Bachelor Thesis

Nyāya for iPad

Interactive Environment for BoolTool

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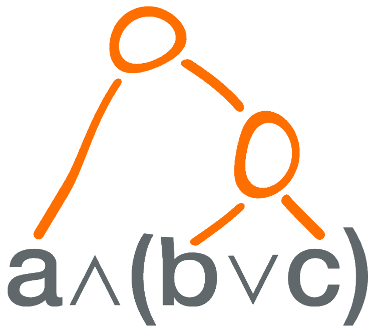

29 December 2012

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Abstract

If wishes were horses
Beggars would ride:
If turnips were watches
I would wear one by my side.
And if if's and an's were pots and pans,
The tinker would never work!

This nursery rhyme from the 16th century has some propositions! But are they true? Propositional logic provides a toolset to answer this question and many other questions, where propositions are made and connected. Nyāya for iPad will introduce the formalism of propositional logic interactively. A series of tutorials will put the user in a position to formalize this poem and to ~~asses~~ if the implications made by this poem can be true.

Contents

1. Introduction

The aim of logic in computer science is to develop languages to model the situations we encounter as computer science professionals, in such way that we can reason about them formally. [6]

Logic is used daily. Although the core of reasoning and the foundation of computer science, logic still takes time and practice to be mastered ~~sound and complete~~. Uncertainty in the formalisms of logic leads to fundamental inaccuracies in the modeling of various applications in computer science. Therefore logic is a mandatory part of every computer science course.

Each tool that promotes a deeper and more accurate understanding of formalisms and applications of logic, or simply provides an easier introduction to formal logic, is a welcome addition to the toolbox of training.

1.1. Propositional logic

Propositional logic is – to put it simply - the entry point and the innermost core of logic. It is a powerful formal language, which can be used in many fields. But it also has limits of expressiveness and so there are many more powerful formal languages of logic, which can not be mastered without a sufficient understanding of propositional logic.

1.2. BoolTool

BoolTool by the Computational Logic Research Group at the University of Innsbruck allows the manipulation and evaluation of Boolean functions. The tool supports different representations of Boolean functions and a variety of different algorithms. Propositional logic is one of many representations of Boolean functions.

1.3. Nyāya

The aim of Nyāya was to build an interactive environment on an iPad, that allows the user to learn simple facts about the formalism of propositional logic and standard transformations of Boolean functions. The environment had to be self-explanatory and had to be integrated with BoolTool.

2. Related Work

Nyāya for iPad is not the first program, that processes expressions of propositional logic. Besides powerful SAT-solvers and automatic provers, which rarely can be used by beginners, there are some software products, that can be used on a basic level of experience with propositional logic and Boolean expressions. Most of them provide a (short) introduction to propositional logic, but they seldom offer tutorials or exercises.

The following list presents some software products accessible via website and apps available for iPad.

2.1. Websites

- **PLogic Applet** by S. Lukins, A. Levicki, and J. Burg at the Wake Forest University, is a tutorial program for propositional logic "that serves a double role as an educational tool and a research environment"[1] and focuses on interactive theorem-proving.

- **BoolTool** by the Computational Logic research group at the University of Innsbruck "is an interface to the program BoolTool which allows the manipulation and evaluation of boolean functions."[2]. It computes truth tables and binary decision diagrams and checks for satisfiability and validity.

- **Wolfram Alpha** by Wolfram Research – the makers of Mathematica – supports propositional logic by calculating truth tables and minimal forms, but does not draw syntax trees or binary decision diagrams. Instead it draws a logic circuit and a venn diagram from the input. Additionaly it calculates the truth density and the boolean operator number of the input formula.

  Wolfram Alpha does not calculate exactly for an arbitrary number of variables in propositional formulas. For example no truth table, conjunctive normal form, no disjunctive normal form is calculated for the input $a \veebar b \veebar c \veebar d \veebar e \veebar f \veebar g \veebar h \veebar i \veebar j$. The truth density is only sampled and does not match the exact result 0.5.

[1] `http://www.cs.wfu.edu/~burg/papers/PropLogic.pdf`
[2] `http://cl-informatik.uibk.ac.at/software/booltool/?page=info`

2.2. Apps for iPad

Some apps for iPad or iPod touch that handle aspects of propositional logic.

- **Constraints** by Davide Cucciniello is a "SAT based propositional (boolean) logic engine defined by a list of models, where a model includes a list of constraints (a Knowledge Base) each defined by a propositional formula (x and (y or not z)) including a set of propositional (boolean) variables (x,y,z) and operators (and,or,not)."[3] lets you build models in an interactive way. It also provides a short introduction in propositional logic, but no tutorials.

- **Truth Table Generator** by Mertz Werkz LLP "constructs truth tables for the Boolean expressions you enter".[4] It does that nicely by using standard symbols of propositional logic (and a limited set of atoms), but nothing more.

- **Boolean Algebra Cheat Sheet** by Clint Johnson presents two pages of logic "rules and laws" in low picture quality. So "all of your Boolean logic needs."[5] does not feel quite right.

- **Logic Mania** by Imagination Creations presents seven logic gates in a list. Their semantics are shown in a per-gate-simulation where the user chooses the input and the app shows the result. A combination of gates is not possible. It's quite nice but the statement "THE [sic] reference application for students studying logic gates."[6] seems exaggerated.

- **Circuit Coder** by Trycycle Design HB is a game about building digital circuits, which is an application of propositional logic.

[3] http://www.mysvc.it/myapps/constraints/
[4] http://www.mertzwerkz.com/truth.html
[5] http://itunes.apple.com/at/app/boolean-logic-cheat-sheet/id341959531?mt=8
[6] http://itunes.apple.com/at/app/logic-mania/id434019152?mt=8

3. Concept

The aim of this project was to design an interactive environment on a tablet computer that allows the user to learn simple facts about the formalism of propositional logic and standard transformations of Boolean functions. The environment was meant to be self-explanatory.

The core of this concept builds on tutorials with exercises and a playground where the ~~learned~~ knowledge can be used in different modes. A glossary of terms and a formula calculator (BoolTool) to check formulas will support the user in their learning.

3.1. Tutorials

Nyāya for iPad covers syntax and semantics of propositional logic, but only some basic rules of natural deduction. It introduces normal forms, truth tables and binary decision diagrams as different but equivalent representations of Boolean functions.

The structure of the tutorials and the content of the exercises are heavily based on ~~the according~~ sections of the book *Logic in Computer Science* [6] by M. Huth and M. Ryan. Additional content was taken from the lecture *Logic* [9] by A. Middeldorp.

```
<array>    <!-- root with title and sections -->
  <string>Tutorials</string>       <!-- title -->
  <array>    <!-- section with section title and tutorials-->
    <string>Introduction</string>     <!-- section title -->
      <array>  <!-- tutorial with title and id -->
      <string>Motivation</string>  <!-- tutorial title -->
      <string>11</string>          <!-- tutorial id -->
    </array>
  □
```

Table 3.1.: Tutorials.plist – the configuration file for all tutorials

General and specific configurations for the tutorials and additional content for the exercises are stored in simple property lists[1], which are xml-files with some basic data types for data and collections, that can be easily read and interpreted by different programs. The file "Tutorials.plist" (see table 3.1) provides the basic

[1] http://www.apple.com/DTDs/PropertyList-1.0.dtd (see table B.1 on page 37).

data about available tutorial sections and tutorial titles to build a navigation menu programmatically.

Every tutorial includes a teaching part with examples (html-files in utf-8 encoding) and an interactive knowledge checker with exercises, where the user gets immediate feedback. Every interactive part will present some instructions to master the task.

3.1.1. Introduction

The first tutorial section with four tutorials (11, 12, 13, 14) gives an informal introduction to modeling, i.e. the translation from sentences in natural language to sentences in the formal language of propositional logic.

The content file "QA1.plist" (see table 3.2) contains an array (starts at line 5) of arrays that include sentences and sample solutions (the first exercise starts at line 6). The first string is the sample sentence (at line 7), which must be analyzed by the user and the following strings are sample solutions for different exercises.

```
 5 <array>
 6   <array>
 7     <string>If the barometer falls, then it will rain.</string>
 8     <string>if p then q</string>
 9     <string>the barometer falls; it will rain</string>
10     <string>p → q</string>
11   </array>
12 □
```

Table 3.2.: QA1.plist – content file for the first three tutorials

Each tutorial has its own configuration file (see table 3.3 on the next page) with a dictionary that describes the task and defines the index of the sample solution, with which the user's answer will be checked with some tolerance.

Applications

(11) The aim of logic in general is to reason about situations [6]. In this tutorial it is shown, how two different paragraphs in natural language can be reduced to the same formal sentence "If p and not q, then r. Not r. p. Therefore, q". If the reasoning is correct, the user can use it in both situations.

In the interactive part the user has to 'guess' the formal structure of composite sentences in natural language. The sentence `'If the barometer falls, then it will rain'` from line 7 of `QA1.plist` (table 3.2) has to be translated into `'if p then q'` from line 8 (the solution index is defined as 1 in `11.plist`, see table 3.3 on the next page).

```
<dict>
  <key>questionLabelText</key>
  <string>Guess the structure ...</string>
  <key>answerLabelText</key>
  <string>Use ...</string>
   <key>solutionLabelText</key>
   <string>Sample solution</string>
   <key>questionsFile</key>
   <string>QA1</string>
   <key>solutionIndex</key>
   <integer>1</integer>
</dict>
```

Table 3.3.: 11.plist – configuration file for the first exercise

Propositions

(12) The concept of propositions – simple declarative sentences – as indivisible building blocks of propositional logic is explained in more detail. Some counterexamples are presented and the ambiguity of natural language is demonstrated.

The user has to find the propositions in composite sentences. The correct answer for `'If the barometer falls, then it will rain'` would be `'the barometer falls; it will rain'` from line 9 (the solution index is defined as 2 in `12.plist`).

Connectives

(13) The basic symbols of propositional logic to connect propositions are introduced. "$\rightarrow$", "$\neg$", "$\wedge$", and "$\vee$" will replace "if then", "not", "and" and "or".

For the sentence `'If the barometer falls, then it will rain'` a correct answer is `'p → q'` from line 10 (the solution index is defined as 3 in `13.plist`), but '$\neg p \vee q$' would be accepted too.

Limits

(14) Some examples are given to demonstrate that not every situation can modeled in propositional logic.

The user has to 'guess' whether sentences in natural language are suitable for propositional logic.

3.1.2. Syntax

After the informal introduction into the atoms and connectives of propositional logic, the formal aspects of propositional logic will be introduced to the user.

The content of these exercises will be generated by the app and the user's solution will be checked without tolerance.

Definition

(21) The definition of well formed formulas is explained.

$$P \quad ::= \quad p \quad | \quad (\neg P) \quad | \quad (P \wedge P) \quad | \quad (P \vee P) \quad | \quad (P \rightarrow P)$$

Table 3.4.: Grammar with mandatory parentheses

The user has to check whether a formula matches the strict definition of a propositional formula (see table 3.4). If the formula is well formed, the user has to write down the name of the root connective, i.e negation, conjunction, disjunction or implication. If the formula is not well formed, the user has to leave the answer field empty.

Conventions

(22) The conventions of precedences and associativity of connectives to save parentheses are introduced.

The user has to rewrite formulas from strict syntax to formulas using conventions and vice versa.

$$\begin{array}{cccll} P & ::= & D & | & D \rightarrow P \\ D & ::= & C & | & D \vee C \\ C & ::= & N & | & C \wedge N \\ N & ::= & T & | & \neg N \\ T & ::= & p & | & (P) \end{array}$$

Table 3.5.: Grammar with precedence and associativity

Sub-formulas

(23) Sub-formulas (starting from atoms) are used to build bigger formulas. Big formulas are build from many sub-formulas.

The user ~~have~~ to extract the set of sub-formulas from composite formulas. A correct answer for '$a \vee b \wedge c$' would be '$a, b, c, b \wedge c, a \vee b \wedge c$'. The order of the sub-formulas does not matter and the user can use parentheses as they like it. But no sub-formula may occur more than once.

Syntax Trees

(24) Syntax trees as graphical representation of well formed formulas are introduced.

The user has to write formulas for presented syntax trees. They can use parentheses as they like – still the formulas ~~has~~ to match the syntax trees exactly. '$a \vee b$' does not match the syntax tree representing '$b \vee a$', where the node 'a' is on the right branch of the node '$\vee$'.

Top and Bottom

(25) Some natural deduction rules are introduced. "⊤" (top) and "⊥" (bottom) are defined as abbreviations of conjunctions and disjunctions of formulas with their negation (tautologies and contradictions, table 3.6).

$\neg P \lor P$	$P \lor \neg P$	$\neg P \land P$	$P \land \neg P$
$\top$	$\top$	$\bot$	$\bot$

Table 3.6.: tautologies and contradictions

The user has to simply given formulas.

$\neg\neg P$	$P \lor P$	$P \land P$	$P \lor Q$	$P \land Q$
P	P	P	$Q \lor P$	$Q \land P$

Table 3.7.: basic rules

3.1.3. Semantics

After the introduction of well formed formulas the meaning of logical connectives is defined.

Valuation

(31) The truth assignment for atoms $(p, q, r, \dots)$ is introduced. The extended valuation for negation, conjunction, disjunction and implication is defined. The valuation of arbitrary formulas by evaluating all sub-formulas is described.

The user has to guess or calculate the evaluation of a given formula with a given truth assignment for the atoms of the formula.

Truth Tables

(32) The concept of truth tables is explained and demonstrated with the basic connectives. The valuation of arbitrary formulas by evaluating all sub-formulas is demonstrated again.

The user has to fill in truth tables for formulas with a maximum of three atoms.

Entailment and Equivalence

(33) Semantic entailment and equivalence is defined and explained with various examples.

The user has to guess or calculate whether a given semantic entailment or equivalence holds.

Satisfiability and Validity

(34) The properties satisfiability and validity of propositional formulas are defined and demonstrated. The relationship of these properties with top and bottom is mentioned.

The user has to guess or calculate whether a given formula is satisfiable or valid.

3.1.4. Normal Forms

The advantages of propositional formulas in special shapes will be emphasized. The definitions of implication free forms, negation normal form, conjunctive normal forms and disjunctive normal forms will be provided. ~~An receipt~~ to transform arbitrary propositional formulas into specific normal forms will be delivered. Rules to detect satisfiability or validity from normal forms will be mentioned.

Implication Free Form

(41) By removing the rule for P from the grammar in table 3.5 on page 7 the grammar for implication free forms is defined (see table 3.8).

$$\begin{array}{lcccl} D & ::= & C & \mid & C \vee D \\ C & ::= & N & \mid & N \wedge C \\ N & ::= & T & \mid & \neg N \\ T & ::= & p & \mid & (D) \end{array}$$

Table 3.8.: Grammar without implications

The equivalence transformation (see table 3.9) for removing implications is presented and proved with a truth table.

$$\frac{P \rightarrow Q}{\neg P \;\vee\; Q}$$

Table 3.9.: Equivalence transformation towards implication free form

The user has to check whether a given formula is implication free. If the formula is not implication free the user has to transform it into an implication free form using the equivalence transformation.

Negation Normal Form

(42) By removing all rules for arbitrary negations, the negation normal form is defined (table 3.10 on the next page).

The equivalence transformations to transform negations of conjunctions, negations of disjunctions, and double negations (see table 3.11 on the following page) into negation normal forms are presented and proved with a truth table.

$$\begin{array}{rcccl} D & ::= & C & \mid & C \vee D \\ C & ::= & N & \mid & N \wedge C \\ N & ::= & (D) & \mid & L \\ L & ::= & p & \mid & \neg p \end{array}$$

Table 3.10.: Grammar for negation normal form

$$\begin{array}{ccr} \neg(P \wedge Q) & \neg(P \vee Q) & \neg\neg P \\ \hline \neg P \vee \neg Q & \neg P \wedge \neg Q & P \end{array}$$

Table 3.11.: Equivalence transformations towards negation normal form

The user has to check whether a given formula is in negation normal form. If the formula is not in negation normal form the user has to transform it into negation normal form.

Conjunctive Normal Form

(43) A formula in conjunctive normal form is a conjunctive concatenation of disjunctive clauses. A disjunctive clause is a disjunctive concatenation of literals. A literal is an atom or the negation of an atom.

$$\begin{array}{rcccl} C & ::= & (D) & \mid & (D) \wedge C \\ D & ::= & L & \mid & L \vee D \\ L & ::= & p & \mid & \neg p \end{array}$$

Table 3.12.: Grammar for conjunctive normal form

The distribution of disjunctions over conjunctions is presented (table 3.13 on the next page) and proved with a truth table.

The user has to rewrite formulas to a conjunctive normal form. The presented formula is in negation normal form but may already be in conjunctive normal form.

Disjunctive Normal Form

(44) A formula in disjunctive normal form is a disjunctive concatenation of conjunctive clauses. A conjunctive clause is a conjunctive concatenation of literals. A literal is an atom or the negation of an atom.

The distribution of conjunctions over disjunctions is presented (table 3.15 on page 12) and proved with a truth table.

The user has to rewrite formulas to a disjunctive normal form. The presented formula is in negation normal form but may already be in disjunctive normal form.

$$\begin{array}{cc} P \vee (Q \wedge R) & (P \wedge Q) \vee R \\ \hline (P \vee Q) \wedge (P \vee R) & (P \vee R) \wedge (Q \vee R) \end{array}$$

Table 3.13.: Equivalence transformations towards conjunctive normal form

$$\begin{array}{rcccl} D & ::= & C & \mid & C \vee D \\ C & ::= & L & \mid & L \wedge D \\ L & ::= & p & \mid & \neg p \end{array}$$

Table 3.14.: Grammar for disjunctive normal form

3.1.5. Binary Decision Diagrams

Boolean functions

(51) N-ary Boolean functions are introduced as mapping from n-tupels of 0s and 1s to the set $0, 1$. The Boolean operators $\bar{} \ \ + \ \ \cdot \oplus$ are introduced as special representations of specific unitary and binary Boolean functions. For convenience an exclamation mark $!(B)$ will be used for the negation of a Boolean expression B instead of the bar $\bar{B}$.

The user has to guess or calculate the results for composite expressions.

Boolean expressions

(52) The grammar for Boolean expressions is defined. The equivalence relation of Boolean expressions is explained.

The user has to rewrite formulas with propositional symbols into Boolean expressions. The implication may be a challenge for some users, but is doable because the implication free form was introduced in an earlier tutorial.

Binary Decisions

(53) Binary decision nodes are introduced. The valuation of binary decision trees is explained.

The user has to fill in the result nodes in a binary decision tree for a given Boolean expression.

Binary Decision Diagrams

(54) Arbitrary binary decision diagrams are explained. Ordered and reduced binary decision diagrams are introduced.

The user has to check whether a binary decision diagram is ordered and/or reduced.

$$\begin{array}{cc} P \wedge (Q \vee R) & (P \wedge Q) \wedge R \\ \hline (P \wedge Q) \vee (P \wedge Q) & (P \wedge R) \vee (Q \wedge R) \end{array}$$

Table 3.15.: Equivalence transformations towards disjunctive normal form

$$B \quad ::= \quad p \quad | \quad (\overline{B}) \quad | \quad (B \cdot B) \quad | \quad (B + B) \quad | \quad (B \oplus B)$$

Table 3.16.: Grammar for Boolean expressions

3.2. Playground

~~In~~ the playground the user can create arbitrary propositional formulas by building syntax trees interactively. Truth assignments can be applied and will be visualized. The playground supports a least the following use cases.

- In the *free mode* arbitrary formulas can be created by adding, replacing and removing connectives and atoms. The process starts with an atom, which ~~an~~ be expanded or replaced. Connectives can be changed any time, sub-formulas can be reordered. The smallest possible formula consists of one atom with one symbol from the set $\{\top, \bot, p, q, r, \dots\}$.

- In the *locked mode* only equivalence transformations can be applied to nodes (see table 3.17 on the next page) – depending on the kind of node.

- Truth values can be assigned to leaf nodes, which represent the atoms of the corresponding propositional formula. By default no truth values are assigned to atoms, which is visualized by a blue color of the node. A green color represents 'true', and a red color 'false'. The valuation of connective nodes is calculated automatically and displayed using the same blue, green and red colors.

- Connective nodes of obvious tautologies like $P \vee \neg P$ or $P \rightarrow P$ are displayed with a green color – independent form the valuation status of any sub-node.

- Connective nodes of obvious contradictions like $P \wedge \neg P$ are displayed with a red color – independent form the valuation status of any sub-node.

- While working with a syntax tree, the corresponding propositional formula is shown on top of the playground.

- While selecting a sub-node of the syntax tree – the root of a sub-tree – for manipulation the corresponding sub-formula will be highlighted in the corresponding propositional formula.

P	$\rightarrow$	Q		$\neg$	$\neg P$
$\neg P$	$\vee$	Q		$\boldsymbol{P}$	
	$\neg$	$(P \vee Q)$		$\neg$	$(P \wedge Q)$
$\neg P$	$\wedge$	$\neg Q$	$\neg P$	$\vee$	$\neg Q$
P	$\vee$	P	P	$\wedge$	P
	$\boldsymbol{P}$			$\boldsymbol{P}$	
P	$\vee$	$\neg P$	P	$\wedge$	$\neg P$
	$\top$			$\bot$	
P	$\vee$	$\top$	P	$\wedge$	$\top$
	$\top$			$\boldsymbol{P}$	
P	$\vee$	$\bot$	P	$\wedge$	$\bot$
	$\boldsymbol{P}$			$\bot$	
P	$\vee$	Q	P	$\wedge$	Q
Q	$\vee$	P	Q	$\wedge$	P
P	$\vee$	$(Q \wedge R)$	P	$\wedge$	$(Q \vee R)$
$(P \vee Q)$	$\wedge$	$(P \vee R)$	$(P \wedge Q)$	$\vee$	$(P \wedge R)$
$(P \wedge Q)$	$\vee$	R	$(P \vee Q)$	$\wedge$	R
$(P \vee R)$	$\wedge$	$(Q \vee R)$	$(P \wedge R)$	$\vee$	$(Q \wedge R)$
P	$\vee$	$(Q \vee R)$	P	$\wedge$	$(Q \wedge R)$
$(P \vee Q)$	$\vee$	R	$(P \wedge Q)$	$\wedge$	R

Table 3.17.: Transformations which are offered in locked mode

P	$\leftrightarrow$	Q	P	$\veebar$	Q
$P \rightarrow Q$	$\wedge$	$Q \rightarrow P$	$\neg(P \rightarrow Q)$	$\vee$	$\neg(Q \rightarrow P)$

Table 3.18.: Additional transformations in locked mode

3.3. Glossary

Terms, definitions and truth tables from the tutorials are listed in the glossary in a searchable and hyperlinked form.

3.4. BoolTool

The interactive environment ~~have~~ to contain the functionality of the BoolTool web frontend.

3.4.1. Input

~~At least~~ the embedded BoolTool must support Latin letters as identifiers for atoms, and ~~have~~ to parse the symbols `T` as top, `F` as bottom, `!` as negation operator, `&` as conjunction operator, `+` as disjunction operator, `>` as implication operator, `^` as exclusive disjunction operator, and `(` as left and `)` as right parentheses, because these ASCII-symbols can be found on almost every keyboard.

Standard symbols "$\neg\vee\wedge\rightarrow$" and additional symbols of propositional logic and Boolean expressions should be accepted too (see table A on page 36) to make extended or custom keyboards more usefu limitation of the Latin characters for identifiers should be avoided, because Chinese symbols make good identifiers too (figure 3.1).

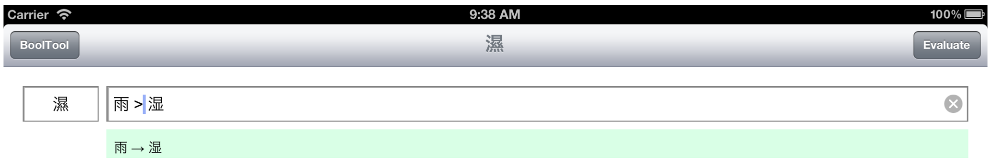


Figure 3.1.: Implication with Chinese symbols for rain and wet

3.4.2. Output

BoolTool calculates validity and satisfiability, conjunctive normal form, disjunctive normal form, truth table and (reduced) ordered binary decision diagram of user's input (figure 3.2).

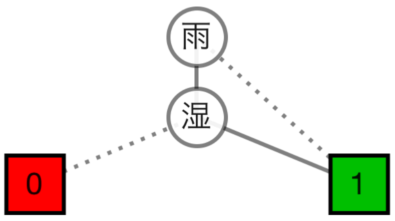


Figure 3.2.: Reduced ordered binary decision diagram

4. Tools and Processes

4.1. Tools

4.1.1. Developing for the iPad

First steps in developing applications for iPad can be made on a computer running Mac OS X (OS) and Xcode (IDE), which is ~~as~~ free download from the Mac App Store. Knowledge of object-oriented programming, object-oriented design patterns, and the C programming language builds a good base to learn the main platform-specific technologies Objective-C, Cocoa, and memory management with automatic reference counting.

In addition to the technical skills, an overview of the necessary steps for Development and Distribution (p. 16) for the iPad platform ~~is to gain.~~

Xcode

Xcode is Apple's integrated development environment to create software for OS X and iOS devices. It includes an iPad simulator, complete API documentations and development guides to various topics. Xcode supports the source management systems ~~git~~ and subversion. Git will be installed along various other development tools with Xcode.

Objective-C

Objective-C is a reflective, object-oriented extension of the C programming language, which was developed by Tom Love and Brad Cox in the early 1980s (a few moments earlier than C++). The syntax for objects and methods is based on Smalltalk. Objective-C method calls will be bound to functions at runtime with no need to be defined formally at compile time. Objective-C is organized in header and implementation files with `@interface` and `@implementation` sections for the declaration and definition of classes, properties, fields and operations. `@interface` must not be mixed up with the Java/C# `interface` directive. The latter one corresponds to `@protocol`.

Cocoa Touch

Cocoa Touch is the name for the object-oriented APIs for iOS (the operating system for iPhone and iPad). Cocoa Touch covers the platform specific Objective-C runtime and a platform specific set of libraries, the frameworks.

- The Foundation framework ~~it~~ provides the basis for programming with Objective-C. In addition to the memory and exception handling it includes the base classes for strings, values, lists, sets and files.

- The UIKit framework provides a set of classes and functions for implementing (touch based) graphical user interfaces. The architecture of this framework follows the Model-View-Controller pattern and the implementation provides a myriad of view and controller classes.

Memory Management

The Objective-C runtime does not offer – surprisingly for Java or C# developers – garbage collection, but dynamic memory management based on reference counting. The necessary retains and releases are added automatically at compile time. This has the consequence that (strong) object graphs must be implemented as directed acyclic graphs. Back references have to be declared as weak. Otherwise objects would never be released.

The disadvantage is that deallocated objects can still be referenced, which would corrupt the event loop, without the possibility of error recovery by exception handling. The advantages are the deterministic and economical run-time behavior. Objects are destroyed at a defined time and a separate thread for garbage collection isn't needed.

Development and distribution

Development and distribution for Apple's platforms includes the coding effort and expenses for administration and configuration. To install software on iOS devices – especially for distribution via the App Store – applications must be cryptographically signed. The necessary certificates are created in the paid members section on Apple's Developer Portal. Certificates, development and distribution profiles contain a bunch of identifiers for the identification and differentiation of developers (Team ID), applications (App-ID) and a list of permissions (entitlements).

4.1.2. Source Code Management

Every software project includes the need for source code management, which minimizes the risk of losing working code by human error or technical failure. This should be done by powerful, yet lightweight tools.

Git

Git is a distributed source code management and revision control system - originally developed by Linus Torvalds for Linux kernel development [1]. Git supports local repositories with full source code history for development. Local repositories can be synchronized and merged with remote repositories for collaboration and backup [4].

Since Apple's IDE Xcode works with Git's local repositories out of the box, it was obvious to use Git as source control for the project.

Github

GitHub [2] is a hosting service for projects that use Git. GitHub offers free accounts for public repositories, which can be seen and downloaded by anyone using a web-browser or a Git client. Committing changes is restricted to users chosen by the owner of the repository on GitHub.

As Nyaya is a student project and the source code should be publicly accessible, GitHub seemed suitable to house the project.

4.2. Project execution

4.2.1. Phases

Exploring UI capabilities

After the informal specification of the feature set and the initial presentation of the project the capabilities of graphical visualization and user interaction were explored on iPad. In this phase several prototypes were developed for interactive syntax ~~tress~~ and exercises.

Core components

After the formulation of the general concept with tutorials including exercices, a playground, a glossary, and the embedding of BoolTool, the main classes for the representation of abstract syntax trees and binary decision diagrams were implemented. After several attempts to cross-compile BoolTool's ocaml sources and to use the binaries on iPad, a left recursive descendent parser for input strings with the syntax propositional logic was implement in Objective-C.

Content, controllers, and configuration

Although the general concept was developed, content ~~was still missing~~. The tutorials had to be written and the exercises had to be generated. Content and configuration files had to be added to the project. The different views ~~has~~ to be controlled and the navigation between the different use cases had to be added.

4.2.2. Development model

The development of this software did no follow a specific development model, but did borrow some principles from agile development.

Test-driven development

Parsers, trees and operations on trees were the ideal application for test driven development. First, the expected results were defined in test cases, then the functionality was implemented. So it was ensured that ~~on~~ every point of the development cycle the core of the application was still working as defined, when all unit tests had succeeded.

Refactoring

Due occurring memory and performance issues on the iPad some implementations had to be reconsidered and some functionality had to be reimplemented. This could be done without ~~headaches~~ because the local repository provided a complete development history and unit tests provided a quick check, whether the reimplementation was correct.

Use cases

With the written concept (see chapter 3 on page 4) of an interactive environment for BoolTool that enables the learning of simple facts about propositional logic the collection of use cases was defined. These use cases represent the real value of the project and they mark the criterion for completion of development.

5. Implementation

5.1. Architecture

The general design of Nyāya follows the Model-View-Controller pattern, which is originated in Smalltalk [5, p.4], that separates the representation of data from the user interaction. Cocoa Touch (see 4.1.1 on page 15) encourages the use of MVC by providing a rich set of useful views and controllers with the framework UIKit. ~~Those~~ cover many use cases of data presentation and user interaction.

5.2. Model

Nyāya must hold different representations of Boolean functions – propositional formulas, abstract syntax trees and binary decision diagrams.

5.2.1. Propositional formulas and Boolean expressions

Since propositional formulas and Boolean expressions are subsets of the set of all Unicode strings, they are easily represented by the standard string classes of actual frameworks.

Due to the unambiguous relationship between propositional formulas and Boolean expressions Nyāya allows the use of a mixed syntax and additional symbols as input for the user's convenience. The input expression $!a \wedge b + c \oplus a$ translates into the propositional formula $\neg a \wedge b \vee c \veebar a$ (see 5.2.3 on page 24).

5.2.2. Abstract Syntax Trees

Cocoa does not provide a class to represent trees, but with instances of a class, that implements the composite pattern [5, p.163ff] arbitrary graphs and therefore syntax trees can be represented easily.

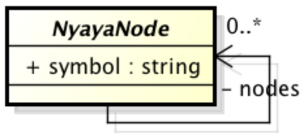


Figure 5.1.: Node class to represent an abstract syntax tree

Node class cluster

The node class is implemented as a class cluster, which is ~~an~~ Cocoa design pattern [3, p.282ff] – an ~~adaption~~ of the the abstract factory design pattern [5, p.87ff]. The abstract and public class `NyayaNode` provides a set of static and public methods (see figure 5.3 on the facing page), that returns instances of non public sub-classes (see figure 5.2) of `NyayaNode`.

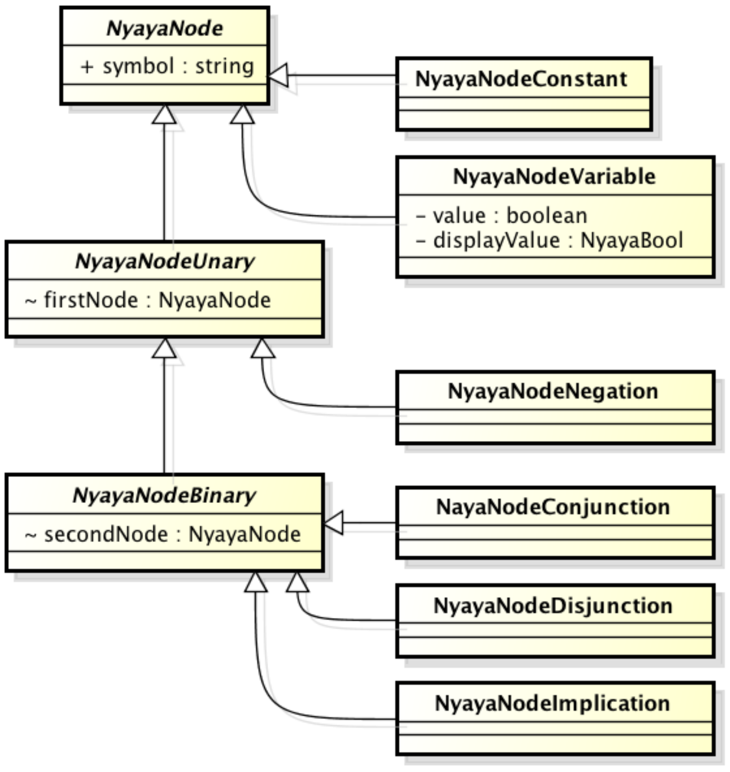


Figure 5.2.: Public root class and non public subclasses

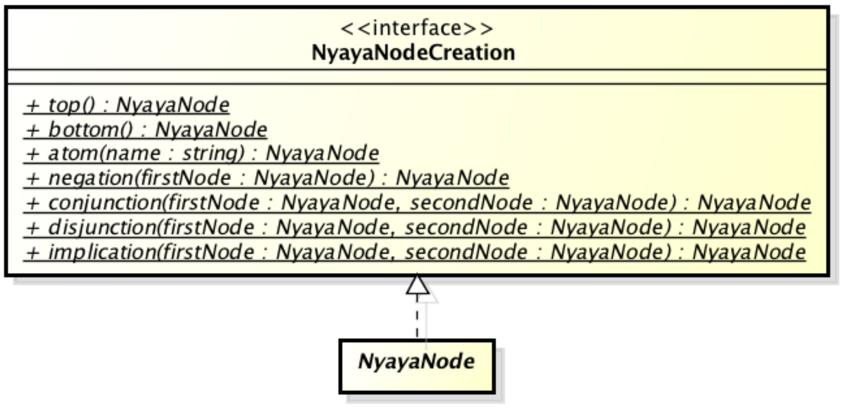
~~Actual~~ the creational methods were implemented as a class category in a different source file. Class categories are a language feature of Objective-C [7, p.225ff] – an ~~adaption~~ of the decorator design pattern [5, p.175ff] – to extend or organize the functionality of given classes beyond their core purpose.

There are base implementations of category methods in the root node class, that will be overridden in subclasses. For example `isLiteral:bool` returns false for all node instances except for instances of variables and instances of negations of variables.

The variable node class adds setters for the categories `Valuation` (figure 5.4 on page 22) and `Display`.

Node class categories

- The category “Creation” implements the production rules of the grammar to create syntax trees recursively (figure 5.3). Since the constructors of all classes in the cluster are hidden, the production of invalid syntax trees is prevented.



<<interface>>
NyayaNodeCreation
+ top() : NyayaNode
+ bottom() : NyayaNode
+ atom(name : string) : NyayaNode
+ negation(firstNode : NyayaNode) : NyayaNode
+ conjunction(firstNode : NyayaNode, secondNode : NyayaNode) : NyayaNode
+ disjunction(firstNode : NyayaNode, secondNode : NyayaNode) : NyayaNode
+ implication(firstNode : NyayaNode, secondNode : NyayaNode) : NyayaNode
NyayaNode

Figure 5.3.: Production rules

- The category “Description” provides methods to convert a syntax tree into one of it’s string representations – either a propositional formula in strict syntax with many parentheses or a formula using precedences and associativity. In most cases, the second form leads to shorter strings with less parentheses. In rare case, only the outer parentheses are omitted.

- The category “Display” allows extended valuations (undefined, false, true) with incomplete truth assignments. It is used for the interactive syntax tree view on the playground, where the user can assign truth values to some or all atoms.

- The category “Attributes” provides information about the number of sub-nodes of a node and the normal forms the sub-tree matches.

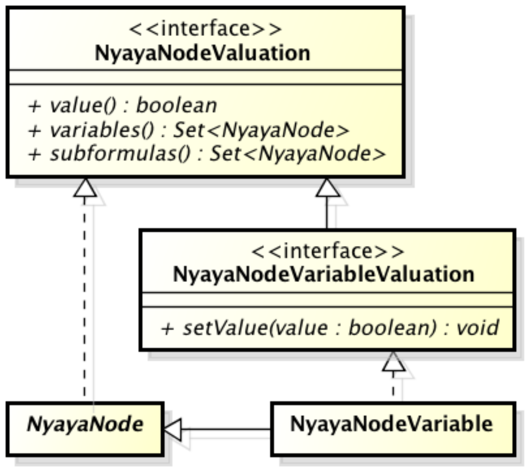
- The category “Transformations” provides equivalence transformations and methods to create semantically different syntax trees by replacing atoms, connectives or sub-trees with atoms, connectives or trees.

- The category “Derivations” defines methods to derive semantically equivalent normal forms from a given syntax tree.

- The category “Random” creates arbitrary syntax trees with a given set of connectives and atoms and within a range for the number of nodes. It is used to create formulas for the exercises.

- The category “Type” provides ~~one~~ method, that returns the type of a node, i.e constant, variable, type of connective as an enum.

- The category “Valuation” (figure 5.4) provides fast valuations with complete truth assignments. It is used to create truth tables and binary decision diagrams.



<<interface>>
NyayaNodeValuation
+ value() : boolean
+ variables() : Set<NyayaNode>
+ subformulas() : Set<NyayaNode>
<<interface>>
NyayaNodeVariableValuation
+ setValue(value : boolean) : void
NyayaNode
NyayaNodeVariable

Figure 5.4.: Valuation of trees

Immutable syntax trees

Instances of node classes are not mutable regarding their function as nodes of abstract syntax trees. This means nodes can be created, but not modified. The symbol of an atom can not be changed, a connective node can not be altered into ~~an other~~ one, and child nodes of a connective node can not be replaced or reordered.

Derivations or transformations do not change the structure of an existing syntax tree, but rather create a new independent syntax tree.

Obviously mutable truth assignments ~~does~~ not affect the immutable structure of a syntax tree, because truth assignments are semantics, not syntax.

Acyclic syntax graphs

Since the representation of abstract syntax trees is implemented immutable, there is no need to create multiple instances for syntactically equivalent sub-trees. At run-time syntax trees are represented by acyclic syntax graphs, where multiple sub-trees can be represented by the same instance-graph (figure 5.5 on the next page).

This eases the detection of obvious tautologies $P \vee \neg P$, $P \rightarrow P$ and contradictions $P \wedge \neg P$, because the sub-tree P on the left side is represented by the same object-graph as the sub-tree P on the right side.

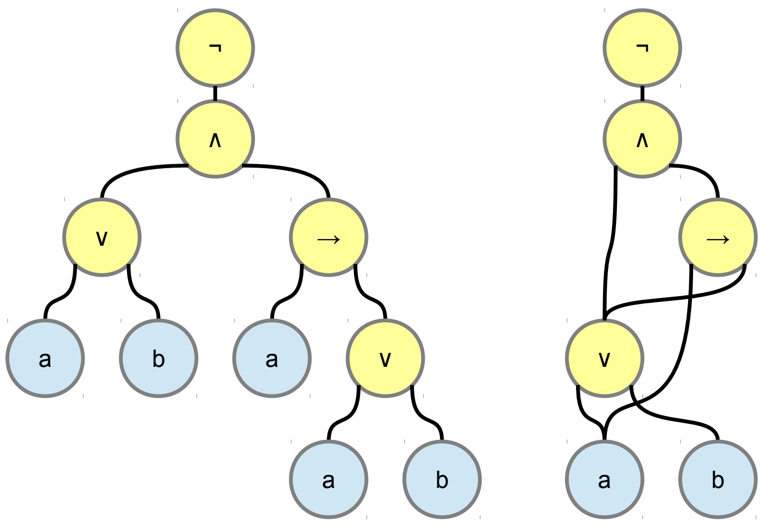


Figure 5.5.: Abstract syntax tree – acyclic graph
$\neg((a \vee b) \wedge (a \rightarrow a \vee b))$

Limitations

The derivation of normal forms will fail on some relatively small syntax trees. especially when the formula contains too many exclusive disjunctions.

With every exclusive disjunction of a formula P and an atom p, that is not already used in P, the number of nodes will at least double when deriving an equivalent implication free form. “Implication free” means also the absence of exclusive disjunctions (see table 3.8 on page 9).

$$\begin{aligned}
\#(P \oplus p) &= 1 \cdot (\#(P) + 2) \\
\#((P \wedge \neg p) \vee (\neg P \wedge p)) &= 2 \cdot (\#(P) + 2) + 3 \\
\#((P \vee p) \wedge (\neg P \vee \neg p)) &= 2 \cdot (\#(P) + 2) + 3
\end{aligned}$$

The syntax tree for an exclusive disjunction of 20 different atoms is build from 39 nodes. The syntax tree of a semantically equivalent implication free form will already contain over four million nodes. Deriving the negation normal form does not increase or decrease the number of nodes significantly, but the necessary distributions of disjunctions will multiply the number of nodes again.

To ensure the s[illegible]ity of Nyāya and since it is near impossible to present a propositional formulas with thousands of symbols to the user in a meaningful way, the derivation of normal forms is aborted, when the results surpass a defined size.

5.2.3. Parser

The backend of `BoolTool`[1] – parsing and transformation of Boolean functions – is implemented in `OCaml`[2], a functional programming language, which is well suited for this kind of task.

After several failed attempts to cross-compile the `OCaml` sources to iPad's processor architecture (ARM), to link the object code to the Xcode project and to bridge and call functions from C, the implementation of a simple translator for propositional formulas (a subset of all possible strings) into syntax trees looked more promising.

The generation of a syntax tree from a formula is carried out in two steps.

Scanning

In the first step the input string is transformed into an array of strings – the list of input tokens – using the standard regular expression class of Cocoa Foundation.

$$\top|\bot|\neg|!|\wedge|\&|.|\vee|\backslash||\backslash+|\veebar|\oplus|\hat{}|=|<>|\leftrightarrow|>|\rightarrow|\models|(|)|,|;|\backslash w+$$

Table 5.1.: Regular expression for the scanner

The set of valid tokens, which includes identifiers, connectives and parentheses was simply defined by writing a suitable regular expression (see table 5.1),

Parsing

In the second step the list of input tokens is parsed top-down using a recursive-descent parsing algorithm [8, p.144ff] following an ebnf grammar outlined in table 5.2~~)~~, that defines precedence and associativity of connectives too.

```
formula       ::= entailment
entailment    ::= sequence [ '⊨' entailment]
sequence      ::= bicondition { ';' bicondition }
bicondition   ::= implication [ '↔' bicondition ]
implication   ::= xdisjunction [ '→' implication ]
xdisjunction  ::= disjunction { '⊻' disjunction }
disjunction   ::= conjunction { '∨' conjunction }
conjunction   ::= negation { '∧' negation }
negation      ::= '¬' negation | '(' formula ')' | identifier
```

Table 5.2.: Core EBNF grammar for the parser

[1] cl-informatik.uibk.ac.at/software/booltool/
[2] ocaml.org

Limitations

Nyāya does not parse as fast and (memory) efficient as BoolTool's parser, primarily because recursion and token probing are more expansive operations in Objective-C than in OCaml. The creation of a syntax graph instead of ~~an~~ syntax tree adds more overhead. But Nyāya's implementation is *good enough*, because *real world* user input is limited to at most few thousands characters.

Unit tests ~~has~~ shown that the there are no memory or run-time issues, although the parsing can take a second or two on an iPad.

Enhancements

Despite the drawbacks mentioned above the benefits far outweigh the disadvantages of implementing ~~an~~ own parser.

- Nyāya parses strings with Unicode characters, therefore identifiers are not limited to Latin letters and $\alpha + \omega$ will be parsed correctly.
- The grammar rules for operators are defined as sets of tokens, which will be initialized at application start.

```
disjunction   ::= conjunction { OR conjunction }

OR             ::= '∨' | '|' | '+' | 'O'
```

Table 5.3.: Excerpts from a localized grammar (Italian)

- Symbols for operators can be localized using the standard localization framework of Cocoa.

```
IMP = "→ > IMPLIES";          IMP = "→ > IMPLICA";
OR  = "∨ | + OR";             OR  = "∨ | + O";
AND = "∧ & . AND";            AND = "∧ & . E";
NEG = "¬ ! ~ NOT";            NEG = "¬ ! ~ NON";
```

Table 5.4.: Localizable.strings in en.lproj and it.lproj

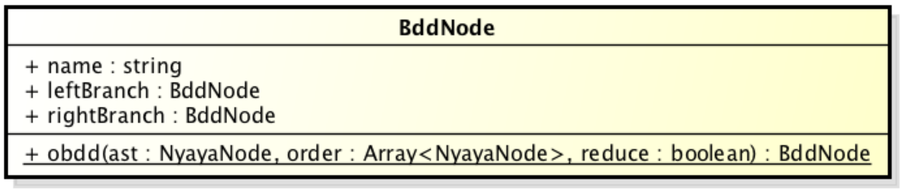
- The parser generates syntax graphs with ~~objective-c~~ run-time objects, which are well suited for the use cases in an interactive environment.

5.2.4. Truth Tables

Truth tables are either small enough to be computed on demand or too big to be stored in memory. Either way there is ~~not~~ reason to store filled truth tables at run-time.

5.2.5. Binary Decision Diagrams

Binary decision trees and diagrams are represented by trees or acyclic directed graphs built from instances of a simple node class with attributes for a name, a left branch and a right branch. The name is either an identifier, i.e. the name



```
BddNode
+ name : string
+ leftBranch : BddNode
+ rightBranch : BddNode
+ obdd(ast : NyayaNode, order : Array<NyayaNode>, reduce : boolean) : BddNode
```

Table 5.5.: Attributes and factory method of BddNode

of a variable, “0” or “1". Nodes with the name “0” or “1” are leaf nodes or result nodes and must not have a left or right branch. The other nodes with the name of a variable are decision nodes and must have valid left and right branches.

The class provides a factory method to create (un)reduced ordered binary decision diagrams from abstract syntax trees (figure 5.5).

5.3. Views and Controllers

Nyāya's main navigation – switching between Welcome, Tutorials, Playground, Glossary and NyBoolTool – is organized by a sub-class of `UITabBarController` (an heir of `UIViewController`). At start the tab bar controller will be instantiated and invoked by Nyāya's application delegate. The tab bar controller will present it's `UITabBar` (an heir of `UIView`) and will appoint of one of ~~it's~~ view controllers, which will present ~~it's~~ view such as the welcome screen.

Tabbing an `UITabBarItem` will cause the tab bar to delegate the event to ~~it's~~ `UITabBarDelegate` – the tab bar controller. The tab bar controller will switch the selected view controller, which then will present ~~it's~~ content.

Except for the welcome view controller all content view controllers inherits from split view controller, which provides a master view controller and a detail view controller. The tutorial master view controller and the BoolTool master view controller shares a list of persisted formulas.

5.3.1. Welcome

The welcome view controller is simple subclass of `UIViewController` and presents ~~it's~~ content in ~~an~~ not so simple `UIWebView`, which is a fully functional, but 'naked' web-browser, i.e. links are followed and there is a page history, but no back-button is presented. The behavior of the web view can be altered by implementing a web view delegate – usually the controller.

5.3.2. Tutorials

The tutorials master view controller presents a table view with five sections of tutorials. The sections organize the tutorial titles for introduction, syntax, semantics, normal forms and binary decision diagrams. Tabbing an entry will cause the detail view controller to present the corresponding tutorial in a web view with an additional exercise button on the top of the view.

Tabbing this exercise button will put the exercise view controller in charge. ~~An~~ suitable overlay view will be opened, and an instance of a matched class implementing of `NyTuTester` will be created.

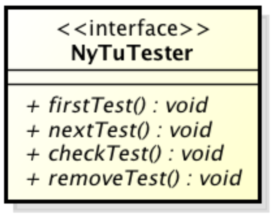


Figure 5.6.: Tester interface

The method `firstTest` initializes the test parameters and fills the test view with instructions and labels. Then it calls `nextTest`, which will fill the test view with a new question by every call. The method `checkTest` evaluates the user's answer and displays the result in the test view. When the test view is closed by the user `removeTest` will dispose resources attached to the test view.

5.3.3. Playground

The playground master view controller presents a table view with the list of stored and selectable formulas. The user can use a formula in this list to add a tree view to the detail view – the canvas view. Or the user can add a new tree view by an tap and hold gesture to the canvas view. The canvas view can hold multiple syntax trees.

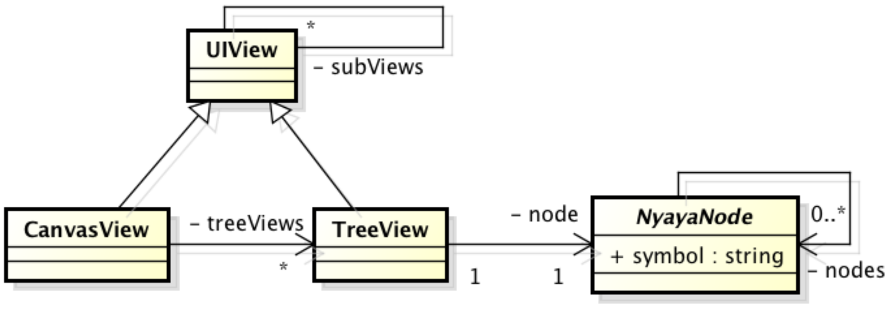


Figure 5.7.: Canvas view with multiple syntax tree views

The nodes of the syntax tree view are drawn as circles around `symbol()` method defined in the category `Display` of the class `NyayaNode`.. The color of the border is determined by the value of `displayValue()`.

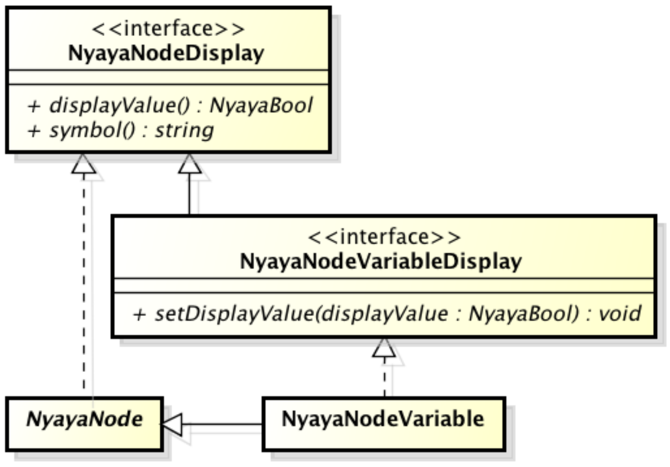


Figure 5.8.: Node display interface

5.3.4. Glossary

The glossary master view controller reads all elements with an id from the glossary content document, creates an ~~alphabetical~~ ordered list of technical terms using the texts included between the corresponding element-tags. This list of technical terms defined by the glossary document is presented in a table view. Tapping a term will scroll the glossary document view – a web view - to the chosen term, controlled by the glossary detail view controller.

5.3.5. BoolTool

The BoolTool master view controller presents a table view with stored and selectable formulas. An editable text field with an attached customized keyboard will allow the user to enter their formulas.

The output will be presented in different views. Read only text views are used for the normal form, a web form is used for the truth table and a customized view will draw the binary decision diagram.

5.4. Application content

Beside the classes to determine~~s~~ the run-time behavior of the application, the storage of application content must be defined.

5.4.1. Content on delivery

Configuration data, localization data and html documents are stored in UTF-8 encoded text files. All graphical content such as icons and diagrams are stored in portable network graphics. These content files are embedded in Nyāya's app bundle and will be downloaded along the application execution data, while receiving Nyāya for iPad from the App Store.

5.4.2. User created content

Formulas from the playground and BoolTool are persisted in the simple property list file `BoolToolData` in the documents folder of the app.

5.4.3. Export and import of content

Single formulas can be exported from or imported ~~in~~to editable text fields by ~~simple~~ using the standard copy and paste mechanism of iOS.

6. Retrospective

The first version of Nyāya is a fully functional eLearning App, which covers ~~it’s~~ purpose well. But it is still far from perfect. Some features have to be re-engineered before additional features can be implemented.

6.1. Important improvements

Although some technical aspects of Nyāya are working correctly, they need a revision, because they are too inflexible or too slow.

- At this time content updates can only be done with an application update in the App Store, which will lead to some delay in the distribution of the correction of typing errors or an update of the glossary.
- Syntax trees are stored memory optimized as acyclic syntax diagrams. Nevertheless the valuation does not use this fact and the same sub-tree will be evaluated multiple times.
- The creation of binary decision diagrams is very slow for formulas with more than 15 different atoms.
- Individual formulas can be imported and exported with the clipboard-mechanism of iOS. But this should also be possible with all persisted formulas at once.

Some aspects of Nyāya~~-~~’s user interface does not use the full richness of Cocoa touch. Others lack the graphical sophistication that users are accustomed on the iOS platform.

- Accessibility features of iOS have to be supported – especially `VoiceOver`, `Zoom`, `LargeText` and `AssistiveTouch`, which will enable Nyāya to reach a wider audience.
- Although English is the technical language of computer science, localizations of the user interface, the tutorials and the glossary will increase the reachable audience ~~too~~.
- Content and user interface should be presented in a visually more appealing manner. ~~For the first~~ css-definitions should be developed, ~~for the second~~ additional images have to be created.

6.2. Outlook

To increase the number of potential users Nyāya could be extended with new ~~feature~~ or Nyāya could be ported to other platforms.

6.2.1. Additional features

~~Even~~ it is unlikely the following features will be implemented in the foreseeable future, the following use cases would be obvious evolutions for Nyāya.

- Creation and editing of arbitrary binary decision diagrams similar to abstract syntax trees.
- Definition of arbitrary Boolean functions with truth tables, propositional formulas, abstract syntax trees or binary decision diagrams.
- Syntax ~~tree~~, truth tables and binary decision diagrams should be exportable too.

6.2.2. Additional platforms

The author of Nyāa is an apologist of native client applications, although he admits that ~~they~~ are many useful use cases for modern web-applications, using html5, css3 and JavaScript. Unfortunately the freely available development tool chains for (graphical) html/javascript-applications are very limited and far from consolidated, although the underlining standards~~-~~html5, css3 and JavaScript 1.8 would provide ~~anything~~ needed, the workload to create sophisticated web-apps is much higher than to develop native apps on the same level.

So the most likely platforms to ~~be~~ support~~ed by~~ Nyāya are Mac OS X and Android.

- For a Mac OS X version some aspects of the user interface must be rethought and re-implemented, because Mac OS X does not support a touch interface.
- For an Android version the model must be translated into Java and the user interface must be re-implemented.

7. Conclusion and Summary

Besides the work as .NET developer for administrative tools of a payment system, the software project Nyāya for iPad was a welcome diversion. Coping ~~an entire~~ different platform and mastering the memory restrictions and the very limited cpu speed of an original iPad (in comparsion to a modern pc) were exciting tasks.

List of Figures

List of Tables

Bibliography

[1] *Git.* `http://git-scm.com`, Nov 2012.

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A. Symbols

Name	Atom	Negation	Conjunction	Disjunction	Implication
		NOT	AND	OR	
ASCII	p,q,r	!	& .	| +	>
Symbol		$\neg$	$\wedge$	$\vee$	$\rightarrow$
UTF-8		C2 AC	E2 88 A7	E2 88 A8	E2 86 92
Unicode		U+00AC	U+2227	U+2228	U+2192
HTML		&not;	&and;	&or;	&rarr;
LaTeX		`\neg`	`\wedge`	`\vee`	`\rightarrow`

Table A.1.: basic symbols in different representations

Tautology	Contradiction	Exclusive Disjunction		Biconditional
TOP	BOTTOM	EOR	XOR	IFF
T 1	F 0	^		<>
$\top$	$\bot$	$\veebar$	$\oplus$	$\leftrightarrow$
E2 8A A4	E2 8A A5	E2 8A BB	E2 8A 95	E2 86 94
U+22A4	U+22A5	U+22BB	U+2295	U+2194
	&perp;		&oplus;	&harr;
`\top`	`\bot`	`\veebar`	`\oplus`	`\leftrightarrow`

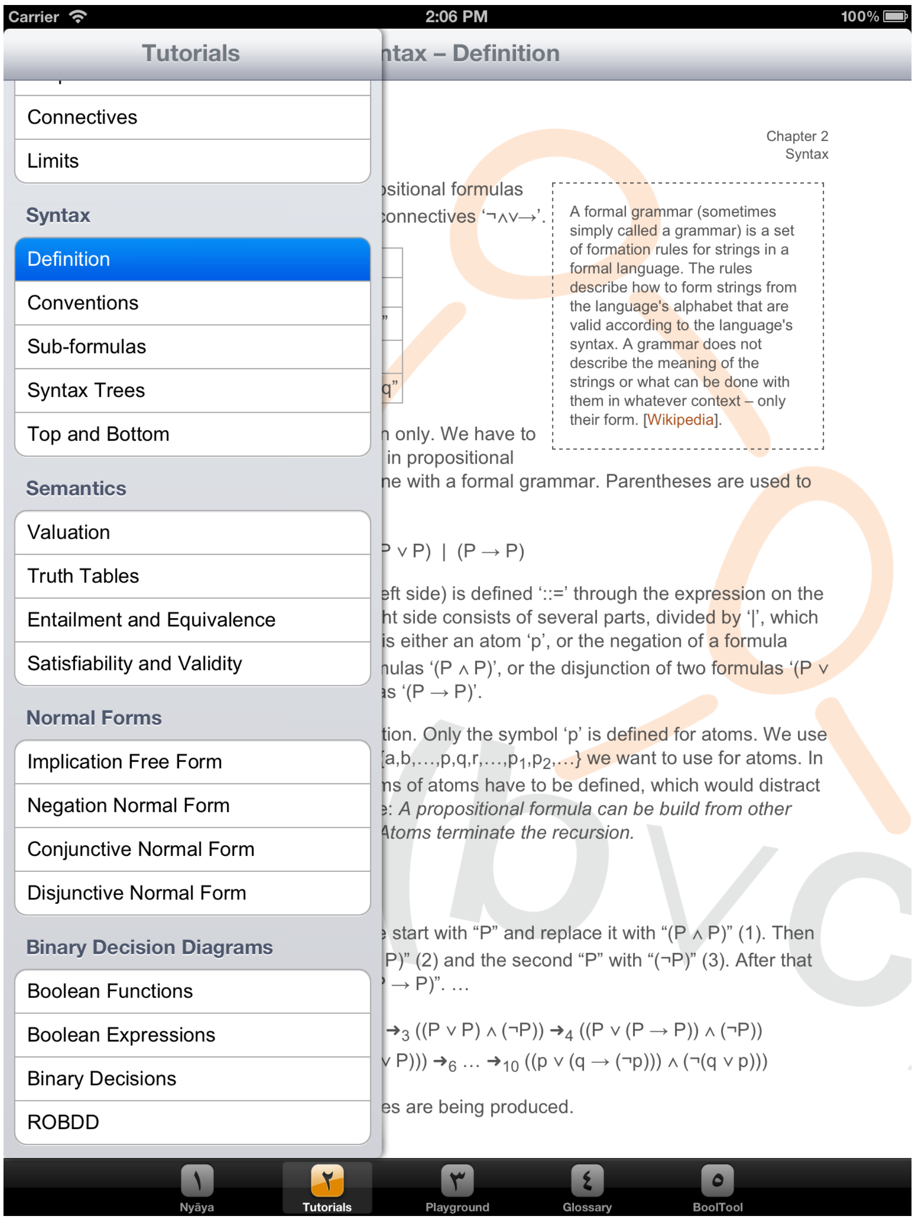
Table A.2.: additional symbols

B. Definitions

```
<!ENTITY % plistObject "(array␣|␣data␣|␣date␣|␣dict␣|␣real␣|␣
    integer␣|␣string␣|␣true␣|␣false␣)" >
<!ELEMENT plist %plistObject;>
<!ATTLIST plist version CDATA "1.0" >

<!-- Collections -->
<!ELEMENT array (%plistObject;)*>
<!ELEMENT dict (key, %plistObject;)*>
<!ELEMENT key (#PCDATA)>

<!--- Primitive types -->
<!ELEMENT string (#PCDATA)>
<!ELEMENT data (#PCDATA)>
    <!-- Contents interpreted as Base-64 encoded -->
<!ELEMENT date (#PCDATA)>
    <!-- Contents should conform to a subset of ISO 8601 (in
        particular, YYYY ’-’ MM ’-’ DD ’T’ HH ’:’ MM ’:’ SS ’Z’.
        Smaller units may be omitted with a loss of precision) -->

<!-- Numerical primitives -->
<!ELEMENT true EMPTY> <!-- Boolean constant true -->
<!ELEMENT false EMPTY> <!-- Boolean constant false -->
<!ELEMENT real (#PCDATA)>
    <!-- Contents should represent a floating point number
        matching ("+" | "-")? d+ ("."d*)? ("E" ("+" | "-") d+)?
        where d is a digit 0-9. -->
<!ELEMENT integer (#PCDATA)>
    <!-- Contents should represent a (possibly signed) integer
        number in base 10 -->
```

Table B.1.: PropertyList-1.0.dtd

C. Screenshots



Chapter 2
Syntax

ositional formulas
connectives ‘¬∧∨→’.

A formal grammar (sometimes simply called a grammar) is a set of formation rules for strings in a formal language. The rules describe how to form strings from the language's alphabet that are valid according to the language's syntax. A grammar does not describe the meaning of the strings or what can be done with them in whatever context – only their form. [Wikipedia].

”

q”

n only. We have to
in propositional
ne with a formal grammar. Parentheses are used to

P ∨ P) | (P → P)

eft side) is defined ‘::=’ through the expression on the
ht side consists of several parts, divided by ‘|’, which
is either an atom ‘p’, or the negation of a formula
nulas ‘(P ∧ P)’, or the disjunction of two formulas ‘(P ∨
as ‘(P → P)’.

tion. Only the symbol ‘p’ is defined for atoms. We use
{a,b,…,p,q,r,…,p_1,p_2,…} we want to use for atoms. In
ns of atoms have to be defined, which would distract
e: *A propositional formula can be build from other*
Atoms terminate the recursion.

e start with “P” and replace it with “(P ∧ P)” (1). Then
P)” (2) and the second “P” with “(¬P)” (3). After that
P → P)”. …

$\rightarrow_3$ ((P ∨ P) ∧ (¬P)) $\rightarrow_4$ ((P ∨ (P → P)) ∧ (¬P))
∨ P))) $\rightarrow_6$ … $\rightarrow_{10}$ ((p ∨ (q → (¬p))) ∧ (¬(q ∨ p)))

es are being produced.

Figure C.1.: Tutorial

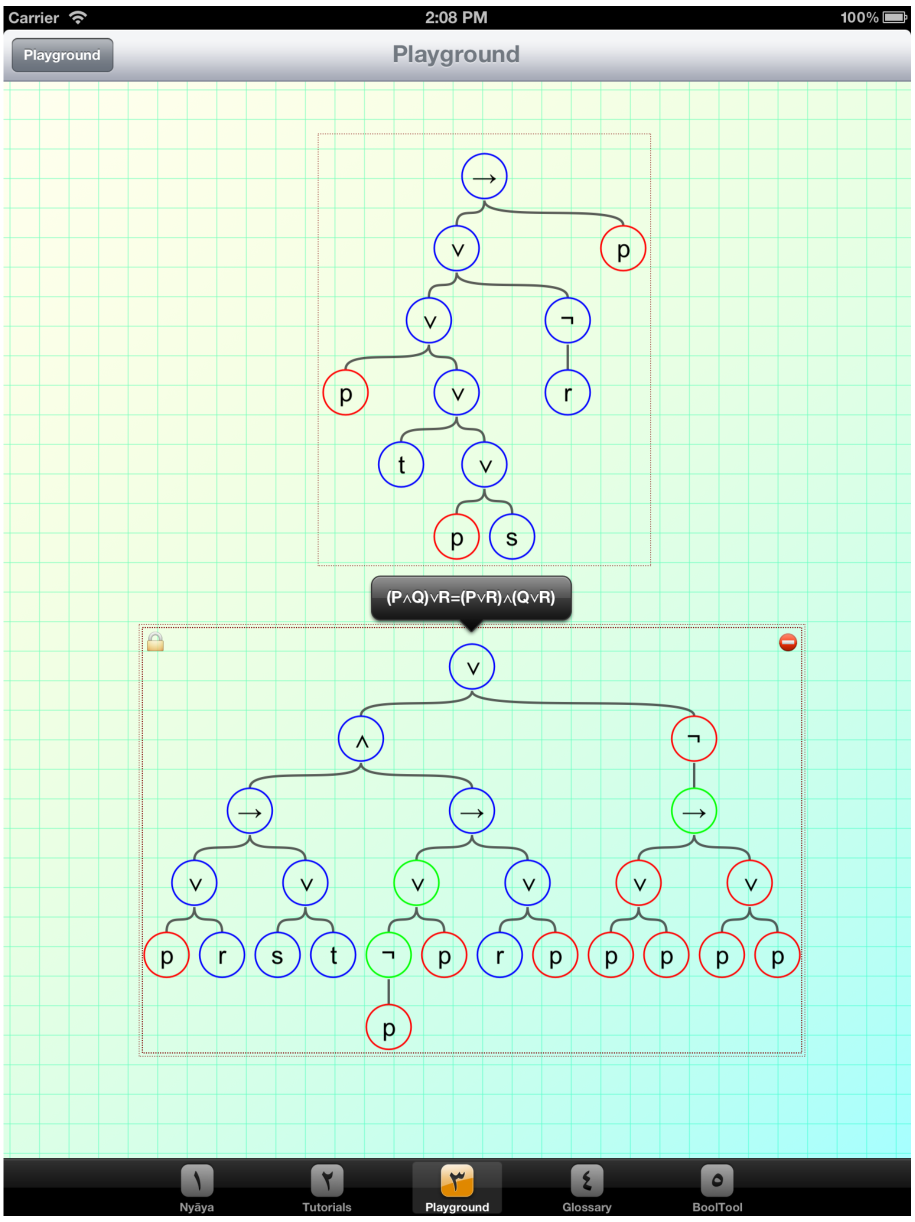
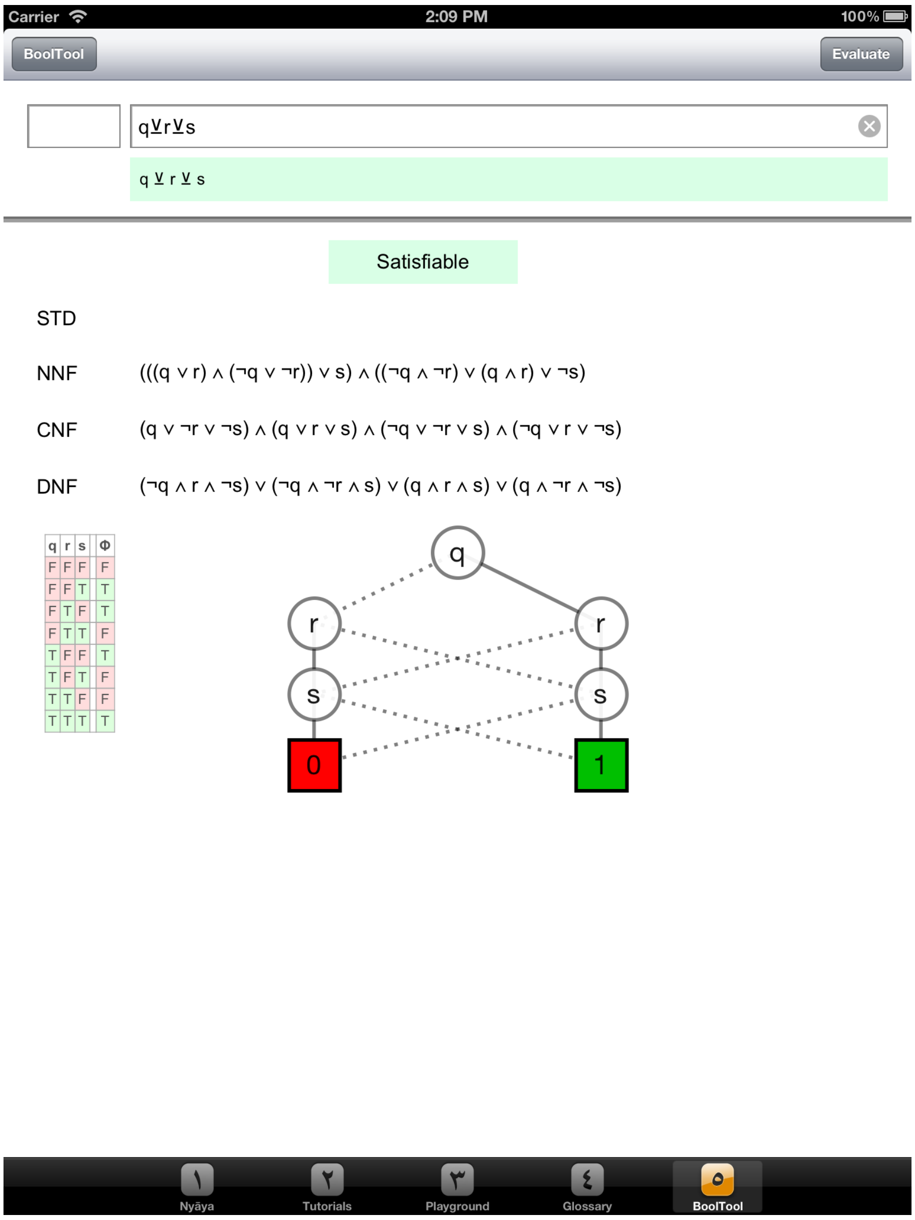


Figure C.2.: Playground



q⊻r⊻s

q ⊻ r ⊻ s

Satisfiable

STD

NNF (((q ∨ r) ∧ (¬q ∨ ¬r)) ∨ s) ∧ ((¬q ∧ ¬r) ∨ (q ∧ r) ∨ ¬s)

CNF (q ∨ ¬r ∨ ¬s) ∧ (q ∨ r ∨ s) ∧ (¬q ∨ ¬r ∨ s) ∧ (¬q ∨ r ∨ ¬s)

DNF (¬q ∧ r ∧ ¬s) ∨ (¬q ∧ ¬r ∧ s) ∨ (q ∧ r ∧ s) ∨ (q ∧ ¬r ∧ ¬s)

q	r	s		Φ
F	F	F		F
F	F	T		T
F	T	F		T
F	T	T		F
T	F	F		T
T	F	T		F
T	T	F		F
T	T	T		T

Figure C.3.: BoolTool