Automata-based Algorithms Visualization Framework

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What is visualizer?

max = 79

73 not greater than current maximum (79)
Visualizers advantages

- Better algorithms understandability
- Dynamic content
- User can choose input data
- Forward and backward tracing
- Detailed comments
Visualizer requirements

- Interface simplicity
- Show all algorithm stages and special cases
- Clear comments for all stages
- Hints for every visualizer element
- Big and small steps
- Automated execution
Visualizers history in ITMO

- Sergey Stolyar
  - Initial stage (1998-1999)
- Matvey Kazakov
  - Transitional stage (1999-2000)
- Georgiy Korneev
  - Evolution stage (2000-2002)
  - Industrial stage (2002-2004)
Initial stage

- First attempts
- Visualizers in Borland Delphi
- Handmade user interface
- Handmade visualizers logic

- Less than ten visualizers were made
- Very slow development
- Lots of errors
Transitional stage

- Visualizers in Java (applets)
- Similar user interfaces
- First attempts in reversing

- About 15 visualizers
- Slow development
- Less errors
Evolution stage

- Common user interfaces (BaseApplet library)
- Common configuration
- Template-based logic
- All visualizers are reversible

- More than 50 visualizers
- Fast GUI development
- Difficulties in reversing
Industrial stage

- Standard user interface
- Automated code generation
- Automated program reverse

- More than 200 visualizers
- Fast logic development
- Automated reverse
- Quick development
Vizi visualization technology

- Visual representation library
- Logic definition language
- Visualizer programming methodology
- Standard project execution flow
- Documentation infrastructure

- Vizi visualization framework binds it together
Standard interface (1)

Drawing area

Comment area

Controls area
Standard interface (2)

- Forward
- Backward
- Auto execution mode
- Restart
- Automated execution delay
- Randomize
- Save/Load dialog
- Number of elements
- Elements: 5
- Delay: 1000
Logic definition language

- XML-based
- Program-like
- Auto-commented
- Auto documentation generation
Visualizer programming Methodology

- Based on Switch-technology
- Formal program transformation
- Automated source code generