Situ\textsuperscript{f} : A Domain Specific Language

and

A First Step Towards the Realization of Situ Framework

by

Hua Ming

A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Computer Science

Program of Study Committee:
Carl K. Chang, Major Professor
    Johnny Wong
    Simanta Mitra
    Jin Tian
    Ting Zhang

Iowa State University
Ames, Iowa
2012

Copyright © Hua Ming, 2012. All rights reserved.
DEDICATION

I would like to dedicate this dissertation to my families and friends, both in Beijing China and in Iowa United States.
TABLE OF CONTENTS

LIST OF TABLES .......................................... v
LIST OF FIGURES ......................................... vi
ACKNOWLEDGEMENTS ...................................... viii
ABSTRACT ................................................ x

CHAPTER 1. INTRODUCTION ............................... 1
  1.1 Review of Situ framework ............................. 1
  1.2 Declarative situations ................................ 1
  1.3 A functional paradigm ................................ 3
  1.4 Situ\textsuperscript{f}-based Environment ............... 5
  1.5 A glance view of the Situ\textsuperscript{f} environment ....... 5
    1.5.1 A retargetable environment ...................... 11
  1.6 My contribution .................................... 12
  1.7 Organization ..................................... 13

CHAPTER 2. OVERVIEW ..................................... 14
  2.1 Background information on situation and human intention .. 14
  2.2 A motivating example ................................ 18
  2.3 The Environment Model of Situ\textsuperscript{f} language .......... 25
  2.4 Context variables under the environment model .............. 28
  2.5 Event passing under Situ\textsuperscript{f}'s environment model ... 31
  2.6 Human-centric Situations ............................ 36
  2.7 An introduction to Situ\textsuperscript{f} language and examples ... 37
    2.7.1 Attribute-Grammar model of Situ\textsuperscript{f} ............ 37
2.7.2 Synthesized attributes, inherited attributes and functional dependency . 38
2.7.3 Paper review example .................................. 43

CHAPTER 3. FORMAL DEFINITION OF Situ $^f$ ......................... 50
  3.1 Syntactical definition of Situ $^f$ ............................ 50
  3.2 Semantic definition of Situ $^f$ through attribute grammar .......... 51
  3.3 SituIO: the IO channel for Situ $^f$ environment ................ 51
  3.4 The Monadic "@" to set up SituIO channel .................... 53
  3.5 The Monadic "()" to convert user data to situation contexts ........ 55
  3.6 A precise description of SituIO under Situ $^f$ language .......... 55
    3.6.1 Overview of semantics of programming languages: denotational, axiomatic
    and operational semantics .................................. 56
    3.6.2 Abstraction of SituIO .................................. 58
    3.6.3 The computational semantics of SituIO .................... 60

CHAPTER 4. Situ $^f$-based ENVIRONMENT .............................. 74
  4.1 Context specification and situation services .................... 75
    4.1.1 XML and context specifications ........................ 77
    4.1.2 The inclusion of situation services ..................... 80
  4.2 XML Situation data structures ................................ 81
  4.3 EOS in Situ $^f$-based environment ............................ 81

CHAPTER 5. IMPLEMENTATION AND FEASIBILITY TEST ............... 82
  5.1 Experiment on JFrame/Swing based User Interface Adaptation .... 82
    5.1.1 Overview of adaptive user interface ..................... 82
    5.1.2 Error, situation and the XML representation of context .... 85
  5.2 Experiment on MyReview, a web-based paper review system .......... 89

CHAPTER 6. CONCLUSION AND FUTURE WORK ........................ 92
  6.1 Conclusion remark .................................. 92
  6.2 Future work ........................................ 93
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>A context-free grammar for <em>SimpleL</em></td>
<td>39</td>
</tr>
<tr>
<td>2.2</td>
<td>Attribute grammar for <em>SimpleL</em></td>
<td>40</td>
</tr>
<tr>
<td>3.1</td>
<td>A context-free grammar representing concrete syntax for <em>Situ</em></td>
<td>68</td>
</tr>
<tr>
<td>3.2</td>
<td>Abstract syntax for <em>Situ</em></td>
<td>69</td>
</tr>
<tr>
<td>3.3</td>
<td>Attribute grammar for <em>Situ</em> (part 1 of 3)</td>
<td>70</td>
</tr>
<tr>
<td>3.4</td>
<td>Attribute grammar for <em>Situ</em> (part 2 of 3)</td>
<td>71</td>
</tr>
<tr>
<td>3.5</td>
<td>Attribute grammar for <em>Situ</em> (part 3 of 3)</td>
<td>72</td>
</tr>
<tr>
<td>3.6</td>
<td>Operational semantics of <em>SituIO</em></td>
<td>73</td>
</tr>
<tr>
<td>4.1</td>
<td>An XML Schema-based context template</td>
<td>78</td>
</tr>
<tr>
<td>4.2</td>
<td>A sample context value collected at runtime using XML</td>
<td>80</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Situt-based environment: the overview</td>
<td>6</td>
</tr>
<tr>
<td>1.2</td>
<td>A simple diagram of the behavior-centric context for a user</td>
<td>7</td>
</tr>
<tr>
<td>1.3</td>
<td>The cascading structure of the context for MyReview login</td>
<td>8</td>
</tr>
<tr>
<td>1.4</td>
<td>A more complete picture of the MyReview login context integrating user's profile</td>
<td>9</td>
</tr>
<tr>
<td>1.5</td>
<td>Context stack</td>
<td>10</td>
</tr>
<tr>
<td>1.6</td>
<td>A Situt-based environment in action</td>
<td>12</td>
</tr>
<tr>
<td>2.1</td>
<td>A Kripke Structure</td>
<td>16</td>
</tr>
<tr>
<td>2.2</td>
<td>A MyReview Example</td>
<td>18</td>
</tr>
<tr>
<td>2.3</td>
<td>Situations $S_1$ and $S_2$</td>
<td>19</td>
</tr>
<tr>
<td>2.4</td>
<td>Login Fail Situation $S_3$</td>
<td>20</td>
</tr>
<tr>
<td>2.5</td>
<td>Example of context variable environment</td>
<td>26</td>
</tr>
<tr>
<td>2.6</td>
<td>System user's demonstrated desire</td>
<td>31</td>
</tr>
<tr>
<td>2.7</td>
<td>Environment model: a working example</td>
<td>34</td>
</tr>
<tr>
<td>2.8</td>
<td>Parse tree and attribute dependency graph</td>
<td>41</td>
</tr>
<tr>
<td>2.9</td>
<td>Parse tree for paper review situation</td>
<td>43</td>
</tr>
<tr>
<td>2.10</td>
<td>Temporal ordering of situations</td>
<td>44</td>
</tr>
<tr>
<td>2.11</td>
<td>An example of the $\text{prog}._\text{url}_i$ grammar symbol in Situt grammar</td>
<td>47</td>
</tr>
<tr>
<td>2.12</td>
<td>Parse tree and attribute propagation graph for Program 2</td>
<td>48</td>
</tr>
<tr>
<td>3.1</td>
<td>An example of reduce expression</td>
<td>69</td>
</tr>
<tr>
<td>4.1</td>
<td>The compiling of a Situt script</td>
<td>74</td>
</tr>
</tbody>
</table>
ABSTRACT

Situ proposes a human centered, dynamic reasoning framework for domain experts to evolve their software. It formally models the relationship between externally observed situation sequences and the rapid evolution of that software system, using real-time usage information from users and contextual capturing on the behavior of a software system relative to its runtime environment.

Situ$^f$ is a continuing effort under Situ framework [1]. In this effort, a domain specific, functional programming language named Situ$^f$ is presented from its design, semantics and a feasibility test through theoretical validation. The targeted users of this language mainly include domain experts and engineers who are versed in the major concepts and paradigms regarding human-centric situations. As argued there, human-centric situations are vitally important to infer a user’s intention and therefore, to drive software service evolution. Situ$^f$ is designed particularly to encourage domain experts and engineers to think and work with situations. An attribute grammar based approach is developed so that through Situ$^f$, relevant real-time contexts can be systematically aggregated around situations. A computational semantics is offered to precisely describe the runtime behavior of a Situ$^f$ program. While the Situ$^f$ language serves as the critical centerpiece of this work, its functioning necessarily requires environmental support from Situ elements outside the language itself, such that altogether they give rise to a Situ oriented system. This environment, named Situ$^f$-based environment, is also introduced.

Keywords: Situ-framework, Situ$^f$-environment, situation, human intention, software evolution, domain-specific programming language, functional programing language, structural operational semantics
CHAPTER 1. INTRODUCTION

1.1 Review of Situ framework

Human intention has long played important roles in both cognitive reasoning and creative software development [2, 3, 4]. How intention can be connected with the software maintenance and evolution process has not been adequately studied [1]. Situ framework was developed to bridge this gap towards a rapid, automated software service evolution process [1, 5]. An important concept brought to light by Situ framework was that of human intention - which is defined as a temporal sequence of situations observed towards achieving a common goal. The goal there is meant to be in the context of system goals directly related to the goal model used in Goal-Oriented Requirement Engineering [6, 7]. Under Situ’s definition, each situation at a particular time instant must encapsulate a user’s behavioral as well as environmental context from which a user’s desire can be served [1]. In order to enrich the concept of Situation with more expressive power for software and service evolution, Ming et al., [5, 8] continued to expand this research spectrum under Situ framework with new concepts, including Situ-module, Situ-morphism and Situ-channel. While in need of more refined and sustainable efforts, the conceptual cornerstone for the Situ framework has been provided by which robust upper-level structures are made possible.

1.2 Declarative situations

In computer programming, the declarative paradigm distinguishes itself from all other paradigms, such as its popular imperative counterpart, in its emphasis to minimize or even eliminate side effects by describing what the program should do rather than how to accomplish it. This defining characteristic of the declarative paradigm stands out especially with regard
to the way functions are created in both their syntax and, more importantly, their semantics. Popular declarative languages include SQL, ML and Haskell. Declarative programming is of particular interest recently, in both the research and the industry due to the fact that eliminating side effects can greatly simplify the writing and debugging of parallel programs.

While it is very impressive that the declarative programming paradigm goes a long way for simplifying the writing of correct parallel programs, especially in this age of multi-core and multi-processors, it is of special interest for the designer of a domain specific programming language under Situ framework. First of all, the description of a situation, in its very nature, is a what rather than how process.

Let us consider a concrete example. A domain expert trying to schedule a meeting for various parties to attend wants to accommodate as many requested meeting times and locations as possible. To start with, she wants to compile everyone’s time and location by first filtering out “impossible” situations for which there are no viable chances, and then reduce the remaining situations to one that would allow most of the intended parties to participate.

The solution that comes out most naturally to help the meeting scheduling expert can be specified as follows:

- the situation for each party is represented as a pair of available time and location;
- the collection of all the availabilities consist in a list of available time and location pairs;
- apply a filter function on each party’s situation to remove the inviable ones, and;
- synthesize all remaining situations into a final situation that works the best to accommodate each remaining situation.

A direct translation from the above scheme is as follows:

\[
\text{synthesize} \rightarrow (\text{filter} \rightarrow [(t_1, loc_1) \ldots (t_n, loc_n)])^1
\]

A declarative language promotes the most straightforward solution leading to a simple computer program. Note that should such a declarative language be available, the domain

\[\text{map reduce}, \text{a well known scheme with its root from functional paradigm, a subcategory under declarative paradigm.}\]
expert will only need to worry about what the filter has to do on each situation, enjoying the complete insulation from how the filter is going to be applied iteratively from one situation to the next throughout the list. A similar case occurs in the synthesis step as described in the above scheme.

More interestingly, should there be an appropriate declarative language support, such a solution can also serve as an executable high level specification targeting strategic design objectives.

Second, a declarative paradigm is consistent with Situ defined situations. According to the definition by Situ, each situation carries a time stamp by which situations can be collected and sequenced into specified time intervals. A key observation is that once a situation is observed and added to a temporal sequence, it becomes immutable - in a sense similar to historical data. Indeed, this impiles that no side effects are allowed under the proposed domain specific language over situations. Once they are generated as function outputs, they are final.

In particular, this kind of immutability is well supported by functional paradigm where no update assignment is allowed.

1.3 A functional paradigm

Functional paradigm emphasizes computing with values rather than with actions. The computation is a direct, explicit description based on what values to use and to generate.

To illustrate the charm of the simplicity intrinsic to a functional paradigm, let us consider the following example using Haskell\textsuperscript{2}.

*Problem: Find the summation of squares of natural numbers up to a particular number.*

A typical imperative program might solve the problem with the following code:

```haskell
sumSq := 0;
i := 0;
while i < n do
```

\textsuperscript{2} A popular functional programming language
\[
\begin{align*}
i &:= i + 1; \\
\text{sumSq} &:= i \cdot i + \text{sumSq}; \\
\end{align*}
\]

end

The variable \textit{sumSq}, which holds the summation value of the squares of natural numbers under consideration, is changed repeatedly during program execution, as is the \textit{count} variable \textit{i}. The effect of the program can only be seen by following the sequence of changes made to these variables by the commands in the program.

In contrast, the following is usually what a professional Haskell programmer will write to solve the very same problem:

\[
\text{sumSq} :: \text{Int} \rightarrow \text{Int} \\
\text{sumSq} \ n = \text{sum} \ (\text{map} \ \text{square} \ [1..n])
\]

In this program, a list is used to store numbers from 1 to \textit{n}, then each of them is squared before being summed up to give the result. This Haskell code snippet uses neither control flow, found in imperative programs, nor recursion, and serves as a good example of a functional style program with elegant simplicity. Note that \textit{square} is a Haskell function that another Haskell function \textit{map} applies as its argument\(^3\) to every member of a list before the \textit{sum} function adding every number in the list to give the summation. The underlying \textit{data-directed} programming style is added value of the functional paradigm. As compared with the meeting scheduler example under section 1.2, the functional skeleton structure demonstrated in the Haskell code snippet above, especially the \textit{map} function, can be used immediately to implement the meeting scheduler design in (1.1) with a functional paradigm.

A program written in a functional programming language, such as the Haskell code snippet we saw earlier, can also be read as \textit{executable specifications of behaviors} \cite{9}. A domain expert, who oftentimes goes beyond simply being a programmer, would like to embrace an executable behavior specification language to edit, compile and test the design specification by actually

\(^3\) therefore, \textit{map} is called the higher order function.
running it on the source code level. In ensuing sections, we will showcase in detail how a Situation oriented domain expert can benefit from such a functional, Situ framework specific programming language.

Functional paradigm has already been used to serve various domain specific engineering purposes. For example, functional reactive programming (FRP) paradigm\cite{10} in which continuously evolving behaviors and discrete events are used to model systems, has been adopted and implemented in applications as diverse as robotics, animation and real-time programming. As to concrete language, Fran\cite{11} is a FRP domain-specific language with its root from Haskell for building reactive animations, using simple vector graphics, text, (animated) bitmaps and sound. In the area of multimedia reactive authoring research, FRP languages are also proposed to catch hold of varying values rendered by runtime animation tasks\cite{12}.

1.4 Situ$^f$-based Environment

As Figure 1.1\footnote{Many thanks for Dr. Les Miller’s highly penetrating technical suggestion.} shows, the central components within Situ$^f$-based environment revolve around serving the Situ$^f$ program. We model the underlying capturing mechanism for context information centered around a situation by SituIO, which by nature is to stream captured context information. SituIO connects internally specified situations written in Situ$^f$ language and the externally observed context variables bound with those situations. In Situ$^f$, each situation can be constructed, either independently or combinatorially, by four built-in functional patterns: map, reduce, filter and apply.

The precise meaning of SituIO is described using computational semantics in 3.6.3.

1.5 A glance view of the Situ$^f$ environment

No computer program can run in a vacuum. Ever since Brian Kernigan and Rob Pike’s classic The Unix Programming Environment hit the shelf, generations of programmers have been deeply aware that the secret of Unix’s huge success is in a big part due to its unusually rich and productive programming environment. At its heart, it is the relationships among
Figure 1.1  *Situ*<sup>f</sup>-based environment: the overview

programs rather than the programs themselves that produce the core power of a system [13]. One of the design objectives of *Situ*<sup>f</sup>-based environment is to provide such a setting in which domain experts can take advantage of a variety of elements centered around the abstraction of a human-centered situation [1].

*Situ* framework envisions and blueprints a rapid software evolution paradigm. *Situ*<sup>f</sup>-environment targets the implementation of this vision by first focusing upon graphical user interface level transitions and commands. From situation services, situation data structures, to the underlying *Situ*<sup>f</sup> runtime, *Situ*<sup>f</sup>-based environment is proposed to embrace all of the above as its core interest, contributing towards a situation-oriented, automated software adaptation paradigm. This design is composed to highlight the human-centric nature of situations under *Situ* framework. A user’s context, especially, a user’s behavioral context, falls into the category of internal dimension of context as opposed to external dimension of context. The latter has been more sufficiently addressed than the former in the context-awareness research community [14]. The reason, as least in part, is due to its being external and therefore easier to observe, for example
location, temperature, time, lighting levels, proximity to other objects and so on. However, to dig deeper into the context, especially to more accurately capture those regarding human factors like user’s goals, tasks, work context, etc., internal context needs to be attended [14] equally well.

![Diagram of behavior-centric context](image)

Figure 1.2 A simple diagram of the behavior-centric context for a user

The internal context, i.e., user’s behavioral context, surrounds the actions of a user and it only comes into existence when a sequence of actions leading to a behavior are being performed. The internal context is created at the outset of an action sequence performed by the user and ends when the behavior is concluded.

An important observation is that behaviors vary in scope ranging from the very general to the very specific. General behaviors contain one or more specific activities. In this sense, we can think of a behavior as a container in which all the sub-behavioral activities at various levels compose a hierarchical structure. To give a concrete example of this context hierarchy, let us consider the login activity inside MyReview, a real world example featuring a web-based paper review system.
In general, a behavior, coupled with its internal context within which it exists, gives rise to a structural context diagram as shown in Figure 1.2. Note that as shown in Figure 1.3, Login context influences not only login behavior, but also MyReview − Login, referring to MyReview username and password submission behavior.

The picture is incomplete when we only look into the context surrounding the receiver of a user’s action within MyReview without investigating the action provider’s functional role. In other words, the user’s profile also creates an important part of the internal context. Suppose that the user uses the MyReview system to organize a workshop under IEEE COMPSAC to meet academic researchers and industrial practitioners to discuss emerging methodologies and techniques to enhance software security. The context goes beyond interacting with the MyReview system, though they are closely related. In order to run a successful workshop, to attract and evaluate scholar paper submissions is indispensable. This activity cannot isolate itself from the context: a security workshop organizer usually is an expert in the area of computer security, which in turn is part of her career path: maybe she is a professor of computer
security from computer science department in a University, currently working on several NSF-funded research projects, one of which is to test the applicability and scalability of certain security theory as being extended to the industry partners. Organizing a workshop is an excellent task to support the project, for which MyReview is used as a tool. The user’s profile is hierarchized through Figure 1.4:

![Figure 1.4](image)

**Figure 1.4** A more complete picture of the MyReview login context integrating user’s profile

While a user’s internal context can mirror her expectation, the challenge is to identify *a priori* the information that exists within the context, especially the internal context: how do you identify the information regarding the behaviors being performed even before the behavior is performed? A side question that comes along is how to exclude irrelevant information from contextual considerations in order to recognize only legitimate situations relative to a user’s goal. *Situ* is designed to set up the environment that serves to answer the first question; we propose to answer the second question by the binding mechanism of context variables built inside the *Situ* language. More detailed discussion is offered in the next chapter.

The ordering of contexts can be adjusted by events. Events are also signals sending off
information about switching of context that often suggests transitioning between situations. The mechanism of events-passing between contexts serves to link context-oriented situations. At any given time, only one internal context is active; as a result, a user’s behavior will be recognized only when it is supported by the active internal context. The diagram in Figure 1.5 shows a concrete example of an active internal context.

Example using MyReview: a web-based paper review system

Figure 1.5  Context stack

Situ\textsuperscript{f}-environment supports context propagation: when the whole system is under a certain active context, all its sub-system will automatically inherit that active context. After a paper reviewer’s successful login, for example, each GUI gadget such as buttons and links can be conceived as carrying the context of that specific reviewer’s profile. This view reflects the human-centered characteristic of Situ\textsuperscript{f}-environment. When an event occurs in a certain context, all changed contextual elements will be published to all its sub-contexts. This is achieved combinatorially by Situ\textsuperscript{f}’s attribute grammar based context handling machinery and its interplay with Situ\textsuperscript{f}-based environment.

Situ framework is context-oriented [1]. Each situation contains information regarding its
environmental context. In this work, an attribute grammar based context handling approach is proposed to define the Situ$^f$ language. The Situ$^f$ language and the correlated environment based on Situ$^f$ together bring home a situation programming model.

Existing approaches mostly remain focused on a user’s external context level. In order to better address issues involving a user’s cognitive activities, our approach will focus on capturing and using the context information surrounding the behavioral performance by a user. To this end, the designer of the Situ$^f$ language pays particular attention to craft the language such that through built-in context binding, monad-based SituIO streaming and pattern-based situation constructing mechanism, situation specifications written in Situ$^f$ intrinsically revolve around a user’s behavioral performance. Having a behavioral-centric context implies a firm and consistent step forward towards the model of human-centered situation proposed by the original Situ framework.

The diagram in Figure 1.6 shows a typical usage scenario that engages a Situ$^f$ program runtime. A domain engineer specifies situations in Situ$^f$ code. Due to the high level situation-oriented perspective, the domain engineer, for different software modules that serves the end user, imports different context specifications to correctly bind contexts information in her Situ$^f$ program. In the meantime, appropriate situation services are included to assist the real-time, context collection task.

1.5.1 A retargetable environment

Underlying software modules vary from domain to domain. The flexibility of allowing the plug and play of domain specific software modules into Situ$^f$-based environment makes it easily retargetable to other software modules whose situational interplay with an end user interests a domain engineer to write situation specification code in Situ$^f$. Besides, one domain expert’s situation specification written in Situ$^f$, once made public under appropriate circumstances, can be imported to assist another domain expert’s situation specification effort using Situ$^f$. Indeed, the central design objectives of the Situ$^f$ language include promoting situation re-usability.

The contribution of Situ$^f$ is that through language features and its built-in support, Situ$^f$ allows domain experts to think and code in terms of situations. Lower level details regarding
specific software modules through which an end user interacts with, as well as the specific services and context specifications are well encapsulated to promote the reusability of the code. Although currently only graphical user interface based user interaction is fully supported by the prototype, future extension can well cover the ground of remote sensory interaction and multi-modal interaction between a human user and a computing device.

1.6 My contribution

This work is the first attempt to realize the conceptual model of Situ framework [1]. The objective is to create a programming model with the following specific aspects:

1. bridging the concept of Situation over to realistic computing circumstances with clear software engineering realizations;

2. creating the Situ-based environment to drive the evolution of graphical user interface based commands and transitions - a subcategory of software evolution proposed by the
original Situ framework;

3. utilizing a Situation as a basic building block into a functional paradigm specification language called Situ$^f$;

4. developing an attribute grammar-based approach to formalize contexts surrounding a situation as attributes, with the purpose of rigorously specifying situations in Situ$^f$;

5. linking situation data structures specified in Situ$^f$ scripts to existing software by the language features and attribution rules built inside Situ$^f$'s attribute grammar;

6. carrying out experiments in MyReview and Java JFrame mechanism to showcase the feasibility of the Situ$^f$-based environment, which in turn provides evidence of the rigor and practicality of the original Situ framework.

1.7 Organization

This work is organized as follows: first Situ$^f$'s underlying data exchange model is introduced, built on top of an XML-based intermediate representation. Then, a series of examples are given revolving around the concepts of Situation contexts, especially action-oriented behavioral context and environmental context. After that, a rigorous definition of the domain specific, functional language Situ$^f$ is given. Our focus centers around the attribute grammar model used in Situ$^f$, which combines the syntax and static semantics of the concept of situation under the grammar production rules, each of which is decorated by a set of attribute equations. Our approach to model contexts as attributes in situations receives particular emphasis.

It is through a situation specification written in Situ$^f$ that a Situ$^f$-based environment can be initiated, set up and finally established. Overall, the big picture that creates and runs such a Situ$^f$-based environment is entirely revolving around situations. Given that context data collection necessarily requires I/O support, SituIO, which finds its root in the Situ$^f$ language itself, is emphasized and precisely described using computational semantics, a.k.a small-step operational semantics. Finally, an evaluation of the approach is given by a feasibility test, followed by conclusion remarks and future work.
CHAPTER 2. OVERVIEW

2.1 Background information on situation and human intention

Among the flurry of research on human intention cutting across Philosophy [2], cognitive science [15], and artificial intelligence [16, 3], two well referenced opinions that directly relate to the purpose that motivates this research stand out.

First, Bratman described intention as mental states motivating actions [2]. His opinion has been adopted and turned into the supporting theory, known as BDI logic, for agent planning research. Targeting Rational agents, a lot of research work has been done in the area of Artificial Intelligence (AI) and Robotics, to infer the mental states of agents. Approaches involving planning theory [17, 18], ontologies [19, 20], closed world mathematical logic such as Kripke semantics [21, 22] are well developed. However, this is not enough for inferencing human intentions. The reasons are found both due to the efficiency issues and in terms of the practical concerns under current state of art. The essential challenge comes from the highly fluid and intangible nature of human’s mental states. To see the gap more clearly, let us use epistemic formulas from Kripke semantics\(^1\) [23] as an example.

The key construct under Kripke semantics is what is so called Kripke structure \(M\), defined as a tuple \(<S, \pi, R_1, \ldots, R_m>\) where:

(i) \(S\) is a non-empty set of states,

(ii) \(\pi : S \rightarrow (P \rightarrow \{\top, \bot\})\) is the truth assignment to propositional atoms per state,

(iii) \(R_i \subseteq S \times S\) (\(i = 1, \ldots, m\)) are so-called accessibility relation.

\(^1\)also known as possible world semantics.
As is shown above, the set \( S \) of states has to be determined before one can start reasoning on the truth value of an Epistemic Formula \([23]\). The Epistemic Formula generally takes the following form\(^2\):

\[
(M, s) \models K_i \phi \iff (M, t) \models \phi \text{ for all } (s, t) \in R_i
\]

Despite its logic form, \( K_i \phi \) expresses the meaning of “Agent i acknowledges \( \phi \)”. The underlying implication is that in order to “understand” a certain epistemological state of agent i’s knowledge \( \phi \) in world \((M, s)\), it is sufficient and necessary to “understand” if that knowledge \( \phi \) still holds in all worlds agent i considers possible. Note that \((M, t)\) can be any of such a possible world relative to a given state \( s \) due to state \( t \)’s “for all” condition. Two key issues stand out when applying the Kripke semantics to human-centered domain:

- If set \( S \) can not be solidly decided, or can never be easily stabilized mostly due to the human factors involved, the above epistemic reasoning can be seriously hampered;

- Even if set \( S \) is decidable but it is very large a set, as is usually the case even for a standalone computer program \([24]\), not to say the case where state changes are made by human beings’ instantaneous decision, the efficiency of reasoning under Kripke semantics-based logic system can be quite a daunting task \([25, 23]\). As shown from the diagram below, to verify agent i’s knowledge \( \phi \) at state \( s \), all possible worlds have to be checked. Those possible worlds are derived from all accessible states sanctioned by agent i’s accessibility relation \( R_i \).

These restrictions generally apply as long as Kripke semantics serves as a key component in the underlying theoretical foundation, which is at the time of this writing prevalently true in AI for knowledge representation, practical knowledge reasoning \([25, 23]\), as well as ontologies such as those based on description logics \([19, 20]\). More concrete examples include the well-known LORA \([26]\) system, a derivative and further extension from Rao and Georgeff’s original BDI logic system that allows the representation and reasoning about beliefs, desires, intentions, and actions of agents within a system, and how these beliefs, desires, intentions and actions change over time \([26, 27]\).

\(^2\)for the sake of brevity, we omit the purly propositional counterparts.
In response to Bratman’s theory, Scheer initiated the second school of opinion regarding the definition of human intention. He pointed out that intention should be considered as a course of actions [28]. In Scheer’s opinion, direct mental states modeling should be avoided by way of capturing action sequence.

Both Bratman and Scheer seem to agree on the point where human intention can be analysed through the observation of action sequences. In addition, sensor-based approaches [29, 30] have recently gained momentum, through which collected information on temporal contexts, closely related user-centric data\textsuperscript{3}, can be timely captured and analysed to improve human life style [31]. It’s worth mentioning that XML-based sensor language helped to seamlessly move sensor data onto the interconnected World Wide Web, to the platform of mobile computing [29] and even to serve the construction of human-robot interfaces [32].

\textsuperscript{3}Examples include user’s geographical locations, etc.
We use XML to describe the structure of sensory data collected and the structure of situations drawn from those data. XML serves as the intermediate form of \textit{Situ} program and prepares the discussion for further analysis of situation modeling that motivates the invention of \textit{Situ} domain specific language.

The XML-encoded Data (or documents) are ordered, labeled tree structures. Among others, XML’s intrinsic hierarchical structure offers enormous flexibility and in the meantime has nurtured a flurry of research in computer science on XML itself, ranging from XML type system analysis based on DTD or XML schema to XML-based document processing techniques; Good examples include statically typed XML processing devices such as XDuce [33] and RELAX NG [34]. By design, \textit{Situ} adopts XML to serve as an intermediate meta-language to capture and represent contextual information attached to each situation. Underpinning its wide-spread applications on sensory data is XML’s semi-structured data model, which is embodied by the form of a mark-up language.

XML can also comfortably serve the purposes of describing the sensory data and of depicting the structure of situations drawn from these data. The intuitive and syntactic nature of XML serves to prepare the discussion of further analysis and modeling of situations under \textit{Situ} which nurtures the birth of \textit{Situ} domain specific language and \textit{Situ}-based environment.

To strike a brand new paradigm featuring rapid and automated software evolution, \textit{Situ} framework [1] developed the concept of minimal intention that is built from a sequence of situations\footnote{where each situation is defined as a triple \{d,A,E\}$_t$, it is human-centric since A and E are human factors; see [1] for details.} with respect to a goal\footnote{referring to system goals as discussed in Goal-Oriented Requirement Engineering [6, 7].}. We take minimal intention as our default definition of intention to avoid terminology confusion. Each situation snapshots software user’s behavioral and environmental contexts as well as the predicted user’s desire based on those contexts.

As part of the big picture, rather than exposing the hierarchical context directly to the domain experts and engineers, we propose that contexts be captured and internally processed inside \textit{Situ}-based environment, which is set up by \textit{Situ} program written by domain experts. More concretely, we abstract the key processing power of \textit{Situ}-based environment as an abstract machine, whose native language is a situation stream language as will be explained later on.
This abstract machine is noted as $Situ^I$-AM. $Situ^I$-AM sets up and maintains its internal states, geared by captured contexts.

### 2.2 A motivating example

Let us first consider a concrete example.

MyReview, a paper review system in use for conference organization has three types of users: paper author, paper reviewer and conference organizer. Each author is given login access to her paper once the initial submission has been completed to the system so that she can keep updating her submission until the deadline is hit. Paper reviewers can login to review those papers assigned by conference organizers following a double blind review policy, and conference organizers once login, can utilize the administration tools such as assign papers to reviewer, batch email to all program committee members etc. A typical scenario of interest is the login situation.

![MyReview Example](image)

**Figure 2.2** A MyReview Example

Our discussion is based on the assumption that a user’s computer has been equipped with a sensory touch detector, basically a situation service shown in Figure 1.1, that can record all the mouse clicks and key strokes over button, links and textboxes etc. In fact, this is the basic setup $Situ^I$-based environment requires in order for it to fulfill its mission. Our $Situ^I$ prototype provides this capability as a default service.
Given that in MyReview, the login interface for users (author, paper reviewer and conference organizer) may seem to provide identical visual effect, a less experienced paper reviewer accidentally hits the conference organizer’s login entrance. *She types in her username and password* ($S_1$) (see footnote 6), *clicked the login button* ($S_2$). The following picture visualizes these two situations with regard to the login interface:

![Login Interface Diagram](image)

**Figure 2.3 Situations $S_1$ and $S_2$**

The minute the login button is clicked after wrong username and password information is typed in, the user sees a login fail page saying “invalid password!” which signals her to relogin ($S_3$).

Each situation such as $S_1$ is intrinsically timestamped, such as $S_{1}^{t1}$. Several times around, the user eventually gets to login successfully; then she *clicked and downloaded one of the four papers assigned to her and started reviewing* ($S_{4}^{t4}$), *uploaded her comment and review score into the system* ($S_{5}^{t5}$). Following a similar vein, she moves on and reviews the next paper . . .

