

# Visual Languages for Supporting Big Data Analytics Development

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**Abstract:** We present BiDaML (Big Data Analytics Modeling Languages), an integrated suite of visual languages and supporting tool to help end-users with the engineering of big data analytics solutions. BiDaML, our visual notations suite, comprises six diagrammatic notations: brainstorming diagram, process diagram, technique diagrams, data diagrams, output diagrams and deployment diagram. BiDaML tool provides a platform for efficiently producing BiDaML visual models and facilitating their design, creation, code generation and integration with other tools. To demonstrate the utility of BiDaML, we illustrate our approach with a real-world example of traffic data analysis. We evaluate BiDaML using two types of evaluations, the physics of notations and a cognitive walkthrough with several target end-users e.g. data scientists and software engineers.

## 1 INTRODUCTION

Using big data analytics to improve decision-making has become a highly active research and practice area (Landset, 2015; Portugal, 2016). Gartner's technical professional advice (Sapp, 2017) recommends six stages for machine learning (ML) applications: classifying the problem, acquiring data, processing data, modeling the problem, validation and execution, and finally deployment. Traditionally, advanced ML knowledge and experience of complex data science toolsets were required for data analytics applications. Emerging analytics approaches seek to automate many of these steps in model building and its application, making ML technology more accessible to those who lack deep quantitative analysis and tool building skills (Rollins, 2015).

Recently, a number of data analytics and ML tools have become popular, providing packaged data sourcing, integration, analysis and visualization toolkits oriented towards end-users. Many of these tools do not require programming language knowledge and are based on simple drag-and-drop interfaces. However, they mostly focus on the ML algorithms and sometimes one-click deployment, but lack domain knowledge and business problem capturing, modeling, traceability to the solution and validation of the solution against the problem. They also lack an explanation of the model from an end-user perspective.

To address this, data analytics and ML steps need to be more tightly connected to the control and management of business and requirements engineering processes. However, the primary focus of most current big data analytics tools and technologies

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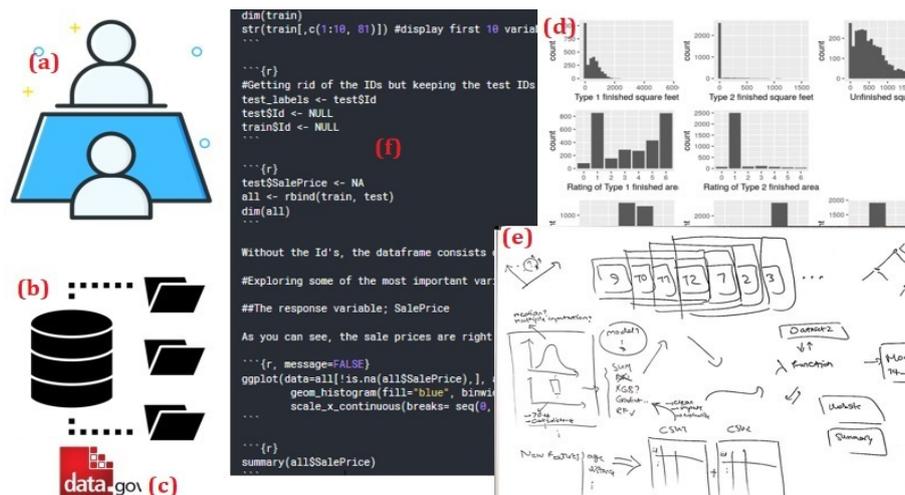


Figure 1: How data scientists currently design their big data analytics solutions.

is on storage, processing, and particularly the data analysis and ML tasks.

Current data analytics tools rarely focus on the improvement of end-to-end processes (Aalst, 2015). To address this issue, better integration of data science, data technology and process science is needed (Aalst, 2015). Data science approaches tend to be process agonistic whereas process science approaches tend to be model-driven without considering the evidence hidden in the data. Bringing scalable process mining analytics to big data toolkits, while enabling them to be easily tailored to accommodate domain-specific requirements, is required (Aalst, 2015). Tools filling these gaps would be useful for end-users like data scientists, for the discovery and exploration phase, to be able to model the problem, extract insights/patterns, and develop predictive and clustering models if it is feasible before they need to involve software engineers.

We present our novel approach to addressing this problem - Big Data Analytics Modeling Languages (BiDaML) - a set of domain specific visual languages (DSVLs) at different levels of abstraction (extended from Khalajzadeh, 2019a), to capture and refine requirements and specify different parts of the data analytics process. Through these DSVLs, we aim to make data analytics design more accessible to end-users and facilitate dialogues with expert data scientists and software engineers. BiDaML provides better tool support and collaboration between different users while improving the speed of implementing data analytics solutions.

The rest of the paper is organized as follows. In Section 2, the background and motivation of this research are described with a real-world example of traffic data analysis. Our approach is discussed in

Section 3 and evaluated in Section 4. A comprehensive comparison to related work is presented in Section 5. Finally, we draw conclusions and discuss key future directions in Section 6.

## 2 MOTIVATING EXAMPLE

We discuss key data analytics steps and the different types of communication needed between users in a data analytics project. A real traffic data analysis example integrating data from diverse data sources including VicRoads' SCATS traffic system (Sydney Coordinated Adaptive Traffic System, an intelligent transport system used to manage traffic signals in the state of Victoria, Australia as well as other states/cities) (VicRoads, 2018) is then demonstrated to reflect the issues and some key challenges in the process of data analytics.

### 2.1 Data Analytics Process Steps

The key steps that data scientists take to design their solutions are illustrated in Figure 1. Business owners, business analysts, data analysts and data scientists need to have (a) several rounds of meetings and interviews with domain experts and users; (b) acquire datasets from different resources; (c) get access to government information; (d) integrate all data items with different format, analyze and visualize them; (e) communicate with each other to discuss the analyses; and (f) finally use different tools to design their approaches and develop their models. However, there is no unified language that allows to facilitate the communication among domain experts, business

owner/analysts and software engineers and they need to wait until their models are usable and deployable. In this section, we will show an example of the traffic data analysis to discuss some of the problems they face during the solution design process.

