jsFLAP

A JavaScript Formal Languages and Automata Package for Computer Science Education

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Background

Visualization in computer science education

Visualization in education

- Interactive visualization and simulation serve an important role in the education of abstract topics
- They complement more traditional learning materials rather than replacing them
- They allow students to engage with concepts very directly, applying what was once highly theoretical

Visualization in education

- In computer science education, visualizations can be especially important

- A model for how this is done is called Visualization-Reinforced Instruction (VRI)*
  - “A form of active learning, in which traditional instructional material is complemented and enhanced with carefully designed animations and simulations of key concepts, models, and algorithms”

*M. Quweider and F. Khan, “Visualization as effective instructional and learning tools in the Computer Science Curriculum,” *2017 ASEE Annual Conference & Exposition Proceedings*, 2017.

Benefits of visualization

- Researchers studied the use of VRI modules for educating about topics including algorithms, the fundamentals of programming, and network security

- VRI were found to have many benefits
  - 76% of students responded that the visualizations helped them to understand the underlying concepts
  - Allowed educators to better understand student misconceptions and misunderstandings which they could then correct
  - Less time overall (lecture + visualization) was required for students to learn the concepts

Challenges for visualizations

- Effective visualizations that enhance education are not easy to create
- Researchers discuss both the benefits and challenges of implementing visualizations in computer science education*
- Two major obstacles to widespread adoption of such visualization tools were identified
  - The learner may not find them to be educationally beneficial
  - The educator may find them to incur too much structural overhead to be worthwhile to implement in their course

*T. L. Naps, G. Rößling, V. Almstrum, W. Dann, R. Fleischer, C. Hundhausen, A. Korhonen, L. Malmi, M. McNally, S. Rodger, and J. Á. Velázquez-Iturbide, “Exploring the role of visualization and engagement in Computer Science Education,” ACM SIGCSE Bulletin, vol. 35, no. 2, pp. 131–152, 2003.

Designing good visualizations

- Effective visualization requires more than just showing a picture or animation of an algorithm, interactivity is critical

- The researchers define a set of best practices for designing visualizations
  - Include execution history
  - Support flexible execution control
  - Support custom input sets
  - Support learner-built visualizations
  - And more…

- These practices help to create a proper education tool with which the user can actively engage with the relevant concepts

Benefits of good visualizations

- When done well, these researchers also espouse the benefits of visualizations for computer science education
  - All respondents to one survey agreed that “using visualizations can help students learn computing concepts”
  - Improved levels of student participation
  - Educators reported a more enjoyable teaching experience
  - Students reported a more fun learning experience

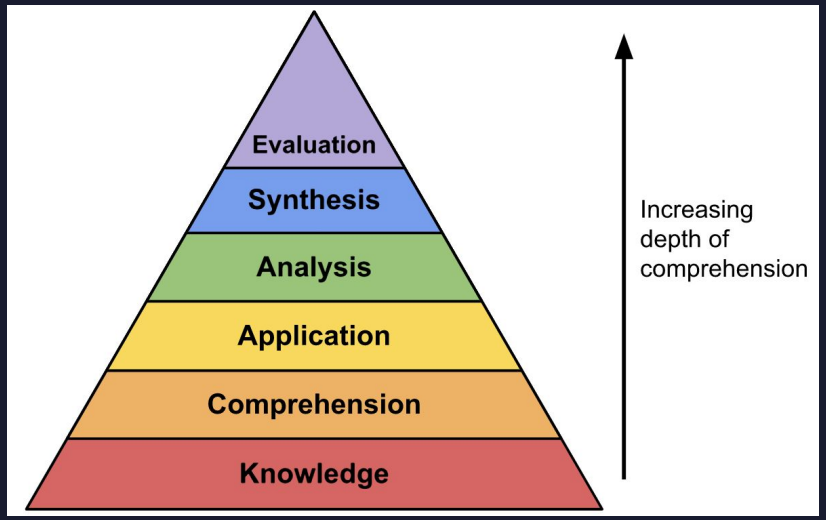
- How does one quantify the benefit that a visualization provides?

Educational theory

- Bloom's taxonomy of the cognitive domain is a hierarchical framework that is used to classify a learner's depth of comprehension along six increasingly sophisticated level*

- This has been used in some form for decades to define educational objectives that educators strive for their students to reach

[1]



*B. S. Bloom, Taxonomy of educational objectives: The classification of educational goals. New York City, New York: Longman, 1984.

Educational theory

- A visualization tool can be judged by which level of Bloom's taxonomy it allows students to reach

- Any visualization tool following the best practices defined earlier should bring students to the Application level
  - At this level, students can take concepts they have learned and apply them to new problems

- An even better tool would bring students to the Synthesis level
  - At this level students can generalize from many facts that they have learned and draw new conclusions by combining multiple concepts

Applications in computing theory

- The theory of computation is a prime candidate for visualization-reinforced learning

- The mathematical definitions for formal languages and finite automata can be difficult for students to understand on their own
    - They already have agreed-upon visual representations in literature, it just isn't interactive

- The concepts of computational theory are foundational to much of computer science, so understanding it is critical

- Because the need is so great, some tools already exist (more on this later)

Background

Formal languages and finite state automata

Formal languages

- A formal language consists of a set of valid words constructed from a set of characters in the language's alphabet according to certain rules

- Many applications in math, logic, linguistics, and computer science including programming language design and the theory of computation

- There are a number of tools that can be used to define formal languages
  - Set notation
  - Grammars
  - Regular expressions
  - Finite state automata

Finite automata

- A finite-state automaton is a form of computer that defines a language by accepting or rejecting different words that are passed to it as inputs

- There are different forms of finite automata with different levels of computational power to accept different types of languages, including
  - Finite automata to accept regular languages
  - Pushdown automata to accept context-free languages
  - Turing machines to accept recursively enumerable languages

- They are all modeled as finite state machines with a finite set of states and transitions to move between those states based on certain criteria
  - Depending on how an automaton has been defined, it may have non-determinism which can alter its computing power in some cases

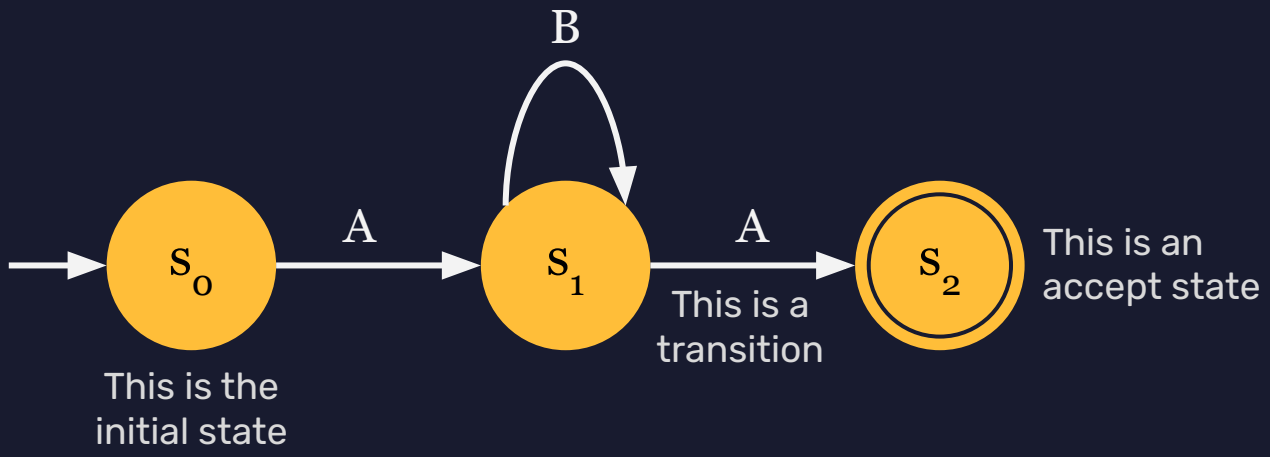
Simple finite automata

- Finite automata for accepting regular languages (NFAs and DFAs) are defined as a 5-tuple $(Q, \Sigma, \sigma, q_0, F)$ where
  - Q is a finite set of states
  - Σ is a finite set of tokens called the alphabet
  - σ is the transition function mapping $Q \times \Sigma \rightarrow Q$
  - q_0 is the initial state
  - $F \subseteq Q$ is the set of accept states

- The language constructed of all words that are the character A followed by any amount of Bs followed by another A could be defined by the automaton $(\{s_0, s_1, s_2\}, \{A, B\}, f, s_0, \{s_2\})$
  Where f is the transition function mapping $(s_0, A) \rightarrow s_1$, $(s_1, B) \rightarrow s_1$, $(s_1, A) \rightarrow s_2$
  Since this transition function does not contain transitions for all combinations of states and alphabet characters, the automaton is non-deterministic

Simple finite automata

- This finite automaton $(\{s_0, s_1, s_2\}, \{A, B\}, f, s_0, \{s_2\})$ where f is the transition function mapping $(s_0, A) \rightarrow s_1$, $(s_1, B) \rightarrow s_1$, $(s_1, A) \rightarrow s_2$ can be represented visually as a directed graph



