EA Analysis perspectives. By exploring the concept of 'holistic' or 'total' overview visualizations, and in the context of Visual Analysis applied to Enterprise Models, these requirements were used to evaluate the gap between what is currently offered by popular EA modelling tools, and what is possible with general purpose visualization toolkits. EA Analysis Requirements (see Table 1) provide the guidelines that complement and support the process described in Section 3.2.

These requirements reflect how and what we can emphasize in an Enterprise Model. For instance, an Analyst can start by identifying the domains of the model, and in an incremental manner point to certain facts from the architecture, e.g. by focusing on groups that have common characteristics in terms of its entities (Emphasize Key Elements) and/or relations (Display Semantic Characteristics).

Another important, but often overlooked issue, is to maximize the effectiveness of these visualizations, that means, to provide an overview of the model that is expressive enough to support the tasks of an analyst. (Naranjo et al., 2013) examine the effectiveness of four overview visualization techniques: Force-directed graphs, Radial graphs, Sunbursts and Treemaps, and further prescribe use cases (i.e. Analytical Scenarios) for EA Visual Analysis.

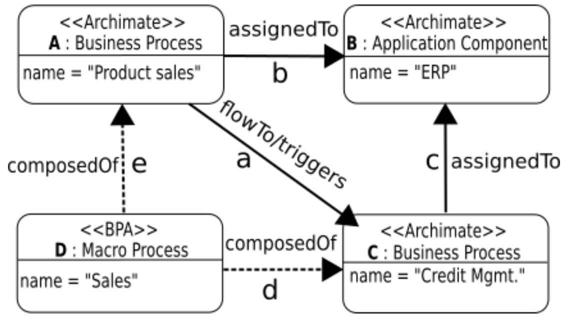


Figure 3: Excerpt of an Enterprise Model.

These cases include the *diagnosis* of Enterprise Models, that is, to discover anomalies in their structure, such as isolated sub-graphs of the model. This pre-emptive aspect of analysis is largely unexplored, but we consider that it is where valuable insights are generated, in the same manner as a physician can identify pathologies with a view to a MRI Scan.

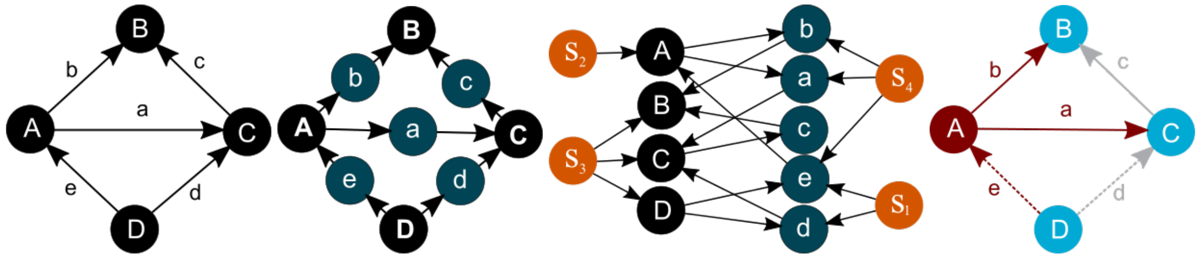
4 PRIMROSe - enterPRIse Model gRaphical Overview AnalysiS

The goal of this section is twofold. On the one hand, it will present the architecture of PRIMROSe, the tool that we developed for performing visual analysis of EMs. On the other hand, it will present the conceptual framework at the base of PRIMROSe, and the way it is structured to support the application of analysis and visualization functions.

Figure 3 presents a trivial model that will be used throughout this section to illustrate our conceptual framework. This figure represents a small excerpt of an Enterprise Model that relates elements from domains, such as Strategy, Infrastructure, or Business Process Architecture. In this model, *A* and *C* are Business Processes, while *B* is an Application Component and *D* is a Macro Process that references processes A and C. For the purpose of illustrating an analysis over this model, we will try to assess the consequences of removing process *A*. This should have an impact on *B*, *C* and *D*, and also implies the removal of relations *a*, *b* and *e*.

