

## *Preface*

These slides are a summary of the the book's Preface:

- the subject of formal language theory;
- the Forlan Project;
- overview of book.

## *Background*

Since the 1930s, the subject of formal language theory has been developed by computer scientists, linguists and mathematicians.

## *Background*

Since the 1930s, the subject of formal language theory has been developed by computer scientists, linguists and mathematicians. Formal languages are sets of strings over finite sets of symbols, called alphabets,

## *Background*

Since the 1930s, the subject of formal language theory has been developed by computer scientists, linguists and mathematicians.

Formal languages are sets of strings over finite sets of symbols, called alphabets, and languages can be described by

- regular expressions (which “generate” languages),
- finite automata (which “accept” languages),
- grammars (which “generate” languages) and
- Turing machines (which “accept” languages).

## *Background*

Since the 1930s, the subject of formal language theory has been developed by computer scientists, linguists and mathematicians.

Formal languages are sets of strings over finite sets of symbols, called alphabets, and languages can be described by

- regular expressions (which “generate” languages),
- finite automata (which “accept” languages),
- grammars (which “generate” languages) and
- Turing machines (which “accept” languages).

The set of identifiers of a programming language is a formal language—one that can be described by a regular expression or a finite automaton.

## *Background*

Since the 1930s, the subject of formal language theory has been developed by computer scientists, linguists and mathematicians.

Formal languages are sets of strings over finite sets of symbols, called alphabets, and languages can be described by

- regular expressions (which “generate” languages),
- finite automata (which “accept” languages),
- grammars (which “generate” languages) and
- Turing machines (which “accept” languages).

The set of identifiers of a programming language is a formal language—one that can be described by a regular expression or a finite automaton.

The set of all strings of tokens that are generated by a programming language’s grammar is another example of a formal language.

## *Background (Cont.)*

Because of its applications, computer science programs typically offer undergraduate and graduate courses in this subject.

## *Background (Cont.)*

Because of its applications, computer science programs typically offer undergraduate and graduate courses in this subject.

- Applications to compiler construction:
  - Regular expressions and finite automata used when specifying and implementing lexical analyzers;
  - Grammars used to specify and implement parsers.



## *Background (Cont.)*

Because of its applications, computer science programs typically offer undergraduate and graduate courses in this subject.

- Applications to compiler construction:
  - Regular expressions and finite automata used when specifying and implementing lexical analyzers;
  - Grammars used to specify and implement parsers.
- Finite automata used when designing hardware and network protocols.

## *Background (Cont.)*

Because of its applications, computer science programs typically offer undergraduate and graduate courses in this subject.

- Applications to compiler construction:
  - Regular expressions and finite automata used when specifying and implementing lexical analyzers;
  - Grammars used to specify and implement parsers.
- Finite automata used when designing hardware and network protocols.
- Turing machines used to formalize the notion of algorithm—enabling study of what is, and is not, computable.

## *Background (Cont.)*

Formal language theory largely concerned with algorithms, both ones that are explicitly presented, and ones implicit in theorems that are proved constructively.

## *Background (Cont.)*

Formal language theory largely concerned with algorithms, both ones that are explicitly presented, and ones implicit in theorems that are proved constructively.

Typically, students apply these algorithms to toy examples by hand, and learn how they are used in applications.

## *Background (Cont.)*

Formal language theory largely concerned with algorithms, both ones that are explicitly presented, and ones implicit in theorems that are proved constructively.

Typically, students apply these algorithms to toy examples by hand, and learn how they are used in applications.

Students would obtain a deeper understanding if they could experiment with the algorithms using computer tools.

## *Background (Cont.)*

Consider, e.g., an exercise in which students are asked to synthesize a deterministic finite automaton that accepts some language,  $L$ .

## *Background (Cont.)*

Consider, e.g., an exercise in which students are asked to synthesize a deterministic finite automaton that accepts some language,  $L$ .

- Conventionally, a student builds machine by hand, then proves it correct.