Background

JFLAP

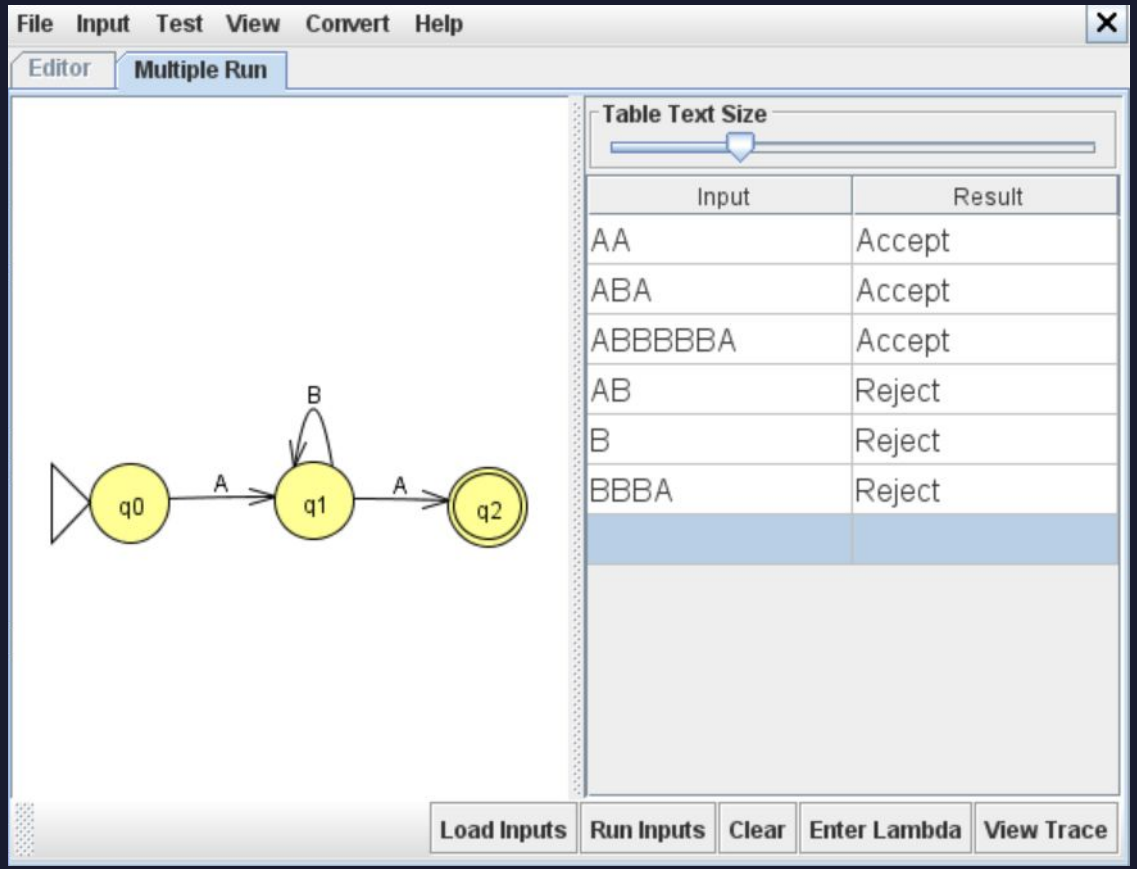
JFLAP

- The Java Formal Languages and Automata Package (JFLAP) is a Java program whose development began in 1990 at Rensselaer Polytechnic Institute

- Allows for the construction and simulation of different types of finite state automata, as well as regular expressions and grammars

- Downloaded over 64,000 times by people in 161 countries, and is used in over 20,000 college courses (including at OSU!)

JFLAP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Load Inputs
Run Inputs
Clear
Enter Lambda
View Trace

The negatives of JFLAP

- Technological overhead
  - Students need to install a third-party program and JVM
  - Can’t use Chromebooks or mobile devices
- Functionality
  - Lacks some educationally useful algorithms like product automata and cycle detection
- Usability
  - User interface reflects the time it was made
  - Generally only one way to achieve anything
  - Missing quality of life features like keyboard shortcuts, editor tabs, and good layout algorithms

The goal

- Create a modern, accessible tool for constructing and simulating finite state automata
  - Support non-deterministic finite automata, pushdown automata, and Turing machines
  - Implement useful algorithms to demonstrate core concepts of computing theory

- Follow best practices for visualization programs
  - High degree of user control for construction and execution
  - Easy for instructors to integrate
  - Avoid student frustration

- Allow users to reach at least the Application stage of Bloom's taxonomy and hopefully the Synthesis stage

Implementation

Technologies

- jsFLAP: The JavaScript Formal Languages and Automata Package
- Implemented using HTML5, CSS3, and JavaScript as well as the jQuery library



*Wikimedia Commons

Design strategy

- Composed of compartmentalized, object-oriented modules
- Code is documented and freely available on GitHub under the MIT license
- High extensibility through modifying modules or adding new ones
  - Should allow customization to suit course-specific needs or to connect to existing systems

Using jsFLAP

- All code is run in the client's browser, no external server connection is required

- Can be accessed at elijahcirioli.com/jsflap, embedded within another site, hosted statically by a school, or packaged into an executable so that students will not require an internet connection

- Only thing required is a modern-enough browser and possibly an internet connection depending on how it is hosted

Development Timeline

- Work began in October 2021 and lasted approximately 11 months
- All originally-intended functionality is present
  - Three types of automata plus, two types of parsing, and many tools
- Additional development may occur in the future to fix bugs and add features
- The goal was to create software that is easy to come back to and easy for others to modify

Features

Automata construction

- The core functionality revolves around constructing finite state automata by clicking and dragging to create states and transitions
  - There are various tools and keyboard shortcuts that can help with this

- When starting the program, the user gets a choice for what kind of automaton they wish to create
  - Finite state automaton
  - Pushdown automaton
  - Turing machine

Simulation

- There are two modes of simulation
  - Multiple
  - Step-by-step

- Simulation outcomes depend on what type of automaton is being simulated
  - Standard and pushdown automata return whether a given word is in their language
  - Turing machines show tape transformations and whether the machine halted (within a set amount of time)

- All simulations update in real-time

Messages

- The importance of features that decrease user frustration should not be discounted