---

6 $S_1$ corresponds to a node in XML format, which is used as the intermediate representation to encode captured situation sequences. Same thing for $S_2, S_3, S_4, . . .$
For concrete syntax offered by \textit{Situ} that a domain engineer can use to write code to create the \textit{Situ} environment, please refer to Chapter 3. We still use XML to explain the machinery, given that it is a \textit{Situ} syntax neutral, intermediate representation. This arrangement strives to emphasize on the semantic transformation critical for any computing environment, including \textit{Situ}-based environment.

Next, we assume that a domain engineer’s program written in \textit{Situ} is already successfully interpreted. This assumes the completion of the of proper establishment of a \textit{Situ}-based environment so as to effectively capture the runtime situation sequence centered around a use case scenario. The context mediates the entire process. The aforementioned MyReview system example is such a concrete case in point.

The particular situation sequence describing the above scenario, after being captured by the mechanisms employed under \textit{Situ} environment, is sequentially represented as follows:
Note that in this situation sequence, since the last login action given by the paper reviewer must be a successful login action, there is no \( S_{3n} \) to represent a Login Fail Situation to follow \( S_{2n} \) in the sequence. By nature, a Login Fail Situation corresponds to an event which is passed back to the Situ\( f \)-based environment, which is formalized as Situ\( f \) virtual machine. This event is analogous to an IO interrupt on a real machine, whereas under Situ\( f \)-based environment the communication is between user’s action imposed on a specific software system (such as MyReview’s graphical user login for paper review interface just demonstrated) and the external environment, generally imagined as the Sifu\( f \) virtual machine. The handling of this event inside Situ\( f \) virtual machine will change the state of the virtual machine correspondingly.

The XML intermediate representation reflecting the capturing of temporal situation sequence is as follows:

\[
\begin{align*}
S_{11}^{t_1}, S_{21}^{t_2}, S_{31}^{t_3}, S_{12}^{t_4}, S_{22}^{t_5}, S_{32}^{t_6}, S_{13}^{t_7}, S_{23}^{t_8}, S_{33}^{t_9}, \ldots, S_{1n}^{t_{1n}}, S_{2n}^{t_{2n}}, S_{41}^{t_{41}}, S_{51}^{t_{51}}
\end{align*}
\]

(2.1)
<action target="login_text_box" src="login.php" />

<output>
  <context target="text_box1">text1</context>
  <context target="text_box2">text2</context>
</output>

</action>

</S1>

<S2 timestamp="t21">
  <action target="login_button" src="login.php">
    <input>
      <context target="text_box1">text1</context>
      <context target="text_box2">text2</context>
    </input>
  </action>

  <output>
    <context>username</context>
    <context>password</context>
  </output>

</S2>

<S3 timestamp="t31">
  <effect>Fail</effect>
  <source>S2</source>
</S3>

</S1>

<S1 timestamp="t12">
  <action target="login_text_box" src="login.php">
    <output>
      <context target="text_box1">text1</context>
      <context target="text_box2">text2</context>
    </output>
  </action>

</S1>
\[ S_1 \]

\[ S_2 \text{ timestamp} = "t_22" \]

\[ \text{timestamp} = "t_41" \, \text{depend}_{on} = "S_1" \]

\[ \text{timestamp} = "t_51" \, \text{depend}_{on} = "S_4" \]
We define an event to be a special situation that semantically splits a sequence of situations into sub-sequences. It is the boundary that delimits scopes of contexts. An event is closely related to the immediate goal of a sub-sequence of situations. In the example of LoginFailEvent, the goal of the sub-sequence of situations up until $S_3$ is the negation of the event message, that is, to login successfully.

Event passing inside Situ$^f$ virtual machine suggests the following pattern:

\[(S_1, S_2, S_3)^* (S_1, S_2) (S_4, S_5)\]  \hspace{1cm} (2.2)

To see that, the repeated situation sequence is $(S_1, S_2, S_3)$: with the event $S_3$ trailing the sequence; This creates $(S_1, S_2, S_3)^*$. The rest is non-repeated situation sequence excluding $S_3$, $(S_1, S_2)$ since no exceptional situations, or events, occur there.

This pattern is generated over captured situation sequence (2.1). Prototypical forms of situations are used in pattern (2.2), where contextual information is taken off. For example $S_1^{t_k}$ and $S_1^{t_{k+1}}$ both have the same **prototypical form** $S_1$, which stands for generic login situation - let alone certain contextual differences such as \{username, password\}. Two failed logins, between one and the other, must have different context variables such as their time stamp, input texts of username and password by the user etc. $S_1^{t_k}$ and $S_1^{t_{k+1}}$ represent two concrete, context-annotated logins at time instant $t_k$ and $t_{k+1}$ respectively. Indeed, we can view $t_k$, the temporal tag decorating a prototypically formed situation $S_1$, as a symbolic annotator implying all associated contexts for $S_1$ at time instant $t_k$. 


2.3 The Environment Model of Situ $^f$ language

In Situ $^f$ language, variables containing context information are stored in places called locations. The set of locations is noted as $\text{Loc}$. Let $l$ denote an arbitrary location of $\text{Loc}$. Given that a machine all has countably many storage locations, we assume that $\text{Loc} = \mathbb{N}$, meaning locations are natural numbers.

The environment for Situ $^f$ context variables is a function that maps each context variable to a storage location. We can imagine a variable environment as a symbol table. More formally, the set of context variable environments is the set of partial functions from context variable to locations:

$$\text{EnvV} = \text{Var} \cup \{\text{next}\} \rightarrow \text{Loc}$$

We use $\text{env}_V$ to denote an arbitrary member of $\text{EnvV}$. The $\rightarrow$ represents a partial function. Moreover, we model the allocation of memory location for a new variable by assuming the existence of a function:

$$\text{new} : \text{Loc} \rightarrow \text{Loc}$$

the $\text{new}$ function above returns a successor for each location. That is done whether this successor location is available or not.

Since we are assuming that $\text{Loc} = \mathbb{N}$, we can think of it in our settings as:

$$\text{new} \ l = l + 1$$

The special context variable $\text{next}$ is used to point to the next available location to be assigned to a variable.

$$\text{next} = \text{new} \ l$$

given that current variable location in our natural number modeling proceeds to $l$. The next diagram provides a more intuitive illustration.

The following introduces a notation for the introduction of a new variable, which when bound to a location will produce a new environment. Suppose that the old environment is
Figure 2.5  Example of context variable environment

$env_V$, now a new context variable $x$ is bound to location $l$, i.e. $env_V[x \mapsto l]$; then the new environment $env'_V$ is:

$$
env'_V(y) = \begin{cases} 
env_V(y) & \text{if } y \neq x \\
l & \text{if } y = x \text{ and } x \text{ is unbound in } env_V \\
error & \text{if } y = x \text{ and } x \text{ is already bound in } env_V
\end{cases}
$$

The following figure shows that we have three context variables $x$, $y$ and $z$. $env_V$ is the function noted by the arrows between $\text{Var} \cup \{\text{next}\}$ and $\text{Loc}$. It shows clearly that $x$ is bound to location $l_1$, $y$ is bound to location $l_2$ and $z$ is bound to location $l_3$. The next free location is $l_4$. No other context variables are bound to any locations.

Note that since $\text{Situ}^f$ programs are computing in functional paradigm and no update assignment is allowed. Every context variable will be assigned one exclusive location and each
location will not change its value once defined. Therefore, in our environment model each location is one-to-one corresponding to a value. This provides notational convenience since we only need to keep track of the binding location of a context variable to understand its semantics.

The set of stores is also defined as a set of partial functions from locations to values. Given that all values in the domain of $Situ^f$ applications are Graphical User Interface based transitions and commands, the value of a context variable can be encoded as a string. Each string is a linear combination of characters($C$), each $Store$ function is a mapping from set of locations to $C^*$. Therefore the set of $Store$ functions is represented as follows:

$$Store = Loc \rightarrow \mathcal{P}(C^*)$$

in which, $\mathcal{P}$ refers to power set.

$Situ^f$, a functional language that is formally defined in the next chapter, strives to provide necessary means to allow a domain expert to set up the $Situ^f$-based environment complying with the original $Situ$ model [1]. In this dissertation, we focus on Graphical User Interface based commands and transitions which appears to be typical in present web-based applications. Domain expert’s vision and expertise injected into the environment through $Situ^f$ program largely determines the effectiveness of the environment. Moreover, context variables under $Situ^f$ environment, whose close correlation with situations are proposed through an attribute grammar based approach, which allows one to look at situations as context-oriented structures [1].

XML’s semi-structure feature and its wide application across multiple domains, especially in the realm of sensory data representation to support many pervasive computing purposes, makes it an excellent choice to serve as an intermediate form to construct and represent situations under $Situ^f$-based environment. XML is used in this work to capture and illustrate the internal workings of the underlying $Situ^f$-based environment. Furthermore, we model $Situ^f$-based environment as a virtual machine, designed to handle situation flows and context variables from a computer programming point of view.

This section provides a foundation for the efforts later on to formally define the semantics of $Situ^f$ language, especially in 3.6.2.
2.4 Context variables under the environment model

Let us again consider the paper review system example from 2.1. Due to unfamiliarity with the system, the paper reviewer might have accidentally run into unrelated situations such as clicking a link and being transferred to paper author’s paper submission page, rather than paper reviewer’s review submission interface. This action leads to an erroneous situation since the username and password required to enter authors’s paper submission page is different from the current username and password that are taking effect, namely the one that records a paper reviewer’s identity. An event \((S_7)\) is resulted from this error and will be passed.

\[
(S_1, S_2, S_3)^*(S_1, S_2)(S_6, S_7)
\]  

(2.3)

The XML intermediate representation for Situation sequence (2.3) is as follows:

```xml
<S1 timestamp="t11">
  <action target="login_text_box" src="login.php">
    <output>
      <context target="text_box1">text1</context>
      <context target="text_box2">text2</context>
    </output>
  </action>
</S1>

<S2 timestamp="t21">
  <action target="login_button" src="login.php">
    <input>
      <context target="text_box1">text1</context>
      <context target="text_box2">text2</context>
    </input>
    <output>
      <context>username</context>
      <context>password</context>
    </output>
  </action>
</S2>
```
</output>
</action>
</S_2>
<S_3 timestamp="t_{31}\" >
  <effect> Fail </effect>
  <source> S_2 </source>
</S_3>
<S_1 timestamp="t_{12}\" >
  <action target="login_text_box" src="login.php \" >
    <output>
      <context target="text_box1" > text1 </context>
      <context target="text_box2" > text2 </context>
    </output>
  </action>
</S_1>
<S_2 timestamp="t_{22}\" >
  <action target="login_button" src="login.php \" >
    <input>
      <context target="text_box1" > text1 </context>
      <context target="text_box2" > text2 </context>
    </input>
    <output>
      <context> username </context>
      <context> password </context>
    </output>
  </action>
</S_2>
<S_6 timestamp="t_{61}\" >
Each event is directly from a human action imposed on the software system; an immediate system goal exists with regard to the action [1], and the occurrence of an event from within Situ environment is closely linked to a user’s desire.

Indeed, event is an appropriate mechanism to realize the interaction between the user (feedback) and the software system to better understand the user’s instantaneous desire. A good question to ask in the case of situation sequence (2.3) is: does the user desire to submit a paper, or does she/he simply commits an operational mistake? The latter implies that the user is still committed to her/his original desire: to review paper. The Situ-based environment will inject action around events to more accurately capture the user’s desire.

The passing of event \((S_7)\) works as an interrupt between the user and the Situ virtual machine. It interrupts the output generation of \((S_7)\), namely successful redirection to the paper submission page for paper authors. The internal working of this event is based on the environment model upon which the virtual machine is built. Let us go into certain length of detail of how the environment model employed by Situ works to facilitate its event passing machinery.
2.5 Event passing under Situ’s environment model

Under Situ’s environment model, there are three kinds of errors detected by the environment that can trigger an event.

- A runtime error raised by the software system
- A tendency to use undefined (unbound) context variables or functions
- A tendency to conduct update assignment to a variable location already bound to a context variable

Let us take a look at the events raised in the MyReview system example again, especially the situation sequence at (2.3):
\((S_1, S_2, S_3)(S_1, S_2)(S_6, S_7)\)

The XML intermediate representation for the above situation sequence is:

\[
\begin{align*}
&S_1 \text{ timestamp}="t_{11}" > \\
&\quad <\text{action} target=\text{login\_text\_box} src=\text{login.php} > \\
&\quad \quad <\text{output}> \\
&\quad \quad \quad <\text{context} target=\text{text\_box1} > text1 \;/\text{context} > \\
&\quad \quad \quad <\text{context} target=\text{text\_box2} > text2 \;/\text{context} > \\
&\quad \quad <\text{output}> \\
&\quad \;/\text{action} > \\
&\;/S_1 > \\
&S_2 \text{ timestamp}="t_{21}" > \\
&\quad <\text{action} target=\text{login\_button} src=\text{login.php} > \\
&\quad \quad <\text{input}> \\
&\quad \quad \quad <\text{context} target=\text{text\_box1} > text1 \;/\text{context} > \\
&\quad \quad \quad <\text{context} target=\text{text\_box2} > text2 \;/\text{context} > \\
&\quad \;/\text{input} > \\
&\quad <\text{output}> \\
&\quad \quad <\text{context}> username \;/\text{context} > \\
&\quad \quad <\text{context}> password \;/\text{context} > \\
&\quad \;/\text{output} > \\
&\;/S_2 > \\
&S_3 \text{ timestamp}="t_{31}" > \\
&\quad <\text{effect} > Fail \;/\text{effect} > \\
&\quad <\text{source} > S_2 \;/\text{source} > \\
&\;/S_3 > \\
&S_1 \text{ timestamp}="t_{12}" >
\end{align*}
\]
<action target="login_text_box" src="login.php">
  <output>
    <context target="text_box1">text1</context>
    <context target="text_box2">text2</context>
  </output>
</action>

<S1>
<action target="login_button" src="login.php">
  <input>
    <context target="text_box1">text1</context>
    <context target="text_box2">text2</context>
  </input>
  <output>
    <context>username</context>
    <context>password</context>
  </output>
</action>
</S2>

<S6 timestamp="t61">
<action target="paper_submit_button">
  <input>
    <context>username</context>
    <context>password</context>
  </input>
  <output redirect="submitpaper.php"/>
</action>
</S6>
The two events are situations $S_3$ and $S_7$. Their happening is due to the actions occurred in their immediate previous situations - $S_2$ and $S_6$ respectively. For event $S_7$, the user’s action to click on the paper submission button triggers MyReview system to internally check the cached username and password. The username and password are modeled as context variables by Situ’s environment model.

![Figure 2.7 Environment model: a working example](image-url)
Applying the \textit{env}_\text{V} \ function to \textit{username} \ and \textit{password} \ gives the memory locations in \textit{Situ}^f virtual machine for \textit{username} \ and \textit{password} \ to store the data; afterwards, applying \textit{Storage} \ function on those two locations returns the current value of \textit{username} \ and \textit{password}. In other words, the value \( v \) \ of \textit{a context variable} \( x \) \ can be found by \( v = \textit{store} \circ \textit{env}_\text{V}(x) \), where \( \circ \) \ stands for functional composition.

MyReview system looks these values up in its internally maintained credentials, and delivers a rejection error afterwards. This is a runtime error. An important point to notice is that the context variable of \textit{username} \ and \textit{password} \ are established into the environment by the last \( S_2 \), since the previous one was interrupted by an event, that therefore led to an abortion of the desired context variables.

Note the difference between the MyReview system and \textit{Situ}^f-based environment. The environment model is employed by \textit{Situ}^f-based environment, not MyReview system. The latter happens to be an example under discussion, whereas \textit{Situ}^f-based environment can be set on top of different Graphical User Interface based software system. To tailor the \textit{Situ}^f-based environment to a specific Graphical User Interface based software system, a domain expert needs to use \textit{Situ}^f language, which will be introduced with a concrete example in the next section.

By comparing (2.3) with (2.2), it is clear that these two patterns are not the same, and even less, neither is compatible with the other. The question is: is event \( S_7 \) \ an accident, or is it the user’s real intention? By writing \textit{Situ}^f \script\, a domain expert can choose either interactive mode or default mode to resolve this issue. By default mode, the \textit{Situ}^f \ virtual machine will reason based on its contextual information.

Under default mode, with respect to a goal, for example, \((S_4, S_5)\), (2.3) can be thought of as compatible with (2.2), therefore \( S_7 \) \ is an accident. The reason is that \( S_6 \) \ is a noise with regard to \((S_4, S_5)\) - since none of \( S_6 \)’s context data is found in \( S_4, S_5 \) - \textit{Situ}^f \ virtual machine internally replaces \( S_6 \) with \( \epsilon \), a \textit{least} \ situation, which is a constant situation compatible with any situation type (including situation sequence rendered meta-situation, like \((S_1, S_2)\)), so that \((S_6, S_7)\) will be subsumed into \((S_1, S_2, S_3)^*\), which reduces (2.3) to \((S_1, S_2, S_3)^+(S_1, S_2)(S_4, S_5)\).
After being equipped with the above example that provides a concrete “insider’s” view of Situ$^I$’s intermediate meta-level to expose how situations are represented and analysed inside Situ$^I$-based environment through contextual information, let us now take the domain engineer’s role to see how to write a script in Situ$^I$ domain specific language to set up the Situ$^I$ environment in order to capture those situations via relevant contexts. Before that, an emphasis on understanding of situation from a Situ’s point of view as a human centric construct is necessary [1].

2.6 Human-centric Situations

A critical new ingredient injected into the concept of situation, around which the entire Situ framework [1] is built, is that all situations are human-centric situations. Situ’s perspective on situation strikes a brand new vision in which a human’s dimension is added as an indispensable component.

In the last section, the paper review system example was discussed. From this section on, while still using the same example, our emphasis will be switched to the machinery a Situ$^I$-based environment offers to facilitate the capturing of user’s information which is eventually built into a situation, thus the name human-centric situation.

In addition to providing some intuitive background for those interested in exercising situation programming in Situ$^I$, this example also serves the following purposes:

- it elaborates the concept of behavioral context and how it relates to situations;
- it elaborates the concept of Situ-environment and how it integrates Situation and a real world system;
- it introduces Situ$^I$’s built-in support for situation composition patterns that a domain expert can benefit from.

\[^{7}\text{In this writing, we use domain engineer and domain expert interchangeably.}\]
2.7 An introduction to Situ$^f$ language and examples

Situ$^f$ is a functional specification language. Its central language craft revolves around the idea of a function, from a function name, its inputs (arguments), outputs to more sophisticated techniques like functional composition, partial function, currying, etc... In Situ$^f$, a name is either a function or static data. Situ$^f$'s function models an action or compound action, representing a behavioral context within a situation [1]. The real novelty is the way that Situ$^f$ is proposed, which combines functional paradigm with attribute grammar to model situations for domain specific purposes within the boundary of Situ framework.

2.7.1 Attribute-Grammar model of Situ$^f$

Attribute grammar [35] can be conceived as context-free grammar with an addition of attached context-sensitive conditions and semantics-oriented attribute rules. More precisely, an attribute grammar starts from an context-free grammar, and then:

- add attributes to the nonterminal symbols of the grammar;
- supply attribute equations to define attribute values

Associated with each production in an attribute grammar is a set of attribute rules known as attribute equations. Attribute equations are used to specify the relationships between the attributes of terminals and nonterminals in a grammar production. For the following production prod:

\[ prod : X_0 \rightarrow X_1 \ldots X_k \]

each $X_i, (0 \leq k)$ denotes an occurrence of a grammar symbol, and associated with each nonterminal occurrence is a set of attribute occurrences, denoted as $A(X_i)$ which includes all nonterminal’s attributes.

Each production in an attribute grammar usually has a set of equations, each of which defines the attribute values. In essence, those equations are indeed tantamount to *attribute-definition functions*. The attributes of a nonterminal are divided into two disjoint classes:
synthesized attributes, denoted \( S(X_i) \) and inherited attributes \( I(X_i) \), where \( A(X_i) = S(X_i) \cup I(X_i) \). Briefly, synthesized attributes are used to pass information \textbf{up} a syntax tree; in contrast, inherited attributes are used to pass information \textbf{down} a syntax tree. In particular:

- Terminals may have only synthesized attributes;
- Nonterminals may have both synthesized and inherited attributes.

Figure 2.8 in the following section illustrates these two important terms.

2.7.2 Synthesized attributes, inherited attributes and functional dependency

Synthesized attributes and inherited attributes are two key components for an attribute grammar to propagate attribute values through its derivation tree. Moreover, a dependency graph further enhances a derivation tree by adding functional dependency relations among attribute occurrences to visualize the direction of the propagation flow of the attribute values for the attribute grammar. A handy side effect coming out of the dependency graph is that it serves as a convenient tool to allow intuitive judgement upon circular versus non-circular attribute grammars, without the need of stepping into full length formal proof. This section brings together these concepts and their closely related formalisms, such as Function Dependency (FD), Dependency Graph, etc... to facilitate further discussion.

As a running example, we come up with a simple programming language called SimpleL, which does not have type expressions in variable declarations. The SimpleL language only contains variable declarations and expressions possibly containing those declared variables. The context-free grammar for SimpleL is defined in Table 2.1. For brevity, we only show the basic productions that are directly relevant to ensuing discussions.

It is easy to see that this context free grammar for SimpleL language depicts program scheme shown in Program 1.

The attribute annotated grammar, i.e. attribute grammar for SimpleL, is in Table 2.2.
(1) program → program identifier declList begin exprList end
(2) declList → var identifier expr
(3) declList → var identifier expr ; declList
(4) exprList → expr
(5) exprList → expr ; exprList
(6) expr → + expr expr
(7) expr → − expr expr
(8) expr → identifier | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Table 2.1 A context-free grammar for SimpleL

Program 1 Program scheme for SimpleL language

program p
var
  var q 3;
  var r 5
begin
  + 2 q;
  − r 4
end

Functional dependencies (FD) among attribute occurrences in a production prod can be represented by a directed graph, called dependency graph, denoted by D(prod). The in-depth definition of dependency graph is:

1. The dependency graph, namely $G'$, must contain a vertex $a'$ corresponding to each attribute occurrence $a$ in the counterpart attribute grammar $G$.

2. The dependency graph $G'$ must contain a directed edge $(a', b')$, pointing from $a'$ to $b'$, in correspondence to each attribute occurrence $a$ appearing on the right-hand side in the attribute rule to define an attribute occurrence $b$, in the counterpart attribute grammar $G$.

In Figure 2.8, the dotted lines show the parsing of Program 1 against the context free grammar specified in Table 2.1. A solid arrow shows the flow of attribute values. It also
(1) program → **program** identifier declList begin exprList end
exprList.env = declList.env
(2) declList → **declare** identifier
declList.env = \{identifier.id\}
(3) declList₁ → **declare** identifier ; declList₂
declList₁.env = \{identifier.id\} ∪ declList₂.env
(4) exprList → expr
expr.env = exprList.env
(5) exprList₁ → stmt ; exprList₂
expr.env = exprList₁.env
exprList₂ = exprList₁.env
(6) expr₁ → + expr₂ expr₃
expr₂.env = expr₁.env
expr₃.env = expr₁.env
(7) expr₁ → − expr₂ expr₃
expr₂.env = expr₁.env
expr₃.env = expr₁.env
(8) expr → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
expr.env = \{0,1,2,3,4,5,6,7,8,9\}

|\hline
| (1) program & → **program** identifier declList begin exprList end
| exprList.env = declList.env
|(2) declList & → **declare** identifier
| declList.env = \{identifier.id\}
|(3) declList₁ & → **declare** identifier ; declList₂
| declList₁.env = \{identifier.id\} ∪ declList₂.env
|(4) exprList & → expr
| expr.env = exprList.env
|(5) exprList₁ & → stmt ; exprList₂
| expr.env = exprList₁.env
| exprList₂ = exprList₁.env
|(6) expr₁ & → + expr₂ expr₃
| expr₂.env = expr₁.env
| expr₃.env = expr₁.env
|(7) expr₁ & → − expr₂ expr₃
| expr₂.env = expr₁.env
| expr₃.env = expr₁.env
|(8) expr & → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
| expr.env = \{0,1,2,3,4,5,6,7,8,9\}
|\hline

Table 2.2  Attribute grammar for SimpleL

shows the dependence relation that echoes the attribute flow. Note that since there is no cycle formed by the solid arrows in Figure 2.8, the attribute grammar for SimpleL is a non-circular attribute grammar. In this research, we confine our attention to noncircular grammars only. Theoretically, a grammar is noncircular if it is not possible to build a derivation tree in which attributes are defined circularly. Besides, circularity issues of attribute grammars have already been well solved by Knuth in 1971. He showed that circularity is a decidable property of attribute grammar [36], and proposed an algorithm to test circularity [36]. In 1975, Jazayeri et al. showed that such algorithm is of inherently exponential complexity [37]. We will take full advantage of the intuition a dependency graph offers, such as that in Figure 2.8: after transforming an attribute grammar to a dependency graph, if it is acyclic, then it is sufficient to say that the original grammar is a noncircular attribute grammar. We directly use this conclusion for the rest of this work. By convention, in this work we deal only with well
formed attribute grammars. In a well formed attribute grammar, for each of its left-hand-side nonterminal’s synthesized attribute occurrences, there is exactly one attribute equation in each grammar production. Likewise, for each of its right-hand-side nonterminals’ inherited attribute occurrences, there should be exactly one attribute equation in each grammar production, for the given well formed attribute grammar.

Intuitively, variables such as q and r have to be declared before they are being used. The declaration records a variable by supplying its id which will be stored in the symbol table. A symbol table can be considered the global environment drawn from the environment of the declaration list.

Attribute grammar shares a great deal in common with functional paradigm, or more broadly, declarative paradigm-based programming models. Some researchers even argued that an attribute grammar per se is a declarative functional language [38, 39, 40, 41]. Indeed, our
proposed Situ$^f$ domain specific language follows functional paradigm to allow a domain expert to specify situations. In order to do that, we find that all important contexts surrounding a situation, both environmental contexts and behavioral contexts, fit well into an attribute grammar model. They serve as the attributes for each production to specify situations. The attribute grammar provides a good modeling tool so that we can combine the syntax rules and static semantic rules for Situ$^f$ under one formalism. More interestingly, attribute grammars have several desirable qualities as a model for specifying the intrinsic relations between a situation and its contexts in Situ$^f$. A good example is that it supports modular specification of situations through contexts, as each attribute equation under attribute grammar is local to only one grammar production. Any attribute to each equation can be thought of as a placeholder to an attribute equation, just as parameters to a function in many mainstream languages such as C++, Java etc. In addition, although propagation of attribute values through the derivation tree is not specified explicitly by attribute grammar, it is implicitly defined by the equations of the grammar and the form of a tree. The functional situation specification language Situ$^f$ is based on attribute grammar formalism.

In general, for each situation scenario to be specified in Situ$^f$, the domain expert needs to define production-like grammar rules, with a corresponding set of attribute equations which take each context variable as an attribute. The ensemble of context variables reflects domain specific vocabulary particularly pertaining to the situation domain. While the main success scenario is specified as a functional based production rule in Situ$^f$, the distribution of context variables over that particular situation is captured by the machinery built in the associated set of semantic rules.

Based on the online paper review scenario, the following example is composed to draft a real Situ$^f$ program. In it, the perspective of a domain expert is taken and various language features are picked along the way. Towards the end, the reader is expected to have an overall feeling and some tangible hands-on experience. Having learned this example, readers will be ready to see a complete syntactic and semantic description of the Situ$^f$ language - a main task for the next chapter.
2.7.3 Paper review example

Returning to the paper review example, let us assume a domain expert at work who specializes in the web-based paper review process. She is also trained and understands the fundamentals of situation theory proposed in [1]. First of all, she sketches the main success scenario of a general online paper review scenario.

\[
goal \rightarrow map\left((download.review), [paper_1, paper_2, \ldots paper_n]\right)\]  
\[\text{(2.4)}\]

The parse tree depicted in Figure 2.9 reveals the intrinsic structure of (2.4).

![Figure 2.9 Parse tree for paper review situation](image)

Note that given Situ, a domain specific language, the vocabulary used in Situ script are all domain vocabulary. For example, (2.4) is specific to the online paper review domain where paper, download, review, etc., are frequently used. The main actions captured are modeled as names of functions, e.g. download, review etc. The ”:” notion used in the expression of download.review refers to a composed action incorporating download and review, in which
the output of *download* is pipelined to the input of *review*. Indeed, being a functional language, 
*Situt*’s situation specification particularly reflects this characteristic.

Each situation defined under *Situ* framework [1] contains a temporal tag defining the time instant for its being. The temporal order within a situation sequence is recorded through these temporal tags. Note that in (2.4), the download action happens temporally *before* review as each paper is concerned. Figure 2.10 offers a pictorial explanation. Indeed, the functional composition notion lends itself well to temporal sequencing representation. Specification (2.4) simply reads: for each paper first download it, and then review it.

![Diagram](image)

**Figure 2.10** Temporal ordering of situations

Since each situation lives within its correlated context, under *Situ* framework a situation is conceptually defined to include environmental as well as behavioral context. To capture the context surrounding a situation, a domain expert usually needs to focus first on the data source. This translates to a series of problems. Particularly in this paper review example:

- Most often than not, the domain expert would not be able to know the accurate number
of papers assigned to a reviewer. These details, which are tied to specific circumstances, are beyond the knowledge as well as the concern of a domain expert;

- The concrete software support for downloading and reviewing paper in MyReview system is not shown in (2.4). To connect situations with their working circumstances in real world, this information is indispensable.

To solve these problems, Situ\(f\) provides certain features which are illustrated through Program 2. Program 2 can be considered Situ\(f\)’s implementation of (2.4).

**Program 2** A Situ\(f\) program for paper review situation

```plaintext
include GUI_Service_MyReview
import Context_Spec_MyReview

program _paperReview
  data
    declare paper@129.186.93.0:/home/myreview/COMPSAC2011_Training/Review.php; \\
    declare Review@129.186.93.0:/home/myreview/COMPSAC2011_Training/Review.php;
  
  action
    declare download<None:paper>@129.186.93.0:/home/myreview/COMPSAC2011_Training/Review.php; \\
    declare review<paper:Review>@129.186.93.0:/home/myreview/COMPSAC2011_Training/Review.php;
  
  situation
    map download.review paper();
```

There are several critical points demonstrated through Program 2:

- First, the notion of \@ creates an IO channel in a Situ\(f\) program called paperReview to bind data and action to their real world counterparts: a paper can be downloaded from Review.php page whose server-side url is specified; Review can be submitted and later
on collected also through the same page. Each time a paper is downloaded or a review is submitted through Review.php page, the contextual information will be captured by @ and sent back to program paperReview.

- Notice that review and Review are different program entities in Program 2: the former is the action whereas the latter is the result coming out of that action thus declared as data in Program 2. This example shows the effect of variables naming in Situ$^f$.

- @ is an I/O based language feature. Once declared, data and action can be used to construct a situation. Another point worth attention in Program 2 is by the use of (), which follows declared data paper. () is another I/O based feature Situ$^f$ offers. It is a data constructor: paper() returns a list of papers resulted by a series of paper downloading actions performed on Review.php page of the deployed MyReview system. The end of such a situation, that is the moment paper() stops constructing papers is when the user leaves Review.php page or simply logs out. User’s leaving triggers an internal end-of-situation event EOS inside Situ$^f$-based environment.

- Closely related with SituIo and its @ operator is the $<\text{program\_url}>^8$ defined in Situ$^f$ attribute grammar, which will be introduced in the next chapter. This symbol specifies how Situ$^f$ runtime is able to find the external counterpart that supplies contextual information to declared data, actions and situations defined by a domain expert’s Situ$^f$ program. Figure 2.11 illustrates it using a concrete example.

By nature, ”@” is a monad type which should be familiar to readers who are experienced in Haskell, in particular Haskell’s I/O mechanism. A monad helps to bind side-effect with a purely functional return value to form a new return type. It really is a sequencing mechanism:

1. to perform an I/O operation;

---

$^8<\text{program\_url}>$ denotes a program url which takes the form of server_IP_address:serverside_absolute_directory. For programs on your local machine, simply use 255.255.255.255;
2. to return the retrieved value through I/O.

Having monad helps to keep a purely functional paradigm while still being able to combine impure side effects. Some computer scientists consider monad an imperative sublanguage inside a purely functional language [42]. Monad has its root in category theory and has already been well studied by logicians and theorists; therefore we do not step into the theoretical side of monad much. Rather, our focus is to precisely specify the semantics arising from monad-based SituIO mechanism so as to well establish the link between situation structures derived from a Situ program and the correlated contextual information gathered externally. Further, we focus on the flow between the user actions and the reaction from the graphical user interface of a software whose evolutionary nature falls into our research spectrum. Under this purpose, the peculiar meaning of Situ’s monadic feature @ is:

1. perform I/O to connect to an existing software’s Graphical User Interface actions.\textsuperscript{9} This

\textsuperscript{9}specified by \texttt{< prog-url >} as in the attribute grammar.
step generates the side effect, and then;

2. return the most recent context values supplied by related GUI gadgets. This step generates the main functional return value of a \textit{Situ} function.

The details of the attribute grammar for \textit{Situ} are given in full length in the next chapter. For now, as a gentle introduction to the formal treatment of \textit{Situ}'s attribute grammar, more importantly, to further explain the motives behind the proposal of Program 2, Figure 2.12 is given to show the attribute propagation around the \textit{paperReview} situation.\footnote{Program 2 defines context-oriented paperReview situation, following the original \textit{Situ} framework where all situations are based on behavioral and environmental contexts.}

Figure 2.12 Parse tree and attribute propagation graph for Program 2

The data and action declarations in Program 2 set up the data, as well as the action to
construct a situation. @ operator connects data structures like paper and Review to their real-world data source. For Program 2, the source of data for paper and review are the server-side Review.php page. This simply means that each time the user downloads a paper through Review.php page, the context surrounding that paper such as author list, email contact and abstract etc . . . will be collected over the Graphical User Interface and sent back to Program 2. More concretely, through paper(), context information of all assigned papers are captured incrementally one after another and are given as input to review action. When the user finishes reviewing that paper and generates a Review, the Review will be captured in terms of its context ensemble: an aggregation of review comments, review score, suggestions to the Program Committee, etc. The communication is carried out while all intermediate results are recorded through XML intermediate representation.

Situ4 provides four built-in functional patterns as situation constructors to propagate contexts, or in attribute grammar’s terms: attributes, to the entire parse tree. These four built-in patterns are map, filter, reduce and apply. The map pattern is used in Program 2 in statement map download.review paper() to describe a situation where a reviewer needs to download and then review every paper assigned to her/him. The map pattern, commonly found in functional programming paradigm, applies its first input, i.e. the temporally combined action of downloading and then reviewing (download.review) to its second input - a list of papers. Readers familiar with functional programming know well that theoretically map represents a higher-order function that applies the first argument it accepts, which is a function or a composed function, to its second argument, usually a sequence of data such as the paper list aforementioned. Situ4 introduces map pattern so that its first argument can be re-used for all members in its second argument. Overall, applying map pattern over a list is to transform the list to another by working on each and every member of the list according to its first argument; specifically in specification (2.4), a list of reviewed papers that are attached with review comments and scores etc . . . are the end result for the main success scenario for specification (2.4).

This section only illustrates map example. The precise computational meaning of map, reduce, filter and apply is given using small-step operational semantics in 3.6.2.
CHAPTER 3. FORMAL DEFINITION OF $\text{Situ}^f$

The motivation behind the design of $\text{Situ}^f$ domain specific language is to provide a set of features easy to use yet powerful enough to meet the following requirements:

- Situation centric: the basic language constructs revolve around situation definition given in [1]. In every aspect, $\text{Situ}^f$ is a continued research effort under the original $\text{Situ}$ framework towards a programming model;

- Simplicity: in essence, $\text{Situ}^f$ is a language to specify situations. A program, or script written in it emphasizes the ”what” rather than ”how” process, therefore it encourages smaller than average program size. As explained earlier, functional paradigm fits in nicely, hence the name $\text{Situ}^f$.\(^1\);

- Situation modularity and situation re-usability: more likely than not, a domain expert usually focuses on one situation at a time. Separate concerns, when combined with situations, translate to the need of a reusable and modular situation specification mechanism;

- Conducive to the generation of an environment. The main aim of this work is to construct a $\text{Situ}^f$-based environment that provides an initial realization of $\text{Situ}$ framework.

Under these goals, we give a formal definition for $\text{Situ}^f$. The syntactical part of the definition is provided through a context free grammar, and an attribute grammar based approach and operational semantics are employed to define the semantics.

3.1 Syntactical definition of $\text{Situ}^f$

The context free grammar, i.e., concrete syntax, of $\text{Situ}^f$ is shown in Table 3.1.

\(^1\)The superscript “f” refers to the term “functional”
Since attribute grammar is based on context-free grammar, which directly specifies concrete syntax, we will not discuss in depth the abstract syntax of Situ\textsuperscript{f} here. But to make the picture complete and to show the simplicity of the structure of the Situ\textsuperscript{f} program, we attach Situ\textsuperscript{f}'s abstract syntax in Table 3.2.

### 3.2 Semantic definition of Situ\textsuperscript{f} through attribute grammar

Table 3.3 through 3.5 give the definition of Situ\textsuperscript{f} in terms of attribute grammar.

(For formatting purposes we split Situ\textsuperscript{f}'s attribute grammar into Table 3.3 through Table 3.5.)

### 3.3 SituIO: the IO channel for Situ\textsuperscript{f} environment

To closely follow and provide built-in support for the original Situ framework [1], where each situation is identified to be associated with a set of behavioral as well as environmental contexts, Situ\textsuperscript{f} includes in its language proper a unique context-oriented I/O mechanism called SituIO. Through SituIO:

- Low level information processing idiosyncrasies are encapsulated, allowing domain experts to focus more on the level of situation specification;
- The reasoning model of a purely functional language is maintained;
- The contexts surrounding each situation is collected in real time and directly provides low level support for Situ\textsuperscript{f}'s attribute grammar-based semantics;
- The human-centric nature of a situation is enhanced in Situ\textsuperscript{f}-based environment.

Before further elaborating the definition of SituIO mechanism, let us first conduct a brief historical review over sensitive IO issues affecting functional programming model [43].

A functional program contains a number of definitions, including values, functions, etc., as shown the top of page 52.

\[
v :: \text{Number}
\]
\[ v = 40 \]

\[
\text{function} :: \text{Number} \rightarrow \text{Number} \\
\text{function } n = v + n
\]

The net effect of these definitions is associating a fixed value with each name:

- for \( v \): a Number(Integer) 40;
- for function: a mapping from Number to Number.

Next let us take into account defining a function to get an integer value from an IO. Some approaches, for instance [44, 45] is to include the following operation:

\[
\text{inputNum} :: \text{Number} \tag{3.1}
\]

The intent is to read an Number from the input stream where the value read becomes the value given to \( \text{inputNum} \). Each time \( \text{inputNum} \) is evaluated it will be given, possibly, a new value, therefore not a fixed value under the very same function name: \( \text{inputNum} \). To see why this causes a problem, let us examine the following example:

\[
\text{input}_d = \text{inputNum} - \text{inputNum} \tag{3.2}
\]

Suppose the first input read through the input action is 4, and the next is 2. The result of \( \text{input}_d \) is 2 or -2, depending on the order in which the arguments to the operation \( '-' \) are evaluated. This uncertainty breaks the reasoning model over functional models: for any function that takes the same input (including no input) the output should be the same\(^2\), therefore \( \text{input}_d \) should always be equal to zero, which is \textbf{not} the case should \( \text{inputNum} \) be defined as in (3.1).

The reason for this is precisely that the meaning of an expression is \textit{also} determined by \textit{where} it occurs in a program. This breaks the functional model. More serious is the fact that

\(^2\)Mathematical definition of a function as you can find in any elementary math texts.
since any function in a functional language can use `inputNum` just as any other pure function, its unpure definition can be “epidemic” to the reasoning chaining to a greater range. Because of this, I/O has turned out to be a troublemaker for functional programmers for an extended period of time. A good historical overview can be found in [43].

In thinking about input/output, it makes more sense to think of actions happening in sequence, e.g., some input might be read first, and then on the basis of that further input might be read, or output might be produced. The current Haskell language standard follows this scheme, and provides the type `IO a`, that is, do some I/O and then return a value of type `a`. I/O is Haskell’s primitive built-in mechanism as well as the mechanism to sequence these I/O’s.

What Haskell and other functional languages have not offered, but is indeed needed by Situ’s language however, is to connect the stream of external contexts with each internally specified situation. The context stream is generated by user’s raw actions, such as mouse click, filling out a textbox, etc. Those actions lead to raw context data, which after having been collected and fetched into SituIO, are organically organized as meaningful components surrounding a defined situation. Situ’s treatment of contexts and situations follows immediately the original conceptual definition of situation found in [1], i.e.

\[ \text{situation} \sim (d, A, E)_t \]

where \( A \) and \( E \) stands for behavioral contexts and environmental contexts respectively, whereas \( d \) reflects human desire, all captured at time instant \( t \).

As compared with mainstream IO type usually found in a functional language such as Haskell, SituIO distinguishes itself by its intrinsic, domain specific support for human centric situations, which provides indispensable support for the task of user-centric reasoning of situations.

### 3.4 The Monadic ”@” to set up SituIO channel

Situ provides two languages features, ”@” and ”()”, to support SituIO.
"@" is designed to bind context stream with a program url. A program url, whose grammar symbol is <prog_url> shown in Table 3.1, follows "@" in a legitimate Situ\textsuperscript{f} program. It can be thought of as a context generator to initiate the flow of context values captured at the interface level into the data or action variable declared on the left hand side of "@". The interface between human user and software typically consists of a GUI or of sensory type. The program url can reference both locally and remotely deployed software components. Program 2 contains the following program url:

\begin{equation}
129.186.93.0 : /home/myreview/COMPSAC2011_Training/Review.php \tag{3.3}
\end{equation}

(3.3) points out that context values surrounding the paper review situation as specified in Program 2 are generated from the PHP program called Review.php, which is deployed under the directory of: /home/myreview/COMPSAC2011_Training, on server whose IP address is 129.186.93.0.

Note that in Program 2, data type variables like paper, Review and action type variables such as download and review, are all bound to the user interface (3.3) by "@", meaning that (3.3) is the user interface where a user’s behavioral as well as the environmental contexts are captured. This binding enabled by "@" set up the context I/O channel so that the context values collected through interface (3.3) are available for SituIO mechanism and to be assigned as context values for paper(data), Review(data), download(action) and review(action). The context values for each declared data and action are governed by the attribute grammar given in Table 3.3 through Table 3.5. Situ\textsuperscript{f}’s context I/O pipeline is impossible without "@".

"@" is used to set up the context I/O pipeline, and therefore it is always used in the declaration section of a Situ\textsuperscript{f} program for data and action variables. The underlying workings of Situ\textsuperscript{f} runtime, especially the conversion from externally captured raw data to internally meaningful context, is intimately controlled under the "\(\)" operator.
3.5 The Monadic "()" to convert user data to situation contexts

Following lazy evaluation strategy, "()" is designed by the call-by-name principle, as opposed to the call-by-value principle. It incrementally supplies contextual data captured externally one unit at a time to the specified situation under a Situ$^f$ program. From a domain expert point of view, "()" reifies the iterator pattern.

In the specification of paper review situation of Program 2:

\[
\text{map download.review paper() (3.4)}
\]

"()" is used to supply one paper at a time to the action of download and review, under the control of the built-in situation constructor - map. Each paper is declared in the data section and is bound to an external program url resource. Note that (3.4) does not give any information as to the number of papers to download and review. This is because that under Situation (3.4):

- the actual number of papers in general becomes known at run-time only;
- the actual number of papers is beyond the scope of core purposes or interests of a domain expert;
- "()" is in fact an iterator over contextual data, e.g. paper, for example (3.4).

The adoption of iterator pattern in the design of "()" targets to make situation specification more re-usable, flexible and friendly to domain experts.

3.6 A precise description of SituIO under Situ$^f$ language

In this effort, structural operational semantics is used to precisely describe the machinery of the internal workings of SituIO at runtime, with special focus on the monadic "()" feature already introduced to Situ$^f$. "()" well insulates the runtime complexity of incrementally fetching contextual data from external context sources one at a time. Looking at Program 2, the point should be clear that by encapsulating those low-level details as to how many papers are expected to be reviewed, or for each paper how to get the related contexts from a user’s action, etc. . . ,
the domain expert can focus entirely on the most important part of specifying a paper review situation without missing a beat.

3.6.1 Overview of semantics of programming languages: denotational, axiomatic and operational semantics

The semantic considerations are of the utmost importance both in the design of the whole or part of a programming language and during the reasoning about properties of a particular program written in that language. Historically, three types of semantics stand out during theoretical and practical development of modern programming languages.

*Denotational semantics* was the first mathematical account of program behavior; it arose in the late 1960s [46, 47, 48] and was pioneered by Dana Scott and Christopher Strachey. In denotational semantics, the behavior of a program is described by defining a *function* that assigns meaning to every construct in the languages. The meaning of a language construct is called its *denotation*. Typically, for an imperative program, the denotation will be a state transformation, which again is a function that describes how the final values of the variables in a program are found from their initial values.

*Structural operational semantics* came into existence around 1980 due to Gordon Plotkin [49]. By borrowing some of the techniques developed for denotational semantics, structural operational semantics proposed a more satisfactory and simpler operational theory where greater emphasis is placed on defining the effect of running a program in terms of its structure. More specifically, behavior of a program is specified by defining a transition system whose transition relation describes the evaluation steps of a program. Structural operational semantics made it possible to give a simple account of concurrent programs, which is in general very complicated, using denotational semantics. Structural semantics is syntax-directed; it uses *abstract syntax* to set the stage to define allowable states, which eventually leads to the desired transition system. Two or more different operational semantics can be defined for a single language, for example the *big-step* operational semantics, a.k.a. evaluation semantics, gives a high-level, rather abstract description (from programmer’s point of view) of a language, while the *small-step* operational semantics, a.k.a. computation semantics, tends to provide an account of a language
from a point of view that is closer to an interpreter or compiler.

Axiomatic semantics \cite{50, 51} takes a more direct approach than the other two kinds of semantics: rather than deriving rules by first defining the behavior of programs and then generating rules from this definition, axiomatic semantics takes rules in the form of mathematical logics \textit{themselves} as the definition of the language. This includes assertions that must hold before and after the language construct has been executed. The meaning of a program, then, becomes just what can be proved about it based on the rules.

During the '60s and '70s, operational semantics was generally regarded as inferior to the other two styles \cite{52}. They were considered useful for quick and dirty definitions of language features, but inelegant and mathematically weak. Examples include some of the earliest attempts at IBM's research laboratory in Vienna in the late sixties \cite{49}. But in the 80's, the more abstract methods, i.e. denotational semantics, began to encounter increasingly difficult situations such as nondeterminism and concurrency. For axiomatic semantics it was procedures. The simplicity and flexibility of operational methods came to be more and more attractive to the research community. Among these Plotin's \textit{Structural Operational Semantics} \cite{49} is of special interest, for which: Kahn \cite{53} proposed an extension called natural semantics to accommodate higher-order functions beyond first-order ones; Robin Milner used Plotkin's approach to give a labelled semantics to his Calculus of Communication Systems (CCS) \cite{54, 55, 56}. These approaches introduced more mathematically elegant formalisms and showed potential, for powerful mathematical techniques developed in the context of denotational semantics to be transferred to a structural operational setting.

Until this day, operational semantics has remained an active research area in its own right and is often the method of choice for defining programming languages and studying their properties.

Small-step operational semantics, also known as computational semantics, is chosen for this work to precisely define the operational properties of SituIO. We propose a succinct approach when applying operational semantics.
3.6.2 Abstraction of SituIO

To articulate the operational semantics for SituIO, we first propose the following abstractions:

- The grammar symbol "\(<\text{data}\>()" found in Table 3.1 is abstracted as a context stream expression noted by se;
- The grammar symbol "\(<\text{data}\>" found in Table 3.1 is abstracted as a non-stream expression noted by e;
- We distinguish the evaluation for se from that for e by providing the following two forms of evaluation relations:

\[
\Rightarrow_N \quad \text{vs.} \quad \Rightarrow_S
\]

The reason for this refinement is that "()" is a non-compile time I/O operation, there is no way for Situ compiler to know in advance exactly how many data units in total will be streamed. The detailed internal workings of context stream within Situ, which are hidden from the Situ programmer, e.g., a domain expert, will be elaborated through operational semantics given in 3.6.3.

\(\Rightarrow_N\) is the evaluation relation for non-stream expressions. The type of \(\Rightarrow_N\) is:

\[
\Rightarrow_N : D \rightarrow ENV \rightarrow E \rightarrow E
\]

Any non-stream expressions will be evaluated by \(\Rightarrow_N\), which reduce one such expression to another under declaration D, to interpret function and data name, and environment ENV, to internally check the name bindings in Situ.

\(\Rightarrow_S\) is the evaluation relation for context stream expressions. The type of \(\Rightarrow_S\) is:

\[
\Rightarrow_S : D \rightarrow ENV \rightarrow SE \rightarrow <E,SE>
\]
This in turn leads to a derived relation \( \Rightarrow_S^v \), where \( v \) is a value generated from a Non-Stream expression \( e \). The type for \( \Rightarrow_S^v \) is therefore:

\[
\Rightarrow_S^v : D \rightarrow ENV \rightarrow SE \rightarrow SE
\]

Any context stream expressions should be evaluated by \( \Rightarrow_S \).