## 2.2 Example: Traffic Data Analysis

For this real-world large project there was a need to formally capture detailed requirements for a new traffic data platform that would ingest a real-time stream of traffic data received from VicRoads (the Victorian road transport authority), integrate this with other transport data sources, and support modeling and visualization of the transport network at a state-wide level. There were some issues arising in the initiation of the project. The project leader and traffic modeling experts identified the need for a big data platform; however, without a background in software engineering or familiarity with modern data science tools, they were unable to determine whether the big data technology stack offered by the software outsourcing company was likely to meet their needs. Moreover, the software outsourcing company lacked understanding of the domain and thus did not understand what tasks were required of them.

To overcome the communication difficulties, a meeting was arranged between the project leader, the traffic modeling expert, a data engineer/visualization designer, the project team from the software outsourcing company, and the eResearch high performance computing services team. However, the lack of a common language meant that communication could only take place at a high-level rather than at the level of detail necessary to initiate direct technical action. The software outsourcing company produced a plan for software they intended to deploy; however, no plan existed for who would monitor and maintain the software and systems after deployment, such as responding to faults in real-time data ingestion or adding support for new types of data. To justify the cost and time investment into the project, the project leader wanted to be able to reuse the platform for related projects, such as a smart city. However, it was unclear whether the work invested into the design of the transport data platform could be reused in other projects. Moreover, the software outsourcing company lacked deep understanding of the datasets and intended use of the platform, thus were unable to begin work on the project. It was also unclear who would maintain the computing infrastructure, monitor data quality, and integrate new data sources after the initial phase of the project.

We worked with transport researchers and used

BiDaML and toolset to specify the intended software solution workflow. We performed in-depth interviews with the project leader and traffic modeling expert, then used BiDaML tool to document the entire data analytics workflow including data ingestion, transport modeling and simulation, and result visualization. This allowed us to assist in the formation of an alternative software solution that made better use of the systems and services already available. As BiDaML forces the user to consider all phases of the project, the modeling process helped reveal gaps in planning that required attention. We will use the examples of the diagrams we created throughout this paper.

## 2.3 Key Challenges

As illustrated, there is no trace back to the business needs/requirements that triggered the project. Furthermore, communicating and reusing existing big data analytics information and models is shown to be a challenge for many companies new to data analytics. Users need to be able to collaborate with each other through different views and aspects of the problem and possible solutions. Current practices and tools do not cover most activities of data analytics design, especially the critical business requirements. Most current tools focus on low-level data analytics process design, coding and basic visualization of results and they mostly assume data is in a form amenable to processing. In reality, most data items are in different formats and not clean or integrated, and great effort is needed to source the data, integrate, harmonize, pre-process and cleanse it. Only a few off-the-shelf ML tools offer the ability for the data science expert to embed new code and expand algorithms and provide visualizations for their needs.

Data processing and ML tasks are only a small component in the building blocks necessary to build real-world deployable data analytics systems (Sculley, 2015). Figure 2 illustrates these tasks cover a small part of data and ML operations and deployment of models. Business and management modeling tools usually do not support many key data analytics steps including data pre-processing and ML steps. There is a need to capture the high-level goals and requirements for different users such as domain expert, business analyst, data analyst, data scientist, software engineer, and end-users and relate them to low level diagrams and capture details such as different tasks for different users, requirements, objectives, etc. Finally, most of the tools covering ML steps require data science and programming knowledge to embed code and change features based

on the user requirements.

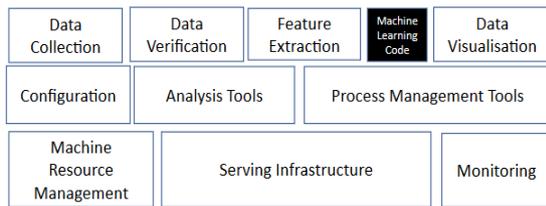


Figure 2: Data analytics steps (adapted from Sculley, 2015).

### 3 OUR APPROACH

Many current big data analytics tools, such as Azure ML Studio, Amazon AWS ML and Google Cloud ML, provide only low-level data science solution design, despite many other steps being involved in solution development (Khalajzadeh, 2019). Therefore, a high-level presentation of the steps to capture, represent, and communicate the business requirements analysis and design, data pre-processing, high-level data analysis process, solution deployment and data visualization is required.

#### 3.1 BiDaML Visual Language

We present BiDaML, a set of domain-specific visual languages using six diagram types at different levels of abstraction to support key aspects of big data analytics:

- **Brainstorming diagram** provides an overview of a data analytics project and all the tasks and sub-tasks that are involved in designing the solution at a very high level;
- **Process diagram** specifies the data analytics processes/steps including key details related to the participants (individuals and organizations), operations, and data items in a data analytics project capturing details from a high-level to a lower-level;
- **Technique diagrams** show the step by step procedures, processes and techniques for each sub-task in the brainstorming and process diagrams at a low level of abstraction;
- **Data diagrams** document the data and artifacts that are produced in each of the above diagrams in a low level, i.e. technical AI based layer;
- **Output diagrams** define in detail the outputs associated with different tasks e.g. output information, reports, results, visualizations, outcomes, etc.
- **Deployment diagram** depicts the run-time configuration, i.e. the system hardware, the software

installed on it, and the middleware connecting different machines to each other.

Figure 3 shows how our diagrams are connected to each other from a high level to a low level. A brainstorming diagram is defined for every data analytics project. Then, at a lower level to include more details and involve the participants, we use a process diagram. Every operation in a process diagram can be further extended by technique and data diagrams, and then, the technique and data diagrams are connected to a result output diagram. Finally, the deployment diagram, defined for every data analytics problem, models deployment related details at a low level.

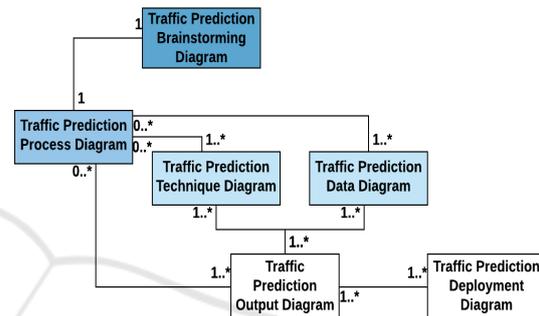


Figure 3: BiDaML diagrams overview for traffic data analysis example.

##### 3.1.1 Brainstorming Diagram

A data analytics **brainstorming diagram**'s scope covers the entirety of a data analytics project expressed at a high-level. There are no rules as to how abstractly or explicitly a context is expanded. The diagram overviews a data analytics project in terms of the specific problem it is associated with, and the task and subtasks to solve the specific problem. It supports interactive brainstorming to identify key aspects of a data analytics project such as its requirements implications, analytical methodologies and specific tasks.

Figure 4 (a) shows the visual notation used. It comprises an icon representing the data analytics problem, tasks which the problem is associated with, a hierarchy of sub-tasks for each task, and finally the specific information about sub-systems used or produced.

We group the building blocks of an AI-powered system into four groups: Domain and business-related activities (BusinessOps); data-related activities (DataOps); artificial intelligence and ML-related activities (AIOps); and development and deployment activities (DevOps). The BusinessOps covers domain

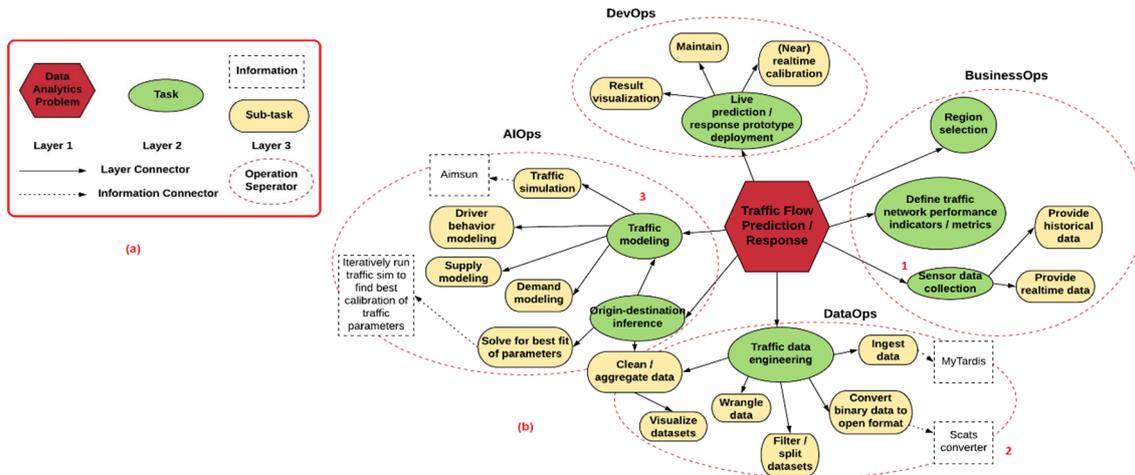


Figure 4: a) Brainstorming diagram notational elements and b) an example for the traffic data analysis problem.

and business knowledge and requirement gathering, modeling and analysis. The DataOps includes data collection/ingestion, data validation, cleansing, wrangling, filtering, union, merge, etc. AIOps covers feature engineering and model selection, model training and tuning. Finally, DevOps covers model integration and deployment, monitoring and serving infrastructure. Figure 4 (b) depicts a high-level brainstorming diagram for traffic data analysis example. From this figure we can see that:

- 1) Sensor data collection will be done in both historical and realtime formats;
- 2) SCATS converter is used to convert binary data to an open format; and
- 3) Traffic modeling consists of traffic simulation, driver behavior modeling, demand modeling, and supply modeling.

### 3.1.2 Process Diagram

The key business processes in a data analytics application are shown in a *process diagram*, whose basic notation is shown in Figure 5. We adapt the Business Process Modeling Notation (BPMN) (OMG, 2011) to specify big data analytics processes at several levels of abstraction. Process diagrams support business process management, for both technical users such as data analysts, data scientists, and software engineers as well as non-technical users such as domain experts, business users and customers, by providing a notation that is intuitive to business users, yet able to represent complex process semantics.

In this diagram type, we use different “pools” for different organizations and different “swim lanes” for the people involved in the process within the same

organization. Different layers are also defined based on different tasks such as business-related tasks (BusinessOps), technical (DataOps and AIOps), and operational tasks (DevOps and application-based tasks). Data and artifacts produced and used in each step can be shown as icons specific to the source and type of data. Preparation of data items or different events trigger other events and redirect the process to the other users in the same or different pool. Particular detailed activities or tasks performed by different users and the order of them are represented using rectangles and arrows. Diamonds show different decision points that can adjust the path based on conditions and double circles show unexpected events that can change the process at any step.

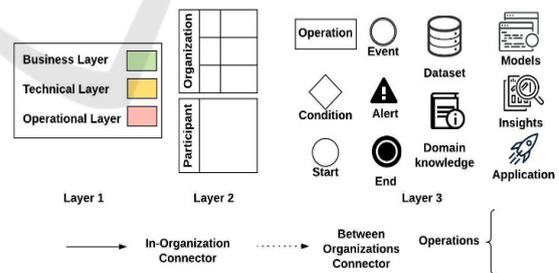


Figure 5: Process diagram notational elements.

A high-level process diagram for our traffic data analysis example is shown in Figure 6. In this, 1) project starts when VicRoads, as the data provider, provides historical data. 2) Domain knowledge is shared with the software outstanding company to provide the project’s cost estimate. 3) Technical lead develops web-based interface. 4) eResearch services provides big data storage/archival using MyTardis (A large scale (research) data management/archival sys-

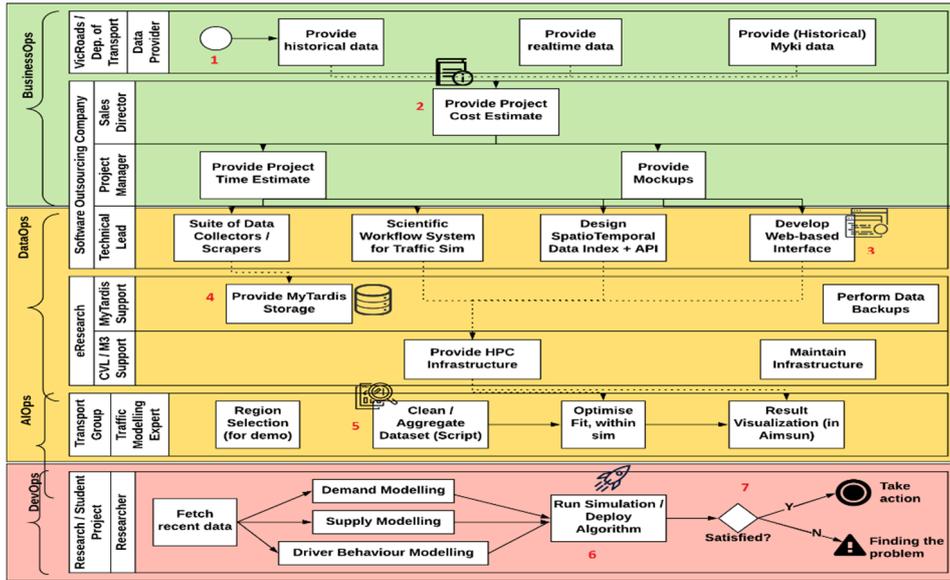


Figure 6: A process diagram example for the traffic data analysis problem.

tem developed by eResearch). 5) The extracted insights are shared with the transport group in order to clean and aggregate the dataset. 6) The researchers run simulations and deploy algorithms, and finally 7) if the final deployed models are satisfactory, then further action to progress the project will be taken, otherwise the problem needs to be found and resolved. In this case, an alert needs to be triggered and an issue tracking ticket assigned to the responsible participant to improve the process and consequently the outcome.

### 3.1.3 Technique Diagram

Data analytics *technique diagrams* extend the brainstorming diagram to low-level detail specific to different big data analytics tasks and sub-tasks. For every sub-task, the process is broken down into the specific stages and the technique used to solve a specific sub-task specified. Figure 7 shows the technique diagram notation.

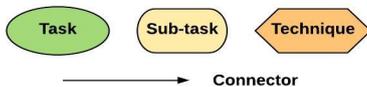


Figure 7: Technique diagram notational elements.

In Figure 8, “Aggregate cycle-by-cycle data into 15 minutes bins” and “Report volumes as NA and log warning if faulty sensor” are used as the methods/techniques to clean/aggregate data, and then the sub-techniques to solve challenges implementing each of the methods are further specified. We can

create such diagrams for every task and sub-task in brainstorming and process diagrams.

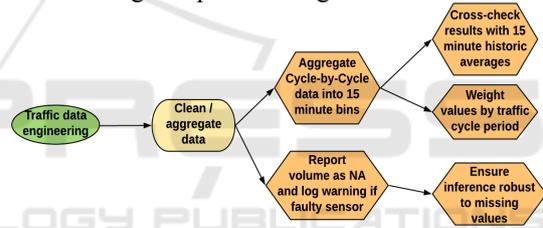


Figure 8: A technique diagram example for the traffic data analysis problem.

### 3.1.4 Data Diagram

To document the data and artifacts consumed and produced in different phases described by each of the above diagrams, one or more low-level *data diagrams* are created, using the notations shown in Figure 9 (a). Data diagrams support the design of data and artifacts collection processes. They represent the structured and semi-structured data items involved in the data analytics project in different steps. A high-level data diagram can be represented by connecting the low-level diagrams for different BusinessOps, DataOps, AIOps, and DevOps.

A data diagram for our traffic analysis problem is shown in Figure 9 (b). Here, data and artifacts related to all tasks and sub-tasks in brainstorming and process diagrams are connected to different data entities. In this case, different data items, features, outliers, the algorithms used, parameters related to these algorithms, model created based on different

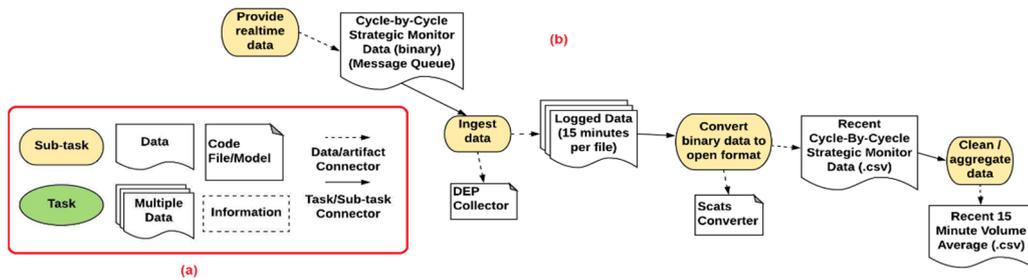


Figure 9: a) Data diagram notational elements and b) an example created for the traffic data analysis problem.

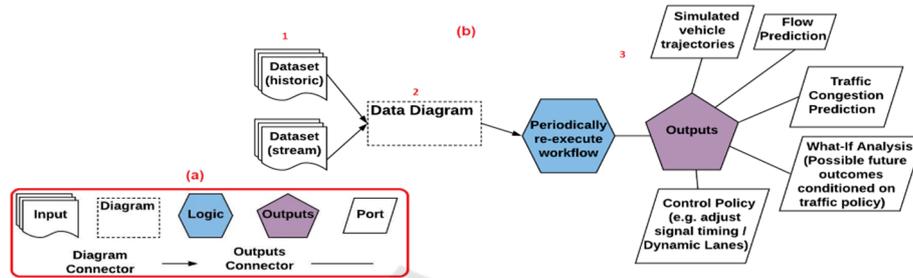


Figure 10: a) Output diagram notational elements and b) an example created for the traffic data analysis problem.

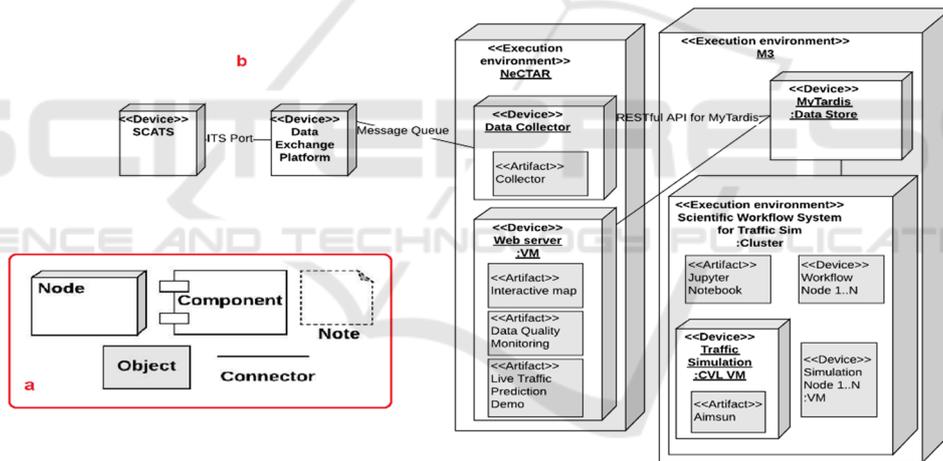


Figure 11: a) Deployment diagram notational elements and b) an example for the traffic data analysis problem.

algorithms, and the evaluation metrics used for the model are captured for the AIOps entity. Data and artifacts produced for other data entities such as DataOps, DevOps, etc can be detailed and depicted with other data diagrams.

### 3.1.5 Output Diagram

*Output diagrams* specify an individual technique in more detail. This diagram type, shown in Figure 10 (a), reuses and merges the technique diagram and data diagrams and adds information on the technique (logic entity) and the data produced by it (as output ports).

Figure 10 (b) shows an application in our traffic data analysis example. Here we see (1) datasets used, (2) part of the data diagram relating to the test for the sampled data set and (3) a data analytics output diagram defining the expected outputs from the technique and data diagrams used for test and its output. From this, we can see the outputs and reports that can be extracted using current techniques and data items, such as simulated vehicle trajectories, flow prediction, traffic congestion prediction, etc.

### 3.1.6 Deployment Diagram

Since the deployment part follows the same rules as

the deployment process in software development, we have adapted the deployment diagram from the Unified Modeling Language (UML) (Ambler, 2004). Our extended UML deployment diagram notation is shown in Figure 11 (a).

In a deployment diagram, three-dimensional boxes, known as nodes, represent the basic elements of the software or hardware. Rectangles indicate the objects in the system and the objects could be contained within the nodes to represent the software artifacts that are deployed and the components that run on those nodes. Lines from one node to another node specify the relationships between elements. Figure 11 (b) shows an example deployment diagram for our traffic data analysis problem, e.g. interactive map, data quality monitoring, and live traffic prediction demo are deployed on the web server, that is in turn deployed within the NeCTAR environment (an OpenStack-based cloud computing environment) (NeCTAR, 2019).

### 3.2 BiDaML Support Tool

We have developed an integrated design environment for creating BiDaML diagrams. The tool support aims to provide a platform for efficiently producing BiDaML visual models and to facilitate their creation, display, editing, storage, code generation and integration with other tools. We have used MetaEdit+ Workbench (MetaCase, n.d.) to implement our tool. Using MetaEdit+, we have created the objects and relationships defined as the notational elements for all the diagrams, different rules on how to connect the objects using the relationships, and how to define low

level sub-graphs for the high level diagrams.

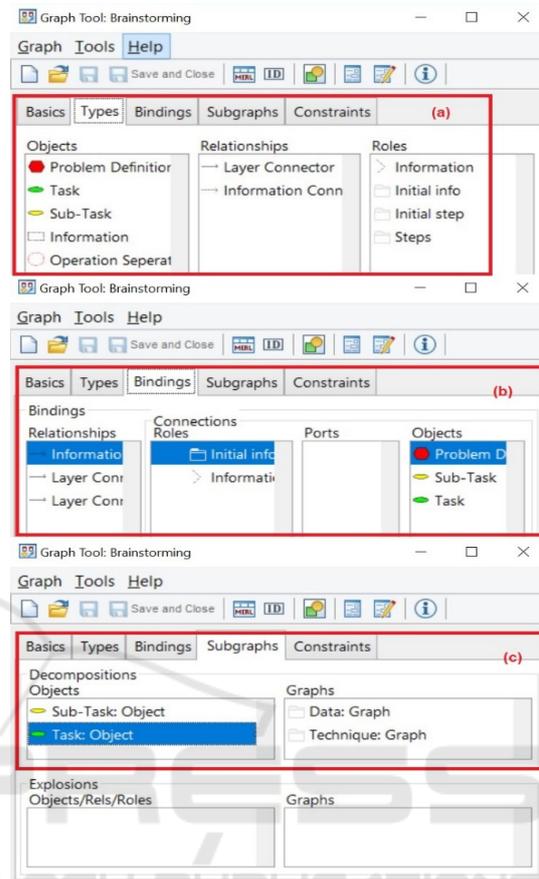


Figure 12: Defining brainstorming notational elements in MetaEdit+.

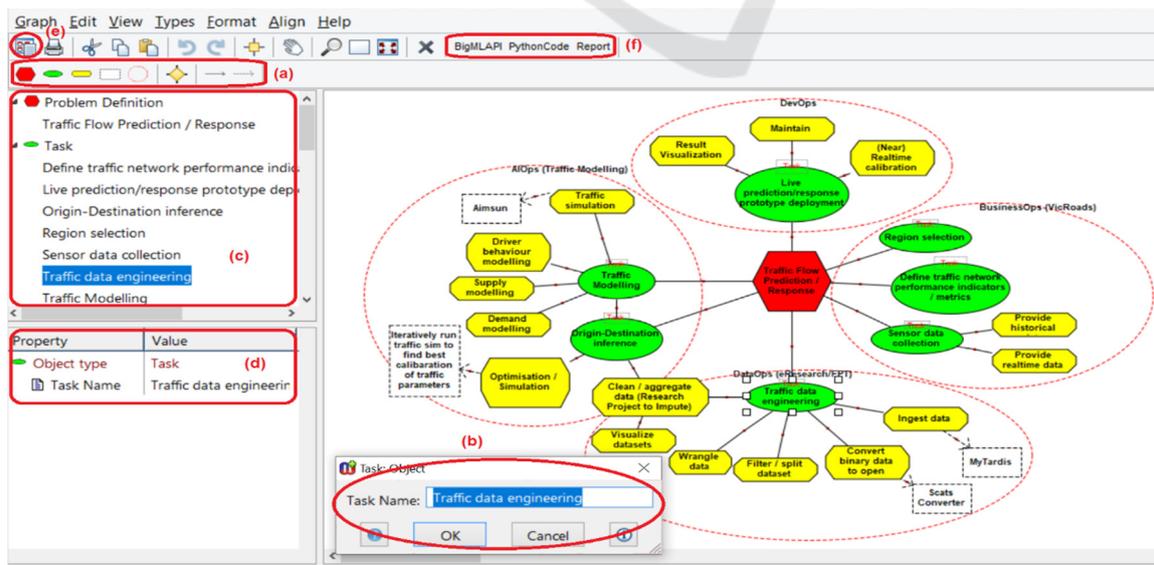


Figure 13: An example of BiDaML tool for creating brainstorming diagram for the traffic data analysis problem.