4.1 Conceptual Framework: Data Structures

In order to support even simple analysis such as the one presented in the previous section, it is necessary



(a) Model Graph G_M (b) Expanded Graph G_E (c) Analysis Graph G_A (d) Visual Result

Figure 4: Transformation stages of the Enterprise Model, from the Model Graph to a Visualization.

to have the capacity to identify or select, and group, individual elements in the model. Taking into account that in Enterprise Architecture analysis working with the relations is as important as working with the elements, the underlying data structures for the analysis are not the raw Enterprise Models. Instead of that, the approach is based on graphs that are an homeomorphism on the EM, which means that they are topologically equivalent to it (Ray, 2012), but make relations first-level elements. We now describe these graphs and the way in which they are built, starting from what we call Model Graph (see Fig. 4(a)).

Model Graph: It is a directed graph $G_M = (V(G_M), E(G_M))$, where $V(G_M)$ is a set of vertices and $E(G_M)$ is a set of edges. Each vertex in $V(G_M)$ references one element of the original EM, and each edge in $E(G_M)$ references a relationship in the model between the corresponding pair of elements. Furthermore, each vertex can have attributes that will be added during the analysis process.

The second data structure, which can be automatically built from the Model Graph, is what we call the Expanded Graph (see Fig. 4(b)).

Expanded Graph: It is a directed and ***bipartite*** graph $G_E = (V(G_E), E(G_E))$, where $V(G_E) = V(G_M) \bigcup E(G_M)$ is the set of vertices, and $E(G_E)$ is the set of edges. Each of these edges connects a vertex from $V(G_M)$ and an edge on $E(G_M)$, or the other way around.

The Expanded Graph contains exactly the same information as the original EM, that is, no new knowledge has been added. In order to do so, and thus really start the analysis process, we need to define the third data structure, which is precisely called the Analysis Graph. Where this graph differs from the previous one is on the introduction of an additional type of vertex called *selector*, which serves to group vertex in a G_E, which stand for elements or relationships of the original EM (see Fig. 4(c)). More precisely, Analysis Graph and Selectors are defined as follows:

Analysis Graph: A directed graph $G_A = (V(G_A), E(G_A))$, where $V(G_A) = V(G_E) \bigcup S$ is the set of vertices, and $E(G_A)$ is the set of edges, each one connecting a pair of vertices. S is the set of new vertices that are not present in $V(G_E)$, and they are called *Selectors*.

Selector: A node in $V(G_A)$ that is not present in $V(G_E)$, but has edges that point to vertices of $V(G_E)$.

4.2 Conceptual Framework: Functions

Ultimately, selectors are the elements in an Analysis Graph that reify the knowledge acquired through an analysis process. Within the proposed framework, selectors are added by means of the application of functions that operate over Analysis Graphs. These functions, which should be specifically defined depending on the kind of analysis been performed, can be of two types: Analysis Functions, and Decorator Functions.

Analysis Function: It is a function $f : G_A \times P \rightarrow G_A$ that inserts selectors on an Analysis Graph. In order to be applied, an analysis function requires a source graph, and a set of parameters which vary depending on the specific function.

Decorator Function: It is an Analysis Function that produces a graph with the same vertices and edges as the original one, but complements the vertices with additional attributes.

Considering these two types of functions, and the available data structures, we can now illustrate the analysis process applied to the sample model. For this, we now define 5 atomic functions which incrementally process G_A (see Fig. 5) and ultimately result in a graph where it is trivial to answer the question "which elements will be affected by the removal of process A (Product Sales)?".

- f_0 is a decorator that adds the domain of an element as an attribute. In the case of the example, elements A, B and C are grouped in the same domain because they represent ArchiMate (The

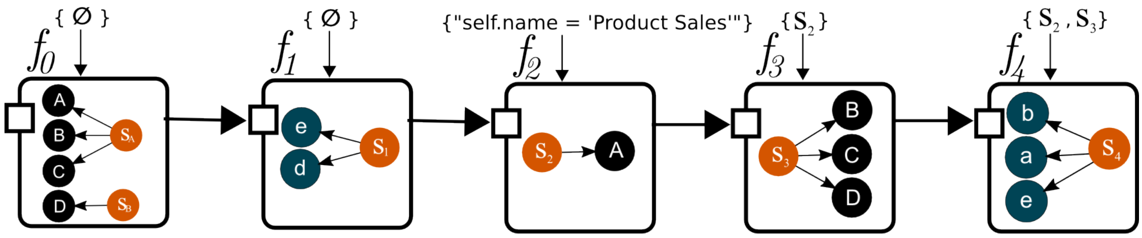


Figure 5: Analysis Pipeline for the example.

Open Group, 2012) concepts, while element D is classified in another domain.

- f_1 is a function that adds a selector (S_1) which groups edges that connect elements from different domains.
- f_2 is a function that adds a selector (S_2) to vertices that satisfy an expression entered as a parameter. In this case, the only element selected is A, which refers to the Process where the attribute `name` equals "Product Sales".
- f_3 is a function that selects model elements that are referenced by a selector received as a parameter. In this case, it selects the elements B, C and D, and introduces the selector S_3 to reference them.
- f_4 is a function that selects the relations between elements in groups of elements defined by selectors. In this case, it select a, b, and c, which are the relations between elements selected by S_2 and S_3.

4.3 Additional Requirements

In order to describe the architecture of the tool, we have another set of requirements that are introduced by the conceptual framework:

1. *Incremental Analysis*: As described by the process in Fig. 2, EA Visual Analysis is incremental, starting with lightweight processing (or even no processing at all) in the initial stage of analysis, and with the application of additional processing on demand, given by the interaction of the user with the tool. In this order of ideas, Analysis Functions should be applied in a composite manner, e.g. as a *pipeline* (see Sec. 5.3), with functions given in terms of Selectors created on previously applied functions (see f_3 and f_4 of Fig. 5).
2. *Reusable and extensible functions*: One of the pillars of Primrose are user-defined analysis functions defined in terms of elements of the model and/or metamodel, complemented with basic graph functions (see Sec. 5.1) that are independent of the EM and its metamodel.
3. *Non-destructive Analysis*: As it could be noted by the reader in Section 4.1, Analysis Functions cannot remove nodes from the Analysis Graph. Filtering is made explicit by the user in terms of the visualization, not the data, i.e. elements are visually hidden, but present in the Analysis Graph.
4. *Independence from the Visualization Framework*: Currently, there is no general-purpose graphical toolkit that satisfies all of the visual requirements for the Visual Analysis of EMs (Naranjo et al., 2012). Each one has its own strengths in various aspects, so the user should select which one to use, depending on the visualization technique and capabilities needed for a specific analysis. Also, specialized users can design their graphic library for EA-specific visualizations.
5. *Customizable Visualizations*: Selectors of the Analysis Graph must be mapped to visual attributes (see Sec. 6.2) of a visualization. This mapping has to be translated into toolkit-specific code and input data.

4.4 Architecture

PRIMROSe architecture is divided into four main components (see Fig. 6):

Model Container

This component manages the Enterprise Model (i.e. the *Data* from Fig. 1) and the Model, Expanded, and Analysis Graphs. The EM and its metamodel are imported and converted into the Analysis Graph G_A through the transformations defined in Section 4.1. This component communicates with the Analysis Component, which operates over G_A and updates it as necessary.

Analysis Component

Its purpose is to manage and apply the Analysis Functions over the graph G_A, which is provided by the Model Container. In order to do so, this component has an Engine that composes and applies the functions sequentially and using a pipeline design pattern.

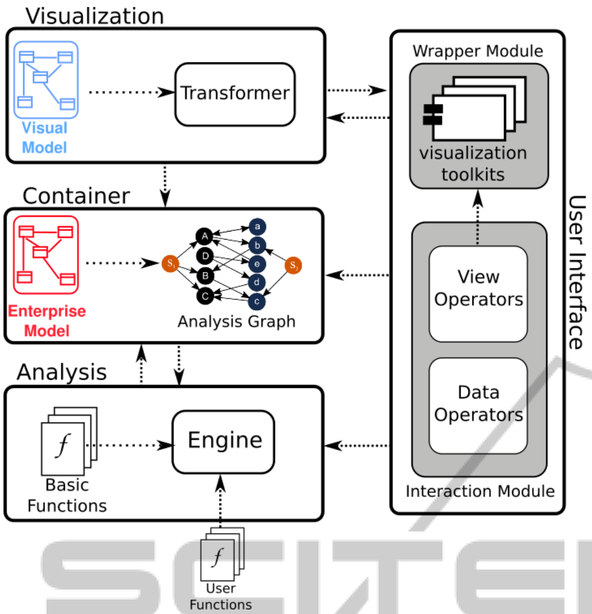


Figure 6: PRIMROSe Architecture.

The order and parameters of these functions are given by the user that interacts with the UI using Data Operators.

Basic Functions are a set of reusable functions provided by the framework, and are independent of the enterprise model and metamodel. Instead, they operate on the structure of any EM, using several graph algorithms. On the other side, **User Functions**, which operate in terms of the EM, are provided in an appropriate package (e.g. a jar file) by the user.

We will cover these aspects in detail on Sec. 5.

Visualization Component

As outlined by the fourth requirement (*Independence from the Visualization Framework*) of Section 4.3, the variability in the visual capabilities of the different visualization toolkits has an impact in the visual results from the analysis.

Taking into account that each toolkit 'knows' how to visualize a graph (or a similar structure) in its own fashion, a Transformer Module translates the processed graph G_A (provided by the Model Container) into tool-specific artifacts, such as code and/or input files, e.g. a GraphML or a Json file that contains the data to be visualized. This transformation is mediated by the Visual Model, and includes the merging of selected attributes from the Enterprise Model, as well as additional properties inserted by Decorator Functions. We will cover this component on Sec. 6.

User Interface

This component manages the View, i.e. the visualizations of the EM. The user explores the model through View Operators that modify the view without further processing or visual mapping (e.g. zooming or panning). These operators are translated into toolkit-specific instructions by the means of wrappers, which are adapters that also contain the canvas that displays the visualized image.

On the other hand, Data Operators cover two fronts: a) Operators that modify visual mapping in the Visualization Component, e.g. the association of a visual attribute (such as color) to a selector, and b) operators that modify the parameters and order of execution of the pipeline in the Analysis Component.

Finally, the UI also has a panel that communicates with the Model Container and displays all the attributes of a selected element of the EM, as well as additional analysis properties inserted by Analysis Functions.

4.5 Implementation

With the conceptual and functional requirements in mind, we implemented PRIMROSe, with the following considerations in its components:

- **Model Container:** Supported by the Eclipse Modeling Framework (EMF), the tool receives as input the enterprise model and metamodel in **ecore** format, which is then processed under a Model Transformation Chain that creates a Model Graph G_M that cross-references elements from the enterprise model, and finally generates the Analysis Graph G_A by the expansion of G_M.
- **Analysis Component:** Analysis Functions are defined in the Java language, extending the logic of the abstract class *AnalysisFunction*. Processing of the graph was made using the Java Universal Network/Graph (JUNG) Framework. Finally, the Engine is supported by the *commons-chain* library of the Apache Software Foundation, which implements the Chain of Responibility pattern (Gamma et al., 1994). User-defined functions are inserted by leaving a jar file in a given folder that the tool is observing, adding new files to the classpath.
- **Visualization Component:** The Visual Model is developed with the help of a Graphical Modeling Framework(GMF) editor, and transformations into toolkit-specific artifacts were made using XPAND templates.
- **User Interface:** Considering that processing power and supported formats of web navigators

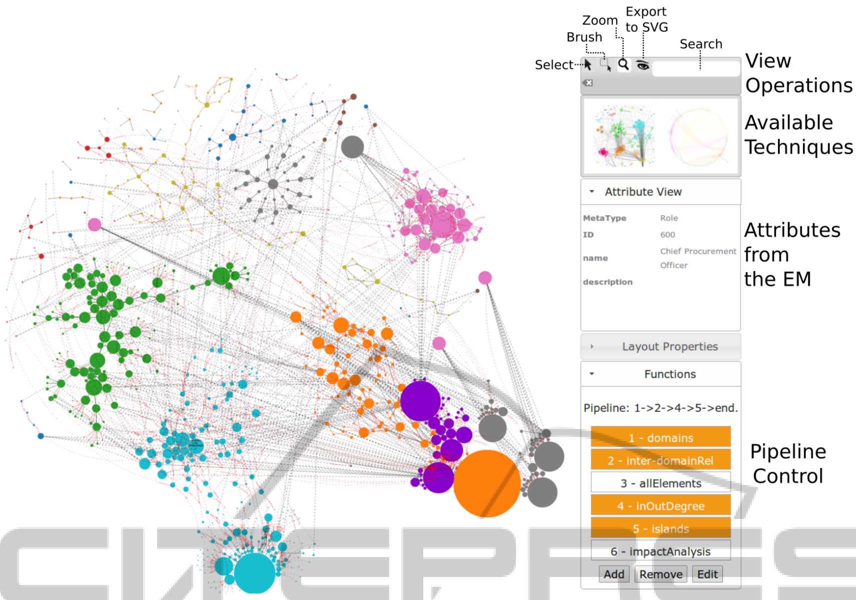


Figure 7: Screenshot of the User Interface.

has improved greatly, we selected Data-Driven Documents – **d3.js** (Bostock et al., 2011) as Visualization toolkit. This library is a JavaScript graphical framework for creating visualizations using standards such as SVG, HTML and CSS, with better performance and flexibility than similar frameworks in other languages (see Fig. 7).

5 ANALYSIS COMPONENT

As described in Section 3, analysis is a dynamic process where the flow of control is constantly changing between the user and the system, with incremental processing oriented by the interaction through data operators.

In this section we will offer more detail of the Analysis component of PRIMROSe, given in terms of its most relevant elements.

5.1 Functions

Each Analysis and Decorator Function comes with an unique identifier, and receives as input the Analysis graph, in addition to custom parameters defined by the creator of the function. Their output is the modified graph, with additional selectors and/or new attributes.

The following snippet of code shows the abstract Java class that is used to implement specific functions:

```
public abstract class AnalysisFunction{
    String id;
    Engine engine;

    // Constructor
    public AnalysisFunction(String i,Engine e){
        ...
    }

    public abstract AnalysisGraph
        process(Map<Object> parameters) {
        ...
    }
}
```

In order to avoid having to start from scratch each time a new function has to be defined, we built a set of basic functions which are all reusable and independent of the metamodel. The following is a brief description of some of the most representative functions among this basic set.

- **allElements:** Adds a selector for all the elements of the Enterprise Model.
- **allRelations:** Adds a selector for all the relations of the Enterprise Model.
- **inOutDegree:** A Decorator Function that inserts as attributes the number of incoming and outgoing relations of a model element.
- **pathsBetween:** Using an Adjacency Matrix, this function inserts a selector for each path between a set of vertices pointed by a selector that is received as a parameter.
- **spanningTree:** Inserts a selector for the edges that form a spanning tree of the model, navigating through its composition relations.

- **islands:** Selects all the isolated sub-graphs and unconnected elements of the model.

5.2 Selectors

The *selection* of relevant vertices is the backbone of Analysis Functions. In order to select subsets of model elements on the graph, the Model Container exposes methods that allow to query the model in terms of Object Constraint Language (OCL) expressions (Object Management Group, 2012).

The following fragment of an Analysis Function shows how we point Selectors to existing vertices of G_A:

```
Selector s1 = new Selector();

String query = "self.name='Product Sales'";

ExpressionParser ep =
new OCLExpressionParser(query, container);

AnalysisGraph graph = container.getGraph();

graph.addNode(s1);

Collection<Vertex> vertices =
container.getVertices(ep.parse());

for(Vertex v : vertices){
    graph.addEdge(s1,v);
}
```

5.3 Pipeline Engine

The pipeline for analysis consists of an ordered series of functions (see Fig. 5) that are applied by an Engine that encapsulates the control flow of the pipeline, acting as a Commander (Wickham et al., 2009).

As described by the *Incremental Analysis* requirement (see Sec. 4.3), the user would need to process a subset of the model, pointed by a selector in a previous step of the pipeline. However, at the same time we would like to preserve the encapsulated nature of each function. For these reasons, the Engine also has a registry of the selectors created on each function, and a method that returns them given a function ID:

```
public class F5 extends AnalysisFunction{
   @Override
   public AnalysisGraph process(
                 Map<Object> parameters){
    String selectorName =
       (String) parameters.get(``selector'');
     Collection<Selector> selectors =
     engine.getSelectors(selectorName);

     for(Selector s : selectors){
     degree(s);
     }
   }
   /* inserts the in/out degree
   as an attribute to every node */
   private void degree(Selector s){
     Collection<Vertex> vertices =
     s.getMembers();
     ....
   }
}
```

6 VISUALIZATION COMPONENT

The Analysis Component is responsible for the processing of the Analysis Graph, which is managed by the Container. However, after each processing, the visualization needs to be updated with the new information. In this case we need to map analytical and model properties to previously defined visual attributes of a visualization technique. Also, the abstract Visual Model needs to be transformed into toolkit-specific code.

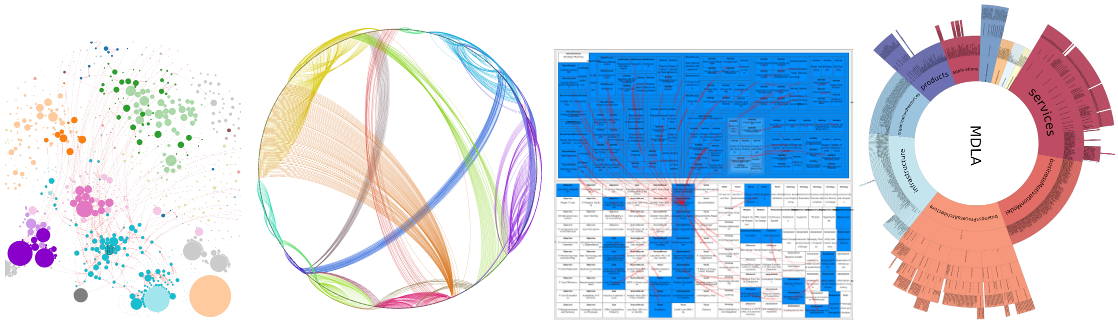
As we have discussed, each visualization toolkit has a very different way of doing the conversion between data and images. For instance, some tools may require the data to be in a format such GraphML or JSON, while others handle tool-specific formats. Moreover, the logic behind the association of visual properties such as position, color or transparency to data elements can differ greatly from tool to tool. While there is an effort to make transparent this conversion –see (Fekete et al., 2011)–, currently we have to describe the visual capabilities of a visualization technique, the mapping of analysis results into this visualization, and the way that a tool implements the visualization.

6.1 Overview Visualization Techniques for EA Analysis

An important task when designing a tool for Visual Analysis is the selection of techniques that improve the understanding of the underlying data, and also support the analysis tasks of the user.

In the process of giving shape to this information, several visualization techniques come at hand (see Fig. 8). In this case, it is useful to describe visualizations independently of the tool that implements them, and of the data to be depicted. For this reason, (Naranjo et al., 2013) provide an abstract definition of a Visualization Technique:

A **visualization technique** can be seen as the combination of **marks** (Bertin, 1983; Mackinlay, 1986) (atomic graphical elements, e.g. circles, squares,



(a) Force-dir. Graph (b) Radial Graph (c) Treemap (d) Sunburst

Figure 8: Selected visualization techniques.

or lines), a **layout** algorithm, some **visual attributes** (e.g. color, size, shape), a set of supported **interactive operations** and a **mapping** between data and such visual attributes.

6.2 Visual Metamodel and Mapping

The mapping of a given visualization technique is the translation between data and visualization domains. In order to perform this translation, we require three elements: 1) A Visual Model of the technique that describes its supported Visual Variables, independent of the data and graphical toolkit employed, 2) concrete values for the Visual Representation of elements and relations of Enterprise Model, and 3) A series of transformations between this visual model and toolkit-specific code and input files, including the model data.

A Visual Model represents this mapping on an individual technique, and conforms to a visualization metamodel (see Fig. 9). Despite being one single artifact, for clarity purposes we will separate the Visual Model into Technique and Representation Models.

Technique Model

A Technique Model instance represents the way a Visualization Technique is depicted, in terms of the symbols it uses (marks), and how they are visually distinguishable, i.e. its visual attributes.

For instance, a Force-directed Graph (see Fig. 8(a)) has two main elements, i.e. marks: *nodes*, that represent EM elements, and *edges*, which represent relations of the Enterprise Model. Nodes can have different *size*, depending on a property of each element, or even a custom attribute inserted by a Decorator Function (e.g. the in/out degree, see Sec. 5.1).

Representation Model

This is where we make the real mapping between abstract Technique Models and the Analysis Graph. For instance, go back to our example in Fig. 4(d), and consider we are using a Force-Directed Graph. The user can assign a value of **red** to the *color* Visual Variable, mapping this value to Selectors S_2 of the function f_2, and S_4 from f_4 (see Fig. 5). In the same fashion, we can assign a **blue** color to Selector S_3, and **gray** to other relations.

Transformations

Having connected the visual and data domains, we would like to actually view the model on our screen. This requires the transformation of our abstract Visual Model into toolkit-specific instructions and input files. This can be made with Model to Model (M2M) and Model to Text (M2T) transformations, starting with a Visual Model. For instance, this is a generated JavaScript snippet, using the d3.js toolkit, that assigns the color and size visual variables:

```
//size - weight attribute of each node
node.attr("r", function(d){return size(d.weight)})
//color
.style("fill", function(d) {
  if(d.selectors.indexOf("S2")>-1){
    return 'red';
  }
  if(d.selectors.indexOf("S3")>-1){
    return 'blue';
  }});
```

7 CONCLUSION

This paper delineates the Visual Analysis of Enterprise Models, emphasizing on the interactive nature of this activity, and taking into account that there is a reasoning process – which goes in parallel– in the brain of the analyst.

Seeing this analysis more as a dialogue than the production of automated and partial results, the contribution of this paper lies in the conceptual framework and architecture that enables the incremental

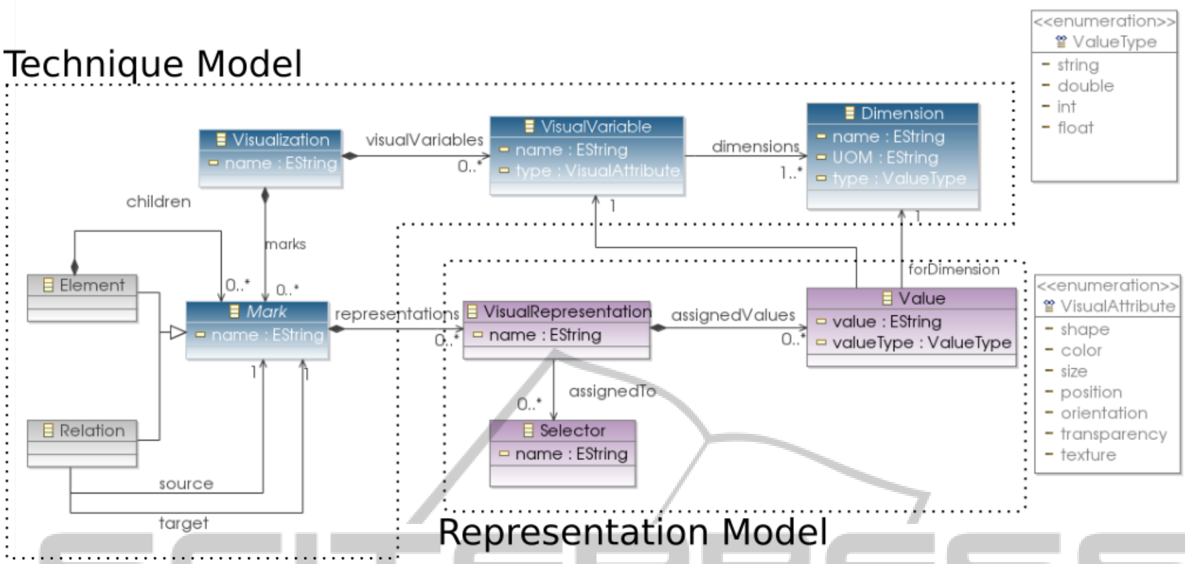


Figure 9: Visual Metamodel with two zones: the Technique Model, which describes constituent elements of a visualization technique, and a Representation Model, which assigns concrete values to groups of elements of the EM pointed by Selectors.

production and refinement of hypotheses that end in assessments that support decision making.

We designed this PRIMROSe framework (and tool architecture) supported by a set of requirements from various perspectives, also taking into account the structural properties of Enterprise Models. Analysis over these models is made with non-destructive functions that select and decorate an analytical abstraction. This Analytical Model is then mapped to a Visual Model representing overview visualization techniques, which is transformed into the necessary artifacts that are needed to depict the results on a given visualization toolkit. The user interacts with the visualization and returns the flow of control to the system, allowing the user to deepen on more detailed analyses.

We omitted the last stage of the process, **Communicate** (see Fig. 2), which deals with the transformation of a visualization and its associated insights into assessments. We think this is the meeting point between PRIMROSe and similar approaches (see Section 2) that complement and enhance analysis.

Extension points for the framework include the traceability of the whole process, which seems a promising field for complementing and enhancing EA documentation, as it would provide evidence of the rationale behind analysis. Moreover, the Analysis Graph should be preserved throughout the lifecycle of the Enterprise Model, as it allows the preservation of the additional facts that are introduced.

On the other hand, we are currently evaluating and augmenting the tool with more complex scenarios involving different EMs of large enterprises that span several thousands of elements and relations. As with every Visual Analysis tool, user feedback shapes the supported functionality, as well as design considerations that involve its usability. This evaluation consists of a given Enterprise Model and a set of Analytical Scenarios, which are complex questions that require some method of analysis to answer. Users will be invited to use PRIMROSe and fill a questionnaire addressing both the Analysis Component and the Visualization Component, in functional (e.g. accuracy, efficiency) and usability (e.g. location of elements, interactive operations) aspects. This will help us shaping the limitations of the tool, measure its effectiveness, and assess the minimal set of basic functions that are useful for the different kinds of EA Analysis.

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