- The editor features a messages window that updates in real time with different information about the automaton being constructed
  - What type of automaton (including non-determinism)
  - The alphabet
  - Whether it contains cycles

- Warnings for common mistakes
  - Unreachable states
  - Lack of initial state
  - Lack of any final states

Usability

- There are a number of features focused on improving the user experience
  - Copy/paste
  - Undo/redo
  - Auto saving
  - Editor themes
  - Keyboard shortcuts
  - Multiple selection
  - Editor panning and zooming (including auto zoom)
  - Optionally snap to grid
  - Multiple ways to access all tools
  - Multiple layout algorithms to make automata look nicer

Equivalence

- NFA to DFA conversion tool
  - Convert any non-deterministic finite automaton to a deterministic finite automaton
  - Demonstrates their equal computing power

- Compare equivalence of two automata
  - Show that multiple automata can represent the same language
  - Test correctness of student solutions
  - Again show NFA and DFA correspondence

Regular expressions

- Input regular expressions and generate equivalent NFAs
- Demonstration of equivalence between representations for regular languages
- Combining concepts to promote synthesis learning

Product automata

- Constructs the cartesian product automaton from two finite automata

- Perform set operations on their final states to perform the same operations on the languages they accept
  - Union, intersection, difference
  - Difference can be used prove equivalence

- Deepen student understanding of connection between finite automata and the languages they represent, as well as providing more tools to solve problems

Future Improvements

Accessibility

Accessibility

- Great work was put in to make jsFLAP accessible, but it should remain a key area of focus for future development
  - Tooltips, color settings, user-driven timing

- Reliance on mouse

- Improved support for screen readers

Future Improvements

Functionality

Grammars

- Grammars are another common way of representing formal languages
- They are not graph-based at all, so they would require a whole new suite of interfaces
- Supported in JFLAP
- Functionality to convert between automata and grammars in both directions

Proofs

- Currently, jsFLAP has functionality for students to prove concepts to themselves, but no formalized proofs that walk them through that concept
- Walk students through using the pumping lemma to show that a language is not regular
- Demonstrate the halting problem for Turing machines
- Broadly moves jsFLAP from an educational tool to a learning platform

Educational platform

- Currently jsFLAP is a tool used within an educational context rather than a place that students can learn computing theory concepts without needing any other resources

- Would need to provide users with lessons and challenges to teach different concepts
  - Could either be preprogrammed or specified in some file format

- Requires system for formally evaluating student work

- This would be a large undertaking, but it could be very powerful if done well

Educational Usage

Use cases

- In an educational context jsFLAP has many use cases
  - Live demonstrations
  - In-class activities
  - Homework assignments
  - Create graphics for slideshows and textbooks
- Cover both basic and advanced topics
- Adding visualization to courses that currently lack it
- Replacing JFLAP
  - Interoperable file formats
  - Feature differences

Specific courses

- jsFLAP is already being used by professor Xanda Schofield for the finite automata unit of their introductory computer science class at Harvey Mudd College
  - They have connected jsFLAP to their autograding system, demonstrating its extensibility

- Oregon State University could follow Harvey Mudd's lead by replacing JFLAP with jsFLAP in the CS 321 Theory of Computation undergraduate course

Conclusion

Conclusion

- Effective visualization tools can greatly benefit students, especially when learning about abstract topics

- Theory of computation is foundational for much of computer science, so jsFLAP was created as a tool to construct and simulate different types of finite state automata

- Provides an easy way for students to engage with the material in a hands-on manner
  - Work through misconceptions
  - Apply practically what was once theoretical

Conclusion

- While not the first tool for this purpose, jsFLAP follows best practices in order to be the most effective learning tool
  - Easy for instructors to integrate into their curriculum
  - Easy for students to use and access
  - Engaging, student-driven visualizations
  - Synthesis of multiple concepts

- Extensible and customizable to suit different learning environments

- jsFLAP has potential to benefit students at all levels of computer science education