Figure 12 shows (a) how the objects, relationships, and roles are defined, (b) how the rules for connecting objects through relationships are defined, (c) how the sub-graphs are connected to different objects of a graph, for a brainstorming diagram. We have defined these for all other diagrams.

The image shows two windows from a software application. The left window, titled 'Generator Output: Traffic: Brainstorming', contains Python code for data analysis. The right window, titled 'Generator Output: Traffic Prediction: Process', contains a report listing operations for different participants.

```

import pandas as pd
import matplotlib.pyplot as plt
import numpy as np
import seaborn as sns
from matplotlib import pyplot
%matplotlib inline
from sklearn.linear_model import LinearRegression
from sklearn.model_selection import GridSearchCV
from sklearn.model_selection import cross_val_score
from xgboost import XGBRegressor

train = pd.read_csv("../train.csv")
test = pd.read_csv("../test.csv")
train.shape
test.shape
train.describe()
test.describe()

fig, axs = plt.subplots(1, 2, figsize=(15,5))
sns.countplot(total=pd.notna(total.PoolQC)).PoolQC,
ax=axs[0])
sns.countplot(total.PoolArea, ax=axs[1])

```

```

Participant Data Provider conducts the following
operations:
Provide (Historical) Mvki data (confidential)
Provide historical data
Provide realtime data

Participant Decision Maker / System conducts the
following operations:
Inspect Result (in realtime)
Take Action

Participant MyTardis Support conducts the following
operations:
Perform Data Backups
Provide MyTardis Storage

Participant Researcher conducts the following
operations:
Run Simulation / Deploy Algorithm (e.g. congestion
clustering)

```

Figure 14: A snippet of the a) python code generated from the brainstorming diagram, and b) report generated from the process diagram.

Figure 13 shows our tool used to create the brainstorming diagram for our traffic analysis example. Here, users (a) choose the notations of objects/relationships and (b) modify the properties of the object/relationship. Notations added to the diagram are all listed (c) and details are shown by clicking on the notations (d). Users can click on any of the objects and create a sub-graph i.e., data, technique, and output diagram for them. Finally, once completed, (e) code generation features can be embedded and modified and (f) and finally Python code, BigML API recommendations and reports can be generated for our traffic data analysis example in this designed brainstorming diagram. Figure 14 (a) is a snippet of the Python code generated from the brainstorming diagram and Figure 14 (b) shows the report generated from the process diagram.

## 4 EVALUATION

We have evaluated the usability and suitability of our visual languages and tool suite in two ways (results originally reported in Khalajzadeh, 2019a). The first was an extensive physics of notations evaluation (Moody, 2009). This was a useful end-user perspective evaluation without having to involve a

large-scale usability trial. To understand how easy BiDaML diagrams are to learn and use, we also conducted a cognitive walkthrough using several target domain expert end-users, including data scientists and software engineers, as test subjects.

### 4.1 Physics of Notations Evaluation

*Semiotic clarity* specifies that a diagram should not have symbol redundancy, overload, excess and deficit. All our visual symbols in BiDaML have 1:1 correspondence to their referred concepts. *Perceptual discriminability* is primarily determined by the visual distance between symbols. All our symbols in BiDaML use different shapes as their main visual variable, plus redundant coding such as color and/or textual annotation. *Semantic transparency* identifies the extent to which the meaning of a symbol should be inferred from its appearance. In BiDaML, icons are used to represent visual symbols and minimize the use of abstract geometrical shapes. *Complexity management* restricts a diagram to have as few visual elements as possible to reduce its diagrammatic complexity. We used hierarchical views in BiDaML for representation and as our future work, we will add the feature for users to hide visual construct details for complex diagrams. *Cognitive integration* identifies that the information from separate diagrams should be assembled into a coherent mental representation of a system; and it should be as simple as possible to navigate between diagrams. All the diagrams in BiDaML have a hierarchical tree-based structure relationship as shown in Figure 3.

*Visual expressiveness* defines a range of visual variables to be used, resulting in a perceptually enriched representation that exploits multiple visual communication channels and maximizes computational offloading. Various visual variables, such as shape, color, orientation, texture, etc are used in designing BiDaML visual symbols. *Dual coding* means that textual encoding should also be used, as it is most effective when used in a supporting role. In BiDaML, all visual symbols have a textual annotation. *Graphic economy* discusses that the number of different visual symbols should be cognitively manageable. As few visual symbols as possible are used in BiDaML. *Cognitive fit* means that the diagram needs to have different visual dialects for different tasks or users. All the symbols in BiDaML are usable for different users and tasks. However, in the future, we will provide different views for different users in our BiDaML support tool, and users will be able to navigate between views based on their requirements.