Note that \( \Rightarrow_S^v \) is a more graphic and intuitive rendering but in essence the same notion as \( \Rightarrow_S \). This point will be especially clear after introducing the semantic rules in 3.6.3.

The symbols used above to explain the type of \( \Rightarrow_N \), \( \Rightarrow_S \) and \( \Rightarrow_S^v \) are specified below:

\( D : \) set of declarations for variables and functions;

\( ENV : \) Environment. It can be thought of as a function that binds a variable to storage location \([46, 47, 57]\). An environment roughly corresponds to a symbol table maintained by the compiler.

\( E : \) set of NonStream expressions;

\( SE : \) set of context stream expressions;

\( v : \) A value returned by \( Situ^f \) of type \( E \).

Note:

1. A concrete instance of value \( v \) is shown in Table 4.2, of section 4.1.1.1;
2. Details about the Environment model for \( Situ^f \)-based environment, i.e., \( ENV \), is provided in 2.3

- The grammar symbol "\(<\text{action}>\)" found in Table 3.1 is abstracted as an action function \( F \):
– F takes as input NonStream context variables $x_1, \ldots, x_k$ and returns a NonStream expression $e$. Formally:

$$F(x_1, \ldots, x_k) \leftarrow e$$

Function definition is represented by the notion of $\leftarrow$. The process in which a user carries out her action under a situation is abstracted by function definition, represented by the notion of $\leftarrow$, and $e$ is the body of the definition. In an overly simplified but essential example of a function definition:

$$F(x) = x^2 + 1$$

$F$ is the functional name variable. $x^2 + 1$ gives the definition of $F$, corresponding to the notion of $\leftarrow$, and $e$ is the body of the definition. Using the notion of $\leftarrow$, this function definition can be represented as:

$$F(x) \leftarrow x^2 + 1$$

3.6.3 The computational semantics of SituIO

Based on the abstractions of SituIO from section 3.6.2, we argue that the context streaming through SituIO can be imagined as a stream language. In pursuant of the semantics of SituIO, we formalize that intuition by using those aforementioned abstractions to propose such a stream language. It is an abstract language since we only care about its meaning and therefore give it an abstract syntax for semantic purposes. We do not intend to move towards any implementation level objectives. By giving computational semantics\(^3\) to such an abstract stream language, the precise meaning of SituIO is captured. The abstract syntax is first provided for this abstract stream language under $Situ^l$.

1. Syntactic categories

\(^3\)also known as small-step operational semantics; for more information, please refer to 3.6.1.
\[ p \in \text{Program} \]

\[ D \in \text{Declaration} \]

\[ se \in \text{Stream Expression for External Context} \]

\[ sx \in \text{Stream Variable} \]

\[ e \in \text{NonStream Expression} \]

\[ x \in \text{Unbound Context Variable} \]

\[ F \in \text{Function Variable} \]

2. Formulation rules

\[ p ::= < \text{se,D} > \]

\[ D ::= F( x_1, \ldots, x_k ) \leftarrow e \]

\[ \text{where } x_1, \ldots, x_k, \text{ are free context variables} \]

\[ se ::= e : se \mid EOS \mid \text{apply } F \text{ se} \mid \text{map } F \text{ se} \mid \]

\[ \quad \text{reduce } F \text{ se} \mid \text{filter } F \text{ se} \]

\[ e ::= F( e_1, \ldots, e_k ) \mid x \mid v \mid \text{True} \mid \text{False} \mid e : e \]
The semantic rules are given in Table 3.6.

Interpretation of the semantic rules:

- Rule Eval: This is the evaluation rule for the base-case stream expression in which a NonStream expression is immediately followed by EOS. This rule links stream and Non-Stream expressions of SituIO. According to the Formulation Rule, "e : EOS" by itself is a stream expression, therefore the evaluation resorts to the \( \Rightarrow \) relation.

Intuitively, when a NonStream expression is followed by EOS, that is equivalent to evaluating e solely, since EOS is just a stream terminating signal. On the other hand, EOS comes only when context streaming is on. Therefore, to evaluate "e : EOS", stream evaluation relation \( \Rightarrow \) is applied.

- Rule Map1: EOS signals the End Of Stream condition for external context values in Situ. EOS echoes the well-known EOF, which signals no more data can be read from an external recourse in a computer operating system such as Unix or Linux as well as a popular language like C. EOS, as shown in the Formulation Rules, is a Stream Expression for External Context in SituIO. This rule means that under Declaration D and Environment \( \rho \), the situation constructor map will computationally evaluate to EOS when signalled an EOS.

- Rule Map2:
  - \( e[v/x] \) denotes the result of substituting the context variable x in a NonStream expression e with context value v returned by SituIO. The precondition is that x is a free variable as pointed out, since the value associated with variables which appear bound plays no role in the evaluation of the expression e. Let us consider the following example. Without loss of generality, pseudo code is used.
The two expressions (let \(a = 6\) in \(a * a + c\)) and (let \(b = 6\) in \(b * b + c\)) have exactly the same value! The exact value depends on the value of \(c\), the unbound and free variable. \(a\) and \(b\) are bound variables and they can be changed to any variables other than \(c\) without affecting the meaning of the expression. However, if we change \(a\) or \(b\) to \(c\), we get a different value: let \(c = 6\) in \(c ^* c + c\) will evaluate to 42. This is because \(c\) is a free variable of the original expressions of (let \(a = 6\) in \(a * a + c\)) and (let \(b = 6\) in \(b * b + c\)), and substituting \(c\) for \(a\) or \(b\) turns a free variable into a bound variable.

In general, changing a free variable into a bound variable will change the value of an expression.

By using \(e[v/x]\), we assume that \(x\) is a free variable. Should name clash occur, changing the free variable name(s) will avoid the hazard.

For additional mathematical machinery about free versus bound variables with regard to other constructs in programming languages, readers are referred to many excellent resources such as [58, 59, 60].

\(-\ F(x) \iff e\) means that the return value of function \(F\) is given by the evaluation of the NonStream expression \(e\), hence \(\iff\) is noted as function definition relation in 3.6.2.

\(-\ since \(se\) is a context stream expression, such as the expression of "paper()" shown in Program 2, it must be evaluated by SituIO’s stream expression evaluation relation \(\Rightarrow S\). Using the declaration \(D\) and under programming environment \(\rho\), the runtime stream expression \(se\) is evaluated through SituIO as the value \(v\) and produces the SituIO residual \(se'\), denoted by: \(D, \rho \vdash se \Rightarrow v S se'\). In other words, the first value in the stream associated with \(se\) is \(v\). To find out about subsequent values we must apply the definition of \(\Rightarrow S\) to \(se'\), i.e.

\[ D \vdash se' \Rightarrow v_1 S se_1 \]

Consequently, after \(n\) steps the result becomes:

\[ v : v_1 : v_2 : \ldots : v_n : se_n \]
\( v : v_1 : v_2 : \ldots : v_n \) is the partial result generated incrementally by map. According to Formulation Rules, \( v : v_1 : v_2 : \ldots : v_n \) is a NonStream expression. While \( se_n \) is not EOS, \( v : v_1 : v_2 : \ldots : v_n : se_n \) is, by Formulation Rules, a stream expression; Once \( se_n \) hits EOS, \( v : v_1 : v_2 : \ldots : v_n : se_n \) remains a Stream expression since

\[
se ::= se : EOS
\]

In other words, the stream terminates and the incremental evaluation of map with regard to the context stream expression is then finished.

- **Note** that \( D, \rho \vdash se \xrightarrow{\pi} se' \) mathematically expresses that SituIO is a **monad**: it returns \( v \) as the return value while causing the side effect \( se' \).

- Computational semantics specifies the evaluation of \( map \ F \ se \) one step at a time, hence computational semantics is also named small-step operational semantics.

- **Rule Filter\(_1\):**

  - Since the substituting context variable \( x \) in NonStream expression \( e \) with context value \( v \) does not involve stream expression, using declaration \( D \) and environment \( \rho \) \( e[v/x] \) is evaluated under the evaluation relation of \( \xrightarrow{\pi} \). It does not directly involve SituIO.

  - When \( e[v/x] \) is NonStream-evaluated to True, i.e.,

    \[
    D, \rho \vdash e[v/x] \xrightarrow{\pi} True
    \]

    the value \( v \) is kept and appended to the partial result so that all value \( v \) that makes \( F(x) \) evaluate to true can be "filtered" and kept. This is exactly what the filter does.

- **Rule Filter\(_2\):** when \( e[v/x] \) is NonStream-evaluated to False, i.e.,

  \[
  D, \rho \vdash e[v/x] \xrightarrow{\pi} False
  \]

  the value \( v \) is **not** kept in the partial result so that in the end all value \( v \) that makes \( F(x) \) evaluate to false will be "filtered out." This complements Rule Filter\(_1\).
• Rule Reduce₁: to fully understand the reduce situation constructor and the reduce rule, let us first examine the example shown in Figure 3.1.

In Figure 3.1, '+' represents an infix addition function and serves as a concrete instance of function symbol “F” in Rule Reduce₁. '+' takes a left and right operand, therefore the name "infix," before returning the summation value. A sequence of numbers, after being "reduced," in this case "added" as shown in Figure 3.1, the computation boils down to one number. This example, although quite simple, illustrates the power of the reduce stream expression, one of the four situation constructors in SituI. Moreover, more complex examples can be quite easily captured by the reduce expression, for instance, to generate a conference proceedings from all accepted papers.

More formally,

'+' is defined as x + y. To follow the Formulation Rule:

\[
'+' \iff x + y
\]

x and y are free variables and the above form can be strictly translated to F(x,y) \iff e, where e refers to x + y for infix function '+' . Notice that '+' takes two parameters as any F in the reduce rule, this is regulated by "F(x₁,x₂)" in the premise of Reduce₁ Rule. If '+', however, is given only one argument, say 3, then that causes a partial application and therefore '+' turns into a curried function [59]. By e[v/x], which is a curried function for F, the follow-on "reduce F se' " expression in the conclusion part of Reduce₁ Rule becomes the sole argument of e[v/x].

• Rule Reduce₂: one way of looking at this rule is that it provides a base case scenario for the recursive Reduce₁ Rule. Its intuitive meaning should be straightforward.

• Rule Apply₁: this rule handles singleton stream where there is only one value being streamed through SituIO.

• Rule Apply₂: this rule points out that if the stream is an empty stream, just having EOS, then nothing happens, i.e. the result is simply EOS when the evaluation finishes.
**Definition:** If a stream expression \( se \) ending in EOS can be successfully evaluated, then \( se \) is said to be legally terminated.

**Theorem 3.6.1.** All SituIO stream expressions are legally terminated by EOS.

**Proof.** The theorem is trivally true for EOS. Note that no semantic rule can apply to EOS implies that it immediately terminates.

If the stream expression takes the form of \( e:EOS \), since it is a legal stream expression by Formulation Rules, the theorem holds.

If the stream expression takes the form of \( map \ F \ se \), that is, it is a map stream expression:

Let \( se = e : se' \). By mathematical induction, we assume \( se' \) can be legally terminated by EOS. There are two cases:

1. \( se' \) is EOS: by applying the Rule Map\(_2\) and then Rule Map\(_1\), \( map \ F \ se \) is successfully evaluated following the semantic rules of SituIO, hence legally terminated by EOS;

2. \( se' \) is not EOS: we apply Rule Map\(_2\) on \( map \ F \ se' \) first. By induction hypothesis, \( D, \rho \vdash map \ F \ se' \) will be, by \( \Rightarrow_S \), evaluated successfully since otherwise \( se' \) will not be legally terminated by EOS.

Therefore, the theorem holds for map stream expression.

If the stream expression is a filter stream expression, i.e., \( filter \ F \ se \):

Let \( se = e : se' \). By mathematical induction, we assume \( se' \) can be legally terminated by EOS. There are two cases:

1. \( se' \) is EOS: by applying the Rule Filter\(_3\) and then Rule Filter\(_1\) or Rule Filter\(_2\) depending the truth value of \( F(e) \), \( filter \ F \ se \) is successfully evaluated by the semantic rules of SituIO, hence legally terminated by EOS;
2. se’ is not EOS: we apply Rule Filter$_2$ or Rule Filter$_1$ on filter F se’ first. By induction hypothesis, $D, \rho \vdash \text{filter } F \text{ se’}$ will be, by $\Longrightarrow_S$, evaluated successfully since otherwise se’ will not be legally terminated by EOS.

Therefore, the theorem holds for filter stream expression.

If the stream expression is a reduce stream expression, i.e., $\text{reduce } F \text{ se}$:

Let $se = e : se’$. By mathematical induction, we assume se’ can be legally terminated by EOS. There are two cases:

1. se’ is EOS: by applying the Rule Reduce$_1$ and then Rule Reduce$_2$, $\text{reduce } F \text{ se}$ is successfully evaluated following the semantic rules of SituIO, hence legally terminated by EOS;

2. se’ is not EOS: we apply Rule Reduce$_1$ on map F se’ first. By induction hypothesis, $D, \rho \vdash \text{reduce } F \text{ se’}$ will be, by $\Longrightarrow_S$, evaluated successfully since otherwise se’ will not be legally terminated by EOS.

Therefore, the theorem holds for reduce stream expression.

Following exactly the same vein, we can show that the theorem holds for apply stream expression also.

Theorem 3.1 guarantees that a runtime environment can safely utilize EOS to delineate SituIO operations. Situ$^f$-based environment, the subject of next chapter, is precisely one of such kind.
<table>
<thead>
<tr>
<th></th>
<th>Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;program&gt; → [include &lt;service_name&gt;][import &lt;situation_spec&gt;]</td>
</tr>
<tr>
<td></td>
<td>program &lt;identifier&gt; data &lt;dataDeclList&gt;</td>
</tr>
<tr>
<td></td>
<td>action &lt;actionDeclList&gt; situation &lt;SituStmtList&gt;</td>
</tr>
<tr>
<td>2</td>
<td>&lt;identifier&gt; → [a ...</td>
</tr>
<tr>
<td>3</td>
<td>&lt;dataName&gt; → None</td>
</tr>
<tr>
<td>4</td>
<td>&lt;dataName&gt; → &lt;identifier&gt;</td>
</tr>
<tr>
<td>5</td>
<td>&lt;dataDeclList&gt; → declare &lt;dataName&gt;@&lt;prog_url&gt;</td>
</tr>
<tr>
<td>6</td>
<td>&lt;dataDeclList^1&gt; → declare&lt;dataName&gt;@&lt;prog_url&gt;; &lt;dataDeclList^2&gt;</td>
</tr>
<tr>
<td>7</td>
<td>&lt;action&gt; → None</td>
</tr>
<tr>
<td>8</td>
<td>&lt;action&gt; → &lt;identifier&gt;</td>
</tr>
<tr>
<td>9</td>
<td>&lt;actionList&gt; → &lt;action&gt;</td>
</tr>
<tr>
<td>10</td>
<td>&lt;actionList&gt;^1 → &lt;action&gt;,&lt; actionList &gt;^2</td>
</tr>
<tr>
<td>11</td>
<td>&lt;input&gt; → None</td>
</tr>
<tr>
<td>12</td>
<td>&lt;input&gt; → &lt;identifier&gt;</td>
</tr>
<tr>
<td>13</td>
<td>&lt;input&gt;^1 → &lt;identifier&gt;,&lt; input &gt;^2</td>
</tr>
<tr>
<td>14</td>
<td>&lt;output&gt; → None</td>
</tr>
<tr>
<td>15</td>
<td>&lt;output&gt; → &lt;identifier&gt;</td>
</tr>
<tr>
<td>16</td>
<td>&lt;output&gt;^1 → &lt;identifier&gt;,&lt; output &gt;^2</td>
</tr>
<tr>
<td>17</td>
<td>&lt;actionDeclList&gt; → declare&lt;actionList&gt;(&lt; input &gt;: &lt; output &gt;) @&lt;prog_url&gt;</td>
</tr>
<tr>
<td>18</td>
<td>&lt;actionDeclList&gt; → declare&lt;actionList&gt;(&lt; input &gt;: &lt; output &gt;) @&lt;prog_url&gt;</td>
</tr>
<tr>
<td></td>
<td>;&lt;actionDeclList&gt;</td>
</tr>
<tr>
<td>19</td>
<td>&lt;situStmtList&gt; → &lt;situStmt&gt;</td>
</tr>
<tr>
<td>20</td>
<td>&lt;situStmtList^1&gt; → &lt;situStmt&gt;;&lt;situStmtList^2&gt;</td>
</tr>
<tr>
<td>21</td>
<td>&lt;situStmt&gt; → map &lt;actionList&gt; &lt;dataName&gt;()</td>
</tr>
<tr>
<td>22</td>
<td>&lt;situStmt&gt; → filter &lt;actionList&gt; &lt;dataName&gt;()</td>
</tr>
<tr>
<td>23</td>
<td>&lt;situStmt&gt; → reduce &lt;actionList&gt; &lt;dataName&gt;()</td>
</tr>
<tr>
<td>24</td>
<td>&lt;situStmt&gt; → apply &lt;actionList&gt; &lt;dataName&gt;()</td>
</tr>
</tbody>
</table>

Table 3.1 A context-free grammar representing concrete syntax for Situ^d
Syntactic categories:

\[ P \text{ in Program} \]
\[ \text{IncludeStmt in Include Statement} \]
\[ \text{ImptStmt in Import Statement} \]
\[ \text{DataDecl in Data Declaration} \]
\[ \text{DataDeclList in Data Declaration List} \]
\[ \text{ActDecl in Action Declaration} \]
\[ \text{ActDeclList in Action Declaration List} \]
\[ \text{SituStmtList in Situation Statement List} \]

Formulation rules:

\[ P ::= [\text{IncludeStmt}] [\text{ImptStmt}] \text{DataDeclList} \text{ActDeclList} \text{SituStmtList} \]
\[ \text{DataDeclList ::= DataDecl | DataDeclList;DataDeclList} \]
\[ \text{ActDeclList ::= ActDecl | ActDeclList;ActDeclList} \]
\[ \text{SituStmtList ::= mapStmt | filterStmt | reduceStmt | applyStmt | SituStmtList;SituStmtList} \]

Table 3.2 Abstract syntax for \textit{Situ}^f

\begin{align*}
\text{reduce } \text{‘}+\text{’ } & 3 : 98 : 1 : 2 : \text{EOS} \\
\text{reduce } \text{‘}+\text{’ } & (3 + (98 : 1 : 2 : \text{EOS})) \\
\text{reduce } \text{‘}+\text{’ } & (3 + (98 + (1 : 2 : \text{EOS}))) \\
\text{reduce } \text{‘}+\text{’ } & (3 + (98 + (1 + (2 : \text{EOS})))) \\
\text{reduce } \text{‘}+\text{’ } & (3 + (98 + (1 + 2))) \\
& 103 \\
\text{‘}+\text{’ } & \text{is an infix addition function} \end{align*}

Figure 3.1 An example of reduce expression
(1) `<program>` → `[include <service_name>] [import <situation_spec>]`  
`program` `<identifier>` `<dataDeclList>`  
`action` `<actionDeclList>` `<situation` `<SituStmtList>`  
`{ <SituStmtList> env = <dataDeclList> env`  
`∪ <actionDeclList> env`  
`∪ <situation_spec> env }`  

(2) `<identifier>` → `[ a ... | z | A ... | Z | _ ]^+ [ 0 | ... | 9 | a ... | z | A ... | Z | _ | \ ]^*`  

(3) `<dataName>` → `None`  
`{ <dataName> env = φ }`  

(4) `<dataName>` → `<identifier>`  
`{ <dataName> env = { <identifier> .id } }`  

(5) `<dataDeclList>` → `declare <dataName>@<prog_url>`  
`{ <dataDeclList> env = <dataName> .env`  
`∪ { <prog_url> .id } }`  

(6) `<dataDeclList^1>` → `declare <dataName>@<prog_url>; <dataDeclList^2>`  
`{ <dataDeclList^1> env = <dataName> .env`  
`∪ { <prog_url> .id }`  
`∪ <dataDeclList^2> env }`  

(7) `<action>` → `None`  
`{ <action> env = φ }`  

Table 3.3 Attribute grammar for Situ^f (part 1 of 3)
Table 3.4  Attribute grammar for Situ (part 2 of 3)
(18) \[\text{<actionDeclList> } \rightarrow \text{declare}<\text{actionList}>(<\text{input}> : <\text{output}>) \text{ @}<\text{prog_url}> ;<\text{actionDeclList}>\] 
\{
\text{<actionDeclList>}_{env} = <\text{actionList}> .env \\
\cup <\text{input}>_{env} \cup <\text{output}>_{env} \\
\cup <\text{prog_url}> .id \cup <\text{actionDeclList}>_{env} \}

(19) \[<\text{situStmtList}> \rightarrow <\text{situStmt}> \] 
\{
\text{<situStmt>}_{env} = <\text{situStmtList}>_{env} \}

(20) \[<\text{situStmtList^1}> \rightarrow <\text{situStmt}> ; <\text{situStmtList^2}> \] 
\{
\text{<situStmt>}_{env} = <\text{situStmtList^1}>_{env} \\
\text{<situStmtList^2>}_{env} = <\text{situStmtList^1}>_{env} \}

(21) \[<\text{situStmt}> \rightarrow \text{map} <\text{actionList} > <\text{dataName} >() \] 
\{
\text{map}_{env} = <\text{situStmt}>_{env} \cup <\text{actionList}>_{env} \\
\cup <\text{dataName}>()_{env} \}

(22) \[<\text{situStmt}> \rightarrow \text{filter} <\text{actionList} > <\text{dataName} >() \] 
\{
\text{filter}_{env} = <\text{situStmt}>_{env} \cup <\text{actionList}>_{env} \\
\cup <\text{dataName}>()_{env} \}

(23) \[<\text{situStmt}> \rightarrow \text{reduce} <\text{actionList} > <\text{dataName} >() \] 
\{
\text{reduce}_{env} = <\text{situStmt}>_{env} \cup <\text{actionList}>_{env} \\
\cup <\text{dataName}>()_{env} \}

(24) \[<\text{situStmt}> \rightarrow \text{apply} <\text{actionList} > <\text{dataName}> \] 
\{
\text{apply}_{env} = <\text{situStmt}>_{env} \cup <\text{actionList}>_{env} \\
\cup <\text{dataName}>_{env} \}

Table 3.5  Attribute grammar for Situ\(^f\) (part 3 of 3)
<table>
<thead>
<tr>
<th>Rule</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule Eval</td>
<td>( D, \rho \vdash e : EOS \implies_S e )</td>
</tr>
<tr>
<td>Rule Map₁</td>
<td>( D, \rho \vdash \text{map } F \ EOS \implies_S EOS )</td>
</tr>
<tr>
<td>Rule Map₂</td>
<td>( D, \rho \vdash se \implies_S se' ) ( D, \rho \vdash F(x) \iff e ) ( D, \rho \vdash e[v/x] \implies_N \text{True} ) ( D, \rho \vdash \text{map } F \ se \implies_S e[v/x] : \text{map } F \ se' )</td>
</tr>
<tr>
<td>Rule Filter₁</td>
<td>( D, \rho \vdash filter F \ se \implies_S v : \text{filter } F \ se' )</td>
</tr>
<tr>
<td>Rule Filter₂</td>
<td>( D, \rho \vdash filter F \ se \implies_S v : \text{filter } F \ se' )</td>
</tr>
<tr>
<td>Rule Filter₃</td>
<td>( D, \rho \vdash filter F \ EOS \implies_S EOS )</td>
</tr>
<tr>
<td>Rule Reduce₁</td>
<td>( D, \rho \vdash reduce F \ se \implies_S e[v/x_1](\text{reduce } F \ se') )</td>
</tr>
<tr>
<td>Rule Reduce₂</td>
<td>( D, \rho \vdash reduce F \ EOS \implies_S EOS )</td>
</tr>
<tr>
<td>Rule Apply₁</td>
<td>( D, \rho \vdash \text{apply } F \ se \implies_S e[v/x] )</td>
</tr>
<tr>
<td>Rule Apply₂</td>
<td>( D, \rho \vdash \text{apply } F \ EOS \implies_S EOS )</td>
</tr>
</tbody>
</table>

Table 3.6 Operational semantics of SituIO
CHAPTER 4. *Situ*\textsuperscript{f}-based ENVIRONMENT

Compiling a *Situ*\textsuperscript{f} program involves the following major steps:

- Parse the *Situ*\textsuperscript{f} script;
- Link situation data structures;
- Link situation services;
- Set up SituIO channel.

The compiling process is refined and visualized by Figure 4.1.

![Diagram](image_url)  
Figure 4.1  The compiling of a *Situ*\textsuperscript{f} script
After a Situ\textsuperscript{f} program is compiled, the corresponding runtime will start up; in the meantime, it brings up an environment shown in Figure 1.1.

A Situ\textsuperscript{f}-based environment (Figure 1.1) brings together all the important issues discussed so far. The centerpiece tying up this environment is Situ\textsuperscript{f} runtime.

While it is true that Situ\textsuperscript{f} programs are designed to precisely specify situations, the collection of context information for those situations is a direct relevant task \cite{1}, and thus it remains a central design purpose of Situ\textsuperscript{f}. The contexts that need be captured for each constituent of a specified situation, both for data and for action, are specified in XML format.

Note that data and action refer to the corresponding grammar symbols, \textless dataName\textgreater{} and \textless action\textgreater{}, defined in Table 3.1. For a domain expert, the detailed aspects of context information are beyond her core concern, therefore Situ\textsuperscript{f} introduces the import clause to incorporate separately specified, XML-formatted context information for each situation.

In general, the context data are derived from actions exerted by a user over a software system. However, most often than not, the software system itself does not provide extra functionality to support context data collection tasks, not to say to report that collection to a third party. The design of Situ\textsuperscript{f} keeps that in mind and proposes a special include clause to let the situation services provide context collection capabilities. The author of this thesis and his colleagues have completed such general situation services: one targeting web-based applications which is written in Java Script, one targeting local Java JFrame based programs which is written in Java. Situation services help make the goal of collecting context information generally more reachable for different Situ\textsuperscript{f} programs.

### 4.1 Context specification and situation services

With concrete examples, this section elaborates on the technical details of context specification, situation services, their relationship with XML, their affiliation to a Situ\textsuperscript{f} program and finally the active roles they play towards a Situ\textsuperscript{f}-based environment.

According to the grammar of Situ\textsuperscript{f} language, the major constituents of a situation are data and actions. In a Situ\textsuperscript{f} script, the situation constructors, i.e., map, reduce, filter and apply, are used to assemble data and actions declared into a meaningful situation. This means that
the context information in a Situ$^f$ program is classified into two categories: data context and action context. Action context is built on top of data context, as the input and output of each action come from data. In this writing, we concentrate on explaining data context, through which action context should seem easy.

In Situ$^f$ environment, context information, either for data or for action, is represented and transmitted using XML format. Furthermore, XML is considered the intermediate representation to exchange information, not just restricted to context information specification, but also serve the purpose of recording situation data structure as well as specifying situation services included in a Situ$^f$-based environment. In particular, there are two ways of defining the structure of any contents represented in XML format: DTDs, the older and more restricted way, and XML Schema, which offers extended possibilities, mainly for the definition of data types in XML [61]. Unlike DTD, which uses a different syntax separate from XML, thus needs a separate parser to interpret [61] its code, XML Schema by itself follows XML-based syntax to define new types. It is worth mentioning that as compared with DTD, which only provides character data type such as #PCDATA(Parsed Character Data) and #CDATA(Unparsed Character Data), XML Schema offers a variety of built-in data types:

- Numerical data types, including integer, Short, Byte, Long, Float, Decimal
- String data types, including string, ID, IDREF, CDATA, Language
- Date and time data types, including time, Data, Month, Year

The rich power for data structure description provided by XML Schema, as well as the ability to extend an existing data type, collectively make XML Schema a better candidate than DTD to serve the purpose of specifying context information in Situ$^f$-based environments.

In this work, we choose XML Schema to configure "context" templates to synchronize the communication between a Situ$^f$ program and the external context collection capabilities, under a Situ$^f$-based environment.
4.1.1 XML and context specifications

To provide concrete explanations and illustrations for key issues involved, let us revisit the paper review example given in Program 2.

The attribute grammar of $Situ^f$ given in Table 3.3 through 3.5 requires that each declared data, represented by grammar symbol $<$dataName$>$, have an attribute called $env$, meaning environment. This is a composite attribute. Its runtime implication depends on the context specification the $Situ^f$ program imports. Each paper declared in Program 2 in fact has the following attributes:

- abstract;
- author_name;
- author_affiliation;
- email_contact;
- paperID;
- submitTime;
- targetted_trackName;

This detailed context information is generally beyond the concern, or knowledge, of a domain expert. But it is very important to answer the attribute grammar requests. $Situ^f$’s support of separation of concerns [62] bridges this gap. More concretely, $Situ^f$ offers an import clause feature. As seen in Program 2, the "contextSpec_MyReview" following the "import" keyword is an instance of $<$situation_spec$>$, which is encoded as an XML Schema given in Table 4.1.

The all keyword represents a built-in mechanism XML Schema offers to construct new types of data. The detail is quoted as follows:

- sequence, a sequence of existing data type elements, the appearance of which in a predefined order is important;
<? XML version="1.0" encoding="UTF-16" ?>

<MyReview:schema xmlns:MyReview="http://www.w3.org/2001/XMLSchema" version="1.0">
  <MyReview:element name="paper" type="paperType">
    <MyReview:complexType name="paperType">
      <all>
        <element name="abstract" type="string" use="required" />
        <element name="author_name" type='string" minOccurs="1" maxOccurs="unbounded" />
        <element name="author_affiliation" type="string" minOccurs="1" maxOccurs="unbounded" />
        <element name="email_contact" type="string" use="required" maxOccurs="1" />
        <element name="paperID" type="integer" use="required" />
        <element name="submitTime" type="date" use="required" />
        <element name="targetted_trackName" type="string" use="required" maxOccurs="1" />
        <element name="conference_name" type="string" use="required" />
      </all>
    </MyReview:complexType>
  </MyReview:element>
</MyReview:schema>

Table 4.1 An XML Schema-based context template

- *all*, a collection of elements that must appear, but the order of which is not important;
- *choice*, a collection of elements, of which one will be chosen.

In fact, XML Schema enables *user-defined data types*, comprising *simple data types*, which cannot use elements or attributes, and *complex data types*, which can use elements and attributes [61]. Complex data types can also be defined from already existing data types. The XML schema given in Table 4.1 essentially provides a template to help bind *paper*, a data variable declared in Program 2, and its closely related context. Note that Table 4.1 provides detailed attributes pertaining to the specific situations associated with the MyReview system. The associating power is further enhanced by the use of *namespace* MyReview in Table 4.1. That said, a paper under a different circumstance, such as the ”EasyChair” software system,
could involve completely different attributes, the use of which requires the importing of a different XML schema. Besides, the use of namespace in an XML Schema helps to disambiguate identical naming and to differentiate between separate situation domains, e.g., MyReview vs. EasyChair. For more background information on namespace mechanism of XML schema, please consult [61].

Upon the import of a context specification where relevant information for a paper is provided, the Situ compiler automatically executes the following action:

\[
paper_{env} = paper_{env} \cup \{ \text{abstract, author\_name, author\_affiliation, email\_contact, paperID, submitTime, targetted\_trackName} \}
\]

**Note:** the initial env attribute of paper only includes its id information. To see that, from production (4) given by the attribute grammar in Table 3.3: \( <\text{dataName}>_{env}= <\text{identifier}> .id \), when paper is declared, it replaces \(<\text{dataName}>\).

In Table 4.1, "paper" is defined as a new type, where abstract, author\_name, author\_affiliation, email\_contact, paperID, submitTime, targetted\_trackName and conference\_name are its built-in fields. Each field, corresponding to the respective context of a "paper," is of a precisely defined data type such as string, integer, etc... The diverse data types available in XML Schema make XML Schema powerful enough to specify highly diverse data different Situ programs may face. In comparison, XML DTD only supports character data types, i.e., #PCDATA, for Parsed Character Data, and #CDATA, for unparsed Character Data,

### 4.1.1.1 Example of context values generated based on context templates

Table 4.2 is a direct instantiation of the XML schema based context template given in Table 4.1. Given that Table 4.2 strictly follows the format prescribed by Table 4.1, the latter is hence named context template.

Table 4.2 presents a concrete runtime example of a data value traveling through SituIO. This XML element is a value for the data variable "paper" declared in Program 3.3, generated
Table 4.2 A sample context value collected at runtime using XML

under the governing of “contextSpec_MyReview” file which contains the XML Schema given in
Table 4.1. The XML context information shown in Table 4.2 for ”paper” also presents itself as
a sample value for env attribute of <dataName>, a grammar symbol instantiated by ”paper,”
from Situ’s attribute grammar in Table 3.3 to Table 3.5. Table 4.2 is a concrete instance of
value v, presented in the abstraction for SituIO in section 3.6.2.

4.1.2 The inclusion of situation services

Situation services extend the capability of a Situ program that includes them. Situation
services are either made by a third party provider and hosted on the cloud, or they can be hosted
on the local machine. The default situation service for Situ is called “common_service_GUI,”.
The details about this default service is provided in the next chapter as part of the feasibility
test of the Situ language. The default service offers the capability that, once deployed at the
targeted url site, can capture and record a software user’s action information which is then sent
back, through SituIO, to where the Situ runtime is deployed. What is captured by the default
service is real time behavioral and environmental contextual information, which is configured
by the central Situ program that generally contains program url addresses. For Program 2, it
To deploy a situation service requires security trust of the hosting system. Security issues under Situ\textsuperscript{f}-based environment is part of our future research direction. An interesting question to ask from the perspective of Situ\textsuperscript{f} is: how can the design of Situ\textsuperscript{f} be evolved to be more situation security aware. This question can be answered as a result of our future work.

4.2 XML Situation data structures

The XML-based situation data structure is encoded and transmitted in XML format. Therefore it also involves XML Schema to define its data type similar to the discussion in 4.1.1. However, the XML situation data structure uses XML format to serve different purposes:

- To record all context data received through SituIO. This includes intermediate, as well as final functional results a running Situ\textsuperscript{f} program generates;
- The records saved in XML situation data structure are all temporally sorted;
- Save all user errors found from historical records affiliated with specific situation services, or freshly captured use errors.

4.3 EOS in Situ\textsuperscript{f}-based environment

For a Situ\textsuperscript{f} program, the compiler emits code to monitor the recorded actions of the software user, most typically through `command_service_GUI`. Once the user moves on to a program url that is out of the scope specified in Situ\textsuperscript{f}, that information, once received, is interpreted as an EOS which wraps up the on-going stream expression evaluation. In the example of Program 2, once user’s mouse clicks a url other than

129.186.93.0 : `/home/myreview/COMPSAC2011 Training/Review.php`

Situ\textsuperscript{f} runtime equivalently receives an EOS from the Situ\textsuperscript{f}-based environment.
CHAPTER 5. IMPLEMENTATION AND FEASIBILITY TEST

Software services are provided to the users through software interfaces. Oftentimes, a software interface, in particular a graphical user interface nowadays, is designed targeting a major user group rather than any single user. Analysis on individual differences provides good clues to possible exceptional usage issues, closely related to the evolution of the interface.

The overall objective of Situ framework is to improve our understanding of software evolution to involve a human-centered situation centric perspective. The Situ$^f$-based environment including the functional Situ$^f$, its underlying programming model, such as SituIO, all revolves around situations: situations are the basic building blocks that are given intrinsic support inside a Situ$^f$-based environment. In this section, we showcase the feasibility of Situ$^f$’s approach from an experimental test point of view; more specifically, we apply our mechanism on two occasions:

- a Java JFrame/Swing based Graphical User Interface software deployed locally. By writing code in Situ$^f$ to adapt the user interface through collectively capturing user’s action context, especially user’s operation errors, and;

- experimental details on the paper review instance on the MyReview system, which is used as the sample case through Program 2 and else throughout this thesis.

5.1 Experiment on JFrame/Swing based User Interface Adaptation

5.1.1 Overview of adaptive user interface

For the interest of designing feasibility tests on Situ$^f$, we take a human centric perspective to first review the relevant research in the area of user interfaces. We pay close attention to the category of interfaces that have the ability to adapt and evolve based on individual user’s
differences and preferences. This kind of interfaces are termed Adaptive User Interfaces. It is helpful to point out a key difference between interfaces as being adaptive and adaptable. Users can opt to set up those built-in options inside an adaptable user interface, which is not the case for an adaptive user interface. This section reviews various methodologies, as well as various challenges, to model, design and evaluate adaptive user interfaces.

To build Adaptive User’s Interfaces essentially requires to build a domain specific user model. According to British Standard Institute (2005), *inclusive design* is the “design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible ... without the need for special adaptation or specialised design.” One kind of users are those with various disabilities. Certain disabilities may not even be always easy to notice by the user herself. [63] enclosed a new inclusive design to embrace users with disabilities. A sequel of that research includes: (1) a methodology to implement the aforementioned inclusive design [64] and; (2) an approach to solve the usability issues derived from inclusive design targeting cell phone scenarios among older users [65]. Health-care systems are another area that finds broad applications of adaptive user interfaces. The user characteristics, issues regarding inclusive interface redesigning as well as the current frontier of adaptive user interface application for health-care systems are discussed in [66]. Users’ spatial ability is closely related to their performance on user interfaces, which is especially true when it relates to using graphical user interfaces. This is due to the intrinsic directional and spatial information carried by the layout of the interface gadgets, the relative position among them and, the finding of the right gadget in the interface is inherently a spatial search process. Fortunately, [67] experimented and showed that users with low spatial ability are able to perform better through improved interface where additional commands are added. Besides their differences in spatial ability, every user has a different set of cognitive skills. Due to [68], these individual differences could be categorised and labelled; further more, [68] utilized visual means to help low spatial ability users to improve their performance in a user interface and achieved encouraging results.

The issue of integrating *inclusive design* approach with adaptive user interfaces indeed has attracted a lot of research efforts. However, to use essentially one interface to accommodate all users or user groups might result in deficient solutions [68]. Intuitively, diverse backgrounds
possibly rooted in different users or user groups may cause confusion in using interfaces, and hence dramatically complicate the matter. The end result is the degrading of certain users’ performance. The key issue there lies in individual differences among different users. Concrete examples of individual differences include the different spatial and cognitive ability. For instance, experimental user interfaces supporting zoom with overview as opposed to details showed that some users performed much better than others using only zoom with an overview [69].

To provide better services to the user, user interfaces must be able to adapt to individual user differences and hopefully, their preferences. Users perceive and accept adaptive interfaces better than non-adaptive static interfaces [70]. Without built-in support and environmental help, it would be very difficult for programmers to code those adaptive user interfaces e.g., added design and implementation overhead is usually required. \(^1\)

The general modeling of user and adaptive systems, the guidelines and examples are discussed in [71]. The authors there also showcased several concrete methods deemed effective to build user-centric adaptive systems. Starting from the driver’s centric point of view, [72] unfolded the discussion about an adaptive route advising system where user preferences were frequently updated. In the end, a more satisfactory adaptive system serving drivers as the user group was concluded.

Directly lending a hand to adaptive user interface construction, both as a standard and as a general guideline, is the modeling of user behavior\(^2\). User’s behavior pattern recognition and the capturing of recognized user profile are effective means to facilitate the interactions between the user and user interface [73]. Further more in their research [73], a personalized assistant was built based on scenario identifications and interconnections.

Other common examples of adaptive user interfaces include those to extract user information and then derive recommendations to users correspondingly. Content-based and collaboration-oriented information extraction are the basic techniques. The content-based, collaboration-oriented information on user’s behavior contributes important data to make sound predictions

\(^1\)Situ\(^f\) language and its infrastructure can be used for this purpose, which is discussed in the next section.

\(^2\)In Situ framework, this is defined as behavioral context [1]
on user’s behavior. Machine learning and statistical data processing approaches offer solid methodologies towards the objective of predicting user behavior. To this end, [74] provided machine learning algorithmic insights to adaptive user interface development. [75] took into account the user-centric context data as a means to statistically learn and adapt user interfaces for better user experience. [76] experimented on Microsoft Office platform to model, predict and answer software user’s instantaneous needs via Bayesian learning techniques. In [76], a user recommendation model was discussed and tested in which collective and sustainable learning of user’s preferences and differences were accomplished. [77] experimented and analysed predictability and accuracy of adaptive systems as complementary measures for the improving of user’s performance. Besides, [76] explored knowledge discovery over user’s behavioral patterns in the reported experiment towards raising the accuracy and predictability of a user recommendation model.

[78] generated a user centric adaptive interface where the focus was given to the evolving of user states; [79] performed analysis on the algorithms to predict user performance over user interfaces. Other interesting work in the field includes investigating the use of user error detection methodology as a means to adapt web pages to suit the abilities of older adults [80].

The previous overview serves to set up the stage for a feasibility test of this work. To show the effectiveness of Situ-based environment, an experiment is carried out that adopts the modeling of an adaptive user interface based on the errors made by the users when they interact with the system. The experiment is conducted with the MyReview paper review system. Errors made by a user are used to adapt, thus evolve, the system accordingly. The evolving of the system is guided by the mitigation of errors committed by the user. While user’s erroneous usage situations have been detected under Situ-based environment, the MyReview system is able to produce multiple situation-driven user interfaces by users’ preferences.

5.1.2 Error, situation and the XML representation of context

The errors a user makes while interacting with an interface may be attributed to different causes, such as adverse environmental conditions. The causes may commonly include, but not limited to, the following:
• Environmental contexts\(^3\);

• Restrictions on the users;

• Inherent complexity carried by the interface;

One type of errors is the so called tapping errors, i.e., a user miss-types or misses a gadget while tapping. Tapping errors can also refer to errors involving the tapping of a wrong gadget followed by reversals (quickly reverse to the previous action) or other errors. The reason behind these errors may be hard to determine: user’s low spatial ability (e.g. user being not able to locate correctly the interface gadgets), or user’s poor motor ability (e.g. user not being able to hit the proper gadget) etc. We include the following kinds of errors for analysis purposes in this experiment:

• Tapping Errors
  
  – Reversals
  
  – Missed Taps

  * Radio Button

  * Text Area

  * Menu

  * Keyboard

  * Check Box

  * Text Box

  * Button

Based on the above list of supported user error types, we have built a situation service, named \textit{user-action-error-detection-local}, which provides an error detection function \texttt{isError}. On the implementation level, it maintains a threshold value for the distance around each gadget included in a GUI. When the tap error occurs within a radius measure given by the threshold value of a particular gadget, such as a text box, then tapping error counts for that particular\(^\text{3}\) such as poor visibility
gadget ramp up. Any taps falling outside of the threshold range are counted as erroneous taps. A sequence of erroneous taps suggest that the positioning of the relevant interface gadget falls out of the comfort/preference zone of the user. Thus, repeated capturing of erroneous taps would cause an increase of the threshold value for that particular gadget which caused the tapping error. This reflects the "adaptive nature" of this experiment.

Program 3 A Situ$^I$ program for error-based adaptive user interface evolution

include GUI_error_detection_local
import contextSpec_user_interface_real_state

program _adaptiveUI
data
declare
  UI_component@255.255.255.255:˜personalInformation_ \ UI.class;
declare
tap@255.255.255.255:˜personalInformation_UI.class;
declare
threshold@255.255.255.255:˜GUI_error_detection_local;

action
declare
  isError<tap:Boolean>@255.255.255.255:GUI_error_ \ detection_local;
declare
  correctiveAction<tap:threshold>@255.255.255.255: GUI_ \ error_detection_local;

situation
  map correctiveAction(filter isError tap());

The user information appeared in the Situ$^I$ Program 3 is displayed in Figure 5.1. Notice that the structure of this design is first discussed and illustrated by Figure 1.4.

The “contextSpec_user_interface_real_state” imported by Program 3 is, as explained in the last chapter, encoded in XML shown below.

<Screen ID=1>
<Screen size>
  <W> 400 </W>
  <H> 300 </H>
</Screen size>

<Gadgets>
  <Panels/>
  <Scrollbars/>
  <Labels/>
  <Text Boxes>
    <Name>
      <Begin>
        <X> 40 </X>
        <Y> 30 </Y>
      </Begin>
      <End>
        <X> 280 </X>
        <Y> 30 </Y>
      </End>
    </Name>
    <Age/>
    </Text Boxes>
  <TextAreaes/>
  <Check Boxes/>
  <Buttons/>
</Gadgets>
</Screen>
The above XML-based context specification of user information shows the benefit of separating the concern of details in a graphical user interface real state. The domain expert can simply import the information, therefore being able to fully concentrate on the most important task, in this example, adaptively evolve the user interface incrementally!

5.2 Experiment on MyReview, a web-based paper review system

For the MyReview experiment, the Situ code that has been written to specify a paper review situation is demonstrated at Program 2. JavaCC [81], i.e., Java Compiler Compiler, is used to generate the parser for Situ. Our input to JavaCC is Situf.jj, a file ending in .jj, which contains production rules from Situ’s Context Free Grammar found in Table 3.1. Java code is injected under each production rule in Situf.jj to carry out the execution of attribute grammar rules given in Table 3.3 to 3.5 as syntax directed semantic actions. After conducting grammatical error checking on Situf.jj to prevent things like left recursion from happening, JavaCC automatically generates a parser for Situ. Specifically, the auto-generated Situ parser is a java file called SitufParser.java. It is automatically named by JavaCC by taking the prefix of the input grammar file name of “Situf.jj”, and then appending “Parser.java” to it. More importantly, at the very end of Situf.jj file, which will only be executed after all parsing is done, lies a segment of java code that takes parsed names—both for data and for action—and XML contexts’ specifications to set up XML context templates, to link in situation data structure and then finally, to start up the related situation services. Under standard java runtime environment, to parse a Situ Program 2 simply requires providing Program 2 as an input file to the auto-generated parser SitufParser.java before running java command javac; after that run the generated java class file using java command java. In the end, the Situ-based environment revolving around the specified paper review situation is started.

A side note is that Java socket is used to implement the context data transportation between a Situ program and its external runtime environment. This is because the site where a Situ program is run, usually locally to a domain expert, is most probably remote to where the MyReview system and the included situation services are deployed. At the current stage, we run Java sockets under a homogeneous environment where no security issues, such as firewall
policies, will arise. In future however, to meet the need of using a heterogeneous environment such as the World Wide Web, Simple Object Access Protocol (SOAP) will be considered to wrap up the sockets so that firewall policies will not deny socket access.
Figure 5.1  The Graphical User Interface for User Information
CHAPTER 6. CONCLUSION AND FUTURE WORK

6.1 Conclusion remark

This work marks the first step towards the realization of \textit{Situ} framework. A domain specific functional programming language called \textit{Situ}$^f$ is proposed to bridge the concept of situation [1] to realistic computing circumstances. In this work, attribute grammar is used to aggregate dynamically captured contexts around each specified situation written in \textit{Situ}$^f$ by a domain expert. The communication between a stream of externally collected contexts and the internally specified situations is further modelled as \textit{Monad-based SituIO}. This way, \textit{Situ}$^f$ is able to maintain its position in the purely functional category. Unlike a traditional language such as ANSI C where I/O is supplied by external libraries, SituIO is a built-in component of \textit{Situ}$^f$ language proper. Therefore, to completely define \textit{Situ}$^f$, this thesis offers a precise mathematical description, namely computational semantics, also known as small-step operational semantics, for SituIO.

The design of \textit{Situ}$^f$ gives rise to an environment that employs XML as the intermediate representation for data transportation, context specification importing, situation services inclusion, as well as other runtime support purposes. Since such an environment, which we name as \textit{Situ}$^f$-based environment, effectively encapsulates nontrivial underlying complexity, a domain expert is able to focus on situation level abstractions. Last, but not least, \textit{Situ}$^f$-based environment closely supports separation of concerns for situation specification. This brings home a set of desirable results such as situation modularity and reusability.

To test the feasibility of our approach, two experiments were conducted. One was done over situations regarding user error based local graphical user interface adaptation; the other was to capture paper-review situations on top of MyReview, a web-based paper review system.
The results showed that Situ $^f$ language, coupled with its affiliated Situ $^f$-based environment, provides sufficient expressive power as well as runtime support to help domain experts who write situation specifications to achieve various domain specific purposes.

### 6.2 Future work

The future work targets the following aspects:

- Add a strict type system on top of Situ $^f$ to facilitate static time checking as well as static time program verification.
- Improve security mechanisms, from the perspectives of both theoretical modelling and practical implementation, for situation services inclusion;
- Engage sophisticated high performance compilation techniques, where functional languages generally have an edge over imperative languages for the purpose of ensuring program correctness.
- Integrate RDF, which shares the XML format, with Situ $^f$-based environment, especially into the mechanism of context specification importing. This way, Situ $^f$-based environment is able to enjoy the benefits derived by knowledge representation and knowledge reasoning techniques.
- Add “error propagation” machinery into Situ $^f$ so that an erroneous situations may be captured in parallel with localizing the user and software errors to closely correspond to the situation specification.
BIBLIOGRAPHY


[61] [http://www.w3.org/XML/](http://www.w3.org/XML/).