## *Background (Cont.)*

Consider, e.g., an exercise in which students are asked to synthesize a deterministic finite automaton that accepts some language,  $L$ .

- Conventionally, a student builds machine by hand, then proves it correct.
- But given right computer tools, another approach possible.



## *Background (Cont.)*

Consider, e.g., an exercise in which students are asked to synthesize a deterministic finite automaton that accepts some language,  $L$ .

- Conventionally, a student builds machine by hand, then proves it correct.
- But given right computer tools, another approach possible.
- First, express  $L$  in terms of simpler languages, making use of various language operations.

## *Background (Cont.)*

Consider, e.g., an exercise in which students are asked to synthesize a deterministic finite automaton that accepts some language,  $L$ .

- Conventionally, a student builds machine by hand, then proves it correct.
- But given right computer tools, another approach possible.
- First, express  $L$  in terms of simpler languages, making use of various language operations.
- Next synthesize automata for those languages, and combine machines using corresponding operations.

## *Background (Cont.)*

Consider, e.g., an exercise in which students are asked to synthesize a deterministic finite automaton that accepts some language,  $L$ .

- Conventionally, a student builds machine by hand, then proves it correct.
- But given right computer tools, another approach possible.
- First, express  $L$  in terms of simpler languages, making use of various language operations.
- Next synthesize automata for those languages, and combine machines using corresponding operations.
- Finally, minimize resulting machine.

## *Integrating Experimentation and Proof*

To support experimentation with formal languages, I designed and implemented a computer toolset called Forlan.

## *Integrating Experimentation and Proof*

To support experimentation with formal languages, I designed and implemented a computer toolset called Forlan.

Forlan is implemented in the functional programming language Standard ML (SML), a language whose notation and concepts are similar to those of mathematics.

## *Integrating Experimentation and Proof*

To support experimentation with formal languages, I designed and implemented a computer toolset called Forlan.

Forlan is implemented in the functional programming language Standard ML (SML), a language whose notation and concepts are similar to those of mathematics.

Forlan is an extension of the Standard ML of New Jersey (SML/NJ) implementation of SML.

## *Integrating Experimentation and Proof*

To support experimentation with formal languages, I designed and implemented a computer toolset called Forlan.

Forlan is implemented in the functional programming language Standard ML (SML), a language whose notation and concepts are similar to those of mathematics.

Forlan is an extension of the Standard ML of New Jersey (SML/NJ) implementation of SML.

It's used interactively, and users are able to extend Forlan by defining SML functions.

## *Integrating Experimentation and Proof (Cont.)*

In Forlan, the objects of formal language theory—finite automata, regular expressions, etc.—are defined as abstract types, and have concrete syntax.



## *Integrating Experimentation and Proof (Cont.)*

In Forlan, the objects of formal language theory—finite automata, regular expressions, etc.—are defined as abstract types, and have concrete syntax.

Instead of Turing machines, Forlan implements a simple functional programming language of equivalent power but that's easier to program in.

## *Integrating Experimentation and Proof (Cont.)*

In Forlan, the objects of formal language theory—finite automata, regular expressions, etc.—are defined as abstract types, and have concrete syntax.

Instead of Turing machines, Forlan implements a simple functional programming language of equivalent power but that's easier to program in.

Forlan includes the Java program JForlan, a graphical editor for finite automata and regular expression, parse and program trees.

## *Integrating Experimentation and Proof (Cont.)*

Forlan implements:

- conversions between regular expressions and different kinds of automata,

## *Integrating Experimentation and Proof (Cont.)*

Forlan implements:

- conversions between regular expressions and different kinds of automata,
- the usual operations (e.g., union) on regular expressions, automata and grammars,

## *Integrating Experimentation and Proof (Cont.)*

Forlan implements:

- conversions between regular expressions and different kinds of automata,
- the usual operations (e.g., union) on regular expressions, automata and grammars,
- equivalence testing and minimization of deterministic finite automata,

## *Integrating Experimentation and Proof (Cont.)*

Forlan implements:

- conversions between regular expressions and different kinds of automata,
- the usual operations (e.g., union) on regular expressions, automata and grammars,
- equivalence testing and minimization of deterministic finite automata,
- a general parser for grammars,

## *Integrating Experimentation and Proof (Cont.)*

Forlan implements:

- conversions between regular expressions and different kinds of automata,
- the usual operations (e.g., union) on regular expressions, automata and grammars,
- equivalence testing and minimization of deterministic finite automata,
- a general parser for grammars,
- tentative algorithms for simplifying regular expressions,

## *Integrating Experimentation and Proof (Cont.)*

Forlan implements:

- conversions between regular expressions and different kinds of automata,
- the usual operations (e.g., union) on regular expressions, automata and grammars,
- equivalence testing and minimization of deterministic finite automata,
- a general parser for grammars,
- tentative algorithms for simplifying regular expressions,
- the functional programming language used instead of Turing machines.



## *Integrating Experimentation and Proof (Cont.)*

The introductory textbook on formal language theory *Formal Language Theory: Integrating Experimentation and Proof* is based on Forlan.

## *Integrating Experimentation and Proof (Cont.)*

The introductory textbook on formal language theory *Formal Language Theory: Integrating Experimentation and Proof* is based on Forlan.

I have attempted to keep the conceptual and notational distance between the textbook and toolset as small as possible.

## *Integrating Experimentation and Proof (Cont.)*

The introductory textbook on formal language theory *Formal Language Theory: Integrating Experimentation and Proof* is based on Forlan.

I have attempted to keep the conceptual and notational distance between the textbook and toolset as small as possible.

Book treats concepts and algorithms both theoretically, especially using proof, and through experimentation, using Forlan.

## *Integrating Experimentation and Proof (Cont.)*

The introductory textbook on formal language theory *Formal Language Theory: Integrating Experimentation and Proof* is based on Forlan.

I have attempted to keep the conceptual and notational distance between the textbook and toolset as small as possible.

Book treats concepts and algorithms both theoretically, especially using proof, and through experimentation, using Forlan.

Book provides numerous, fully worked-out examples of how regular expressions, finite automata, grammars and programs can be designed and proved correct.

## *Integrating Experimentation and Proof (Cont.)*

The introductory textbook on formal language theory *Formal Language Theory: Integrating Experimentation and Proof* is based on Forlan.

I have attempted to keep the conceptual and notational distance between the textbook and toolset as small as possible.

Book treats concepts and algorithms both theoretically, especially using proof, and through experimentation, using Forlan.

Book provides numerous, fully worked-out examples of how regular expressions, finite automata, grammars and programs can be designed and proved correct.

I have tried to simplify the subject's foundations, using alternative definitions when needed.

## *Integrating Experimentation and Proof (Cont.)*

Readers of the book are assumed to have significant experience reading and writing informal mathematical proofs.

## *Integrating Experimentation and Proof (Cont.)*

Readers of the book are assumed to have significant experience reading and writing informal mathematical proofs.

The book assumes no previous knowledge of Standard ML.

## *Integrating Experimentation and Proof (Cont.)*

Readers of the book are assumed to have significant experience reading and writing informal mathematical proofs.

The book assumes no previous knowledge of Standard ML.

Drafts of the book have been successfully used at Kansas State University in a semester long, undergraduate course on formal language theory.



## *Outline of the Book*

Book consists of five chapters:

- **Chapter 1: Mathematical Background** Set theory, induction and recursion, trees and inductive definitions.

## *Outline of the Book*

Book consists of five chapters:

- **Chapter 1: Mathematical Background** Set theory, induction and recursion, trees and inductive definitions.
- **Chapter 2: Formal Languages** Symbols, strings, alphabets, and (formal) languages. Proving language equalities using induction principles. Introduction to Forlan.