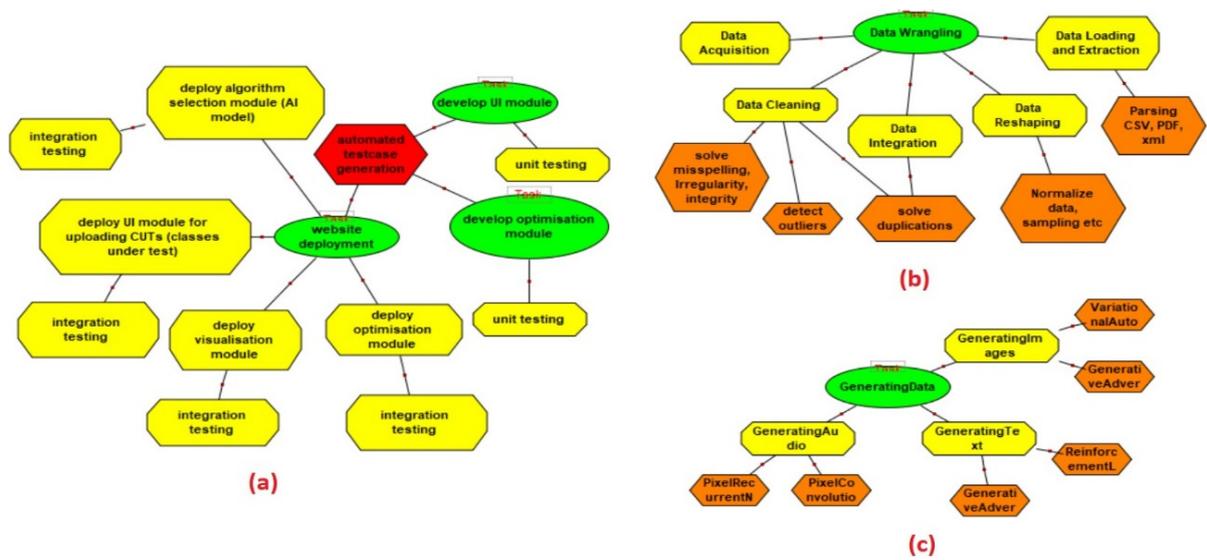


Figure 15: Example brainstorming and technique diagrams from our evaluators.

## 4.2 Cognitive Walkthrough

We asked 3 data scientists and 2 software engineers (all experienced in big data analytics) to carry out a task-based end-user evaluation of BiDaML. The objective was to assess how easy it is to learn to use the visual models and how efficiently it can solve the diagram complexity problem. BiDaML diagrams were briefly introduced to the participants who were then asked to perform three predefined modeling tasks. The first was to design BusinessOps, DataOps, AIOps, or DevOps part of a brainstorming diagram for a data analytics problem of their choice from scratch. In the second, the subject was given a process diagram and asked to explain it, comment on the information represented and provide suggestions to improve it. The third involved subjects designing a technique diagram related to a specific task of the data analytics problem they chose for the first part of the evaluation. Figure 15 shows (a) devOps part of one of the brainstorming diagrams and (b and c) two of the technique diagrams that the data scientists/software engineers drew to help explain their current work tasks of (a) automated testcase generation (b) data wrangling and (c) data augmentation.

Overall, users' feedback indicated that BiDaML is very straightforward to use and understand. Users felt they could easily communicate with other team members and managers and present their ideas, techniques, expected outcomes and progress in a common language during the project before the final solution. They liked how different layers and operations are differentiated. Moreover, they could capture and understand business requirements and

expectations and make agreements on requirements, outcomes, and results through the project. These could then be linked clearly to lower-level data, technique and output diagrams. Using this feedback we have made some minor changes to our diagrams such as the shape and order of some notations, and the relationships between different objects.

However, several limitations and potential improvements have also been identified in our evaluations. Some users prefer to see technique and data diagrams components altogether in a single diagram, while some others prefer to have these separate. Moreover, in the process diagram, some users prefer to only see the operations related to their tasks and directly related tasks. Finally, one of the users wanted to differentiate between tasks/operations that are done by humans versus a tool. In future tool updates, we will provide different views for different users and will allow users to hide/unhide different components of the diagrams based on their preference. Moreover, in our future code generation plan, we will separate different tasks based on whether they are conducted by humans or tools. We will run a larger user evaluation with business and domain expert end-users. The future user study will be conducted in a more structured manner, and the feedback will be collected anonymously. Moreover, in order to evaluate the usability of the current interface for new users of the BiDaML tool, the participants will be given more independent tasks. Finally, BiDaML will be compared with the existing solutions, such as UML.

## 5 RELATED WORK

There are many data analytics tools available, such as Azure ML Studio, Amazon AWS ML, Google Cloud ML, and BigML as reviewed in Khalajzadeh, 2019b. However, these tools only cover a few phases of DataOps, AIOps, and DevOps and none cover business problem description, requirements analysis and design. Moreover, since most end-users have limited technical data science and programming knowledge, they usually struggle using these tools.

Some DSVLs have been developed for supporting enterprise service modeling and generation using end-user friendly metaphors. An integrated visual notation for business process modeling is presented and developed in (Li, 2014) using a novel tree-based overlay structure that effectively mitigates complexity problems. MaramaAIC (Kamalrudin, 2017) provides end-to-end support between requirements engineers and their clients for the validation and improvement of the requirements inconsistencies. SDLTool (Kim, 2015) provides statistician end-users with a visual language environment for complex statistical survey design/implementation. These tools provide environments supporting end-users in different domains. However, they do not support data analytics processes, techniques, data and requirements, and do not target end-users for such applications.

Scientific workflows are widely recognized as useful models to describe, manage, and share complex scientific analyses and tools have been designed and developed for designing, reusing, and sharing such workflows. Kepler (Ludäscher, 2005) and Taverna (Wolstencroft, 2013) are Java-based open source software systems for designing, executing, reusing, evolving, archiving, and sharing scientific workflows to help scientists, analysts, and computer programmers. VisTrails (Callahan, 2006) is a Python/Qt-based open-source scientific workflow and provenance management system supporting simulation, data exploration and visualization. It can be combined with existing systems and libraries as well as your own packages/modules. Finally, Workspace (Cleary, 2015), built on the Qt toolkit, is a powerful, cross-platform scientific workflow framework enabling collaboration and software reuse and streamlining delivery of software for commercial and research purposes. Users can easily create, collaborate and reproduce scientific workflows, develop custom user interfaces for different customers, write their own specialized plug-ins, and scale their computation using Workspace's remote/parallel task scheduling engine. Different

projects can be built on top of these drag and drop based graphical tools and these tools are used in a variety of applications and domains. However, they only offer a limited number of data analysis steps and no data analytics and ML capabilities and libraries.

Finally, some software tools implement algorithms specific to a given graphical model such as Infer.NET (Minka, 2010). This approach for implementing data analytics techniques is called a model-based approach to ML (Bishop, 2012). An initial conceptualization of a domain specific modeling language supporting code generation from visual representations of probabilistic models for big data analytics is presented in (Breuker, 2014) by extending the analysis of the Infer.NET. However, it is in very early stages and does not cover many of the data analytics steps in real-world problems.