## *Outline of the Book*

Book consists of five chapters:

- **Chapter 1: Mathematical Background** Set theory, induction and recursion, trees and inductive definitions.
- **Chapter 2: Formal Languages** Symbols, strings, alphabets, and (formal) languages. Proving language equalities using induction principles. Introduction to Forlan.
- **Chapter 3: Regular Languages** Regular expressions and languages, five kinds of finite automata, algorithms for processing and converting between regular expressions and finite automata, applications of regular expressions and finite automata to hardware design, searching in text files and lexical analysis.

## *Outline of the Book (Cont.)*

- **Chapter 4: Context-free Languages** Context-free grammars and languages, algorithms for processing grammars and for converting regular expressions and finite automata to grammars, and recursive-descent (top-down) parsing.

## *Outline of the Book (Cont.)*

- **Chapter 4: Context-free Languages** Context-free grammars and languages, algorithms for processing grammars and for converting regular expressions and finite automata to grammars, and recursive-descent (top-down) parsing.
- **Chapter 5: Recursive and Recursively Enumerable Languages** A functional programming language, and the recursive and recursively enumerable languages, which are defined using programs. Algorithms for processing programs and for converting grammars to programs. Problems, like the halting problem (the problem of determining whether a program halts when run on a given input), that can't be solved by programs.

## *Further Reading and Related Work*

Book suggests several alternative books on formal language theory that may be consulted for more information or for alternative presentations of the book's material.

## *Further Reading and Related Work*

Book suggests several alternative books on formal language theory that may be consulted for more information or for alternative presentations of the book's material.

Neil Jones pioneered the use of a programming language with structured data as an alternative to Turing machines for studying the limits of what is computable.

## *Further Reading and Related Work*

Book suggests several alternative books on formal language theory that may be consulted for more information or for alternative presentations of the book's material.

Neil Jones pioneered the use of a programming language with structured data as an alternative to Turing machines for studying the limits of what is computable.

We've followed Jones's approach in some ways, but our programming language is functional, not imperative, and has explicit support for symbols and strings of formal language theory.



## *Further Reading and Related Work*

Book suggests several alternative books on formal language theory that may be consulted for more information or for alternative presentations of the book's material.

Neil Jones pioneered the use of a programming language with structured data as an alternative to Turing machines for studying the limits of what is computable.

We've followed Jones's approach in some ways, but our programming language is functional, not imperative, and has explicit support for symbols and strings of formal language theory.

Book briefly surveys other formal languages toolsets. Some are graphically oriented and help students work out relatively small examples.

## *Further Reading and Related Work*

Book suggests several alternative books on formal language theory that may be consulted for more information or for alternative presentations of the book's material.

Neil Jones pioneered the use of a programming language with structured data as an alternative to Turing machines for studying the limits of what is computable.

We've followed Jones's approach in some ways, but our programming language is functional, not imperative, and has explicit support for symbols and strings of formal language theory.

Book briefly surveys other formal languages toolsets. Some are graphically oriented and help students work out relatively small examples.

Others, like Forlan, are embedding in programming languages, and support sophisticated experimentation with formal languages.

## *Notes, Exercises and Website*

“Notes” subsections describe how book’s approach differs from standard practice.

## *Notes, Exercises and Website*

“Notes” subsections describe how book’s approach differs from standard practice.

Book contains numerous fully worked-out examples, many of which consist of designing and proving the correctness of regular expressions, finite automata, grammars and programs.

## *Notes, Exercises and Website*

“Notes” subsections describe how book’s approach differs from standard practice.

Book contains numerous fully worked-out examples, many of which consist of designing and proving the correctness of regular expressions, finite automata, grammars and programs.

Similar exercises, as well as other kinds of exercises, are scattered throughout the book.

## *Notes, Exercises and Website (Cont.)*

Forlan website

<http://alleystoughton.us/forlan>

contains:

- instructions for downloading and installing the Forlan toolset, and JForlan;
- the Forlan manual;
- instructions for reporting errors or making suggestions; and
- the Forlan distribution, including the source for Forlan and JForlan, as well as the  $\text{\LaTeX}$  source for this book.