## 6 CONCLUSIONS

We have described a set of visual notations for specifying data analytics project software requirements and solutions. Our DSVLs, namely BiDaML, are aimed at providing a similar modeling framework for data analytics solution design as UML does for software requirements and design. It is comprised of six high- and low-level diagrammatic types. These diagrams represent both data- and technique-oriented components of a data analytics solution design. A physics of notations analysis and a cognitive walkthrough with several end-users were undertaken to evaluate the usability of BiDaML. We have also used our diagrams to model several complex big data analytics problems.

Our future work includes providing multiple view/elision support for large diagrams in our BiDaML modeling tool. In addition, we see considerable scope for providing back end integration with other data analytics tools, such as Azure ML Studio. Our tool can be used at an abstract level during requirements analysis and design, and then connected to existing software tools that operate at a low level. Therefore, our DSVLs can be used to design, implement and control a data analytics solution. Our tool will support modeling and code generation, together with collaborative work support in the future. Since big data analysis has the same steps, the code generation feature of our tool will provide a set of templates for handling different classes of systems in data analytics projects. These will be leveraged to integrate our BiDaML tool with other data analytics packages.

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## REFERENCES

- Aalst, W. v. d., & Damiani, E. (2015). *Processes Meet Big Data: Connecting Data Science with Process Science*. IEEE Transactions on Services Computing, 8(6), 810-819.
- Ambler, S. (2004). *The Object Primer: Agile Model-Driven Development With Uml 2.0* 3rd Edition: Cambridge University Press
- Bishop, C. M. (2012). *Model-based Machine Learning*. Philosophical Transactions of the Royal Society A, Mathematical, Physical and Engineering Sciences, 371(1984).
- Breuker, D. (2014). *Towards Model-Driven Engineering for Big Data Analytics – An Exploratory Analysis of Domain-Specific Languages for Machine Learning*. Paper presented at the 47th Hawaii International Conference on System Science.
- Callahan, S. P., Freire, J., Santos, E., Scheidegger, C. E., Silva, C. T., & Vo, H. T. (2006). *VisTrails: Visualization Meets Data Management*. Paper presented at the ACM SIGMOD international conference on Management of data.
- Cleary, P. W., Thomas, D., Bolger, M., Hetherington, L., Rucinski, C., & Watkins, D. (2015). *Using Workspace to Automate Workflow Processes for Modelling and Simulation in Engineering*. Paper presented at the 21st International Congress on Modelling and Simulation. <https://research.csiro.au/workspace/>
- Kamalrudin, M., Hosking, J., & Grundy, J. (2017). *MaramaAIC: Tool Support for Consistency Management and Validation of Requirements*. Automated Software Engineering, 24(1), 1-45.
- Khalajzadeh, H., Abdelrazek, M., Grundy, J., Hosking, J., & He, Q. (2019a). *BiDaML: A Suite of Visual Languages for Supporting End-user Data Analytics*. Paper presented at the IEEE Big Data Congress, Milan, Italy.
- Khalajzadeh, H., Abdelrazek, M., Grundy, J., Hosking, J., & He, Q. (2019b). *Survey and Analysis of Current End-user Data Analytics Tool Support*. IEEE Transactions on Big Data, 5. doi:10.1109/TBDDATA.2019.2921774
- Kim, C. H., Grundy, J., & Hosking, J. (2015). *A Suite of Visual Languages for Model-Driven Development of Statistical Surveys and Services*. Journal of Visual Languages and Computing, 26(C), 99-125.
- Landset, S., Khoshgoftaar, T. M., Richter, A. N., & Hasanin, T. (2015). *A Survey of Open Source Tools for Machine Learning with Big Data in the Hadoop Ecosystem*. Journal of Big Data, 2(24). doi:<https://doi.org/10.1186/s40537-015-0032-1>
- Li, L., Grundy, J., & Hosking, J. (2014). *A Visual Language and Environment for Enterprise System Modelling and Automation*. Journal of Visual Languages & Computing, 25(4), 253-277.
- Ludäscher, B., Altintas, I., Berkley, C., Higgins, D., Jaeger, E., Jones, M., Zhao, Y. (2005). *Scientific Workflow Management and the Kepler System*. Concurrency and Computation: Practice and Experience, 18(10), 1039-1065. doi:<https://doi.org/10.1002/cpe.994>
- MetaEdit+ Domain-Specific Modeling tools – *MetaCase*. Retrieved from <https://www.metacase.com/products.html>
- Minka, T., Winn, J., Guiver, J., & Knowles, D. (2010). *Infer.NET 2.4*, 2010. Microsoft Research Cambridge.
- Moody, D. (2009). *The “Physics” of Notations: Toward a Scientific Basis for Constructing Visual Notations in Software Engineering*. IEEE Transactions on Software Engineering, 35(6), 756-779. doi:<https://doi.org/10.1109/TSE.2009.67>
- NeCTAR. (2019). *ARDC’s Nectar Research Cloud*. Retrieved from <https://nectar.org.au/cloudpage/>
- OMG. (2011). *Business Process Model And Notation (BPMN)*. Retrieved from <https://www.omg.org/spec/BPMN/2.0/>
- Portugal, I., Alencar, P., & Cowan, D. (2016). *A Preliminary Survey on Domain-Specific Languages for Machine Learning in Big Data*. Paper presented at the IEEE International Conference on Software Science, Technology and Engineering (SWSTE), Beer-Sheva, Israel.
- Rollins, J. B. (2015). *Foundational Methodology for Data Science*. Retrieved from IBM Analytics:
- Sapp, C. E. (2017). *Preparing and Architecting for Machine Learning*. Retrieved from Gartner Technical Professional Advice:
- Sculley, D., Holt, G., Golovin, D., Davydov, E., Phillips, T., Ebner, D., . . . Dennison, D. (2015). *Hidden Technical Debt in Machine Learning Systems*. Paper presented at the 28th International Conference on Neural Information Processing Systems (NIPS), Montreal, Canada.
- VicRoads. (2018). *SCATS*. Retrieved from <https://www.vicroads.vic.gov.au/traffic-and-road-use/traffic-management/traffic-signals/scats>
- Wolstencroft, K., Haines, R., Fellows, D., Williams, A., Withers, D., Owen, S., Goble, C. (2013). *The Taverna workflow suite: designing and executing workflows of Web Services on the desktop, web or in the cloud*. Nucleic acids research, 41(1), 557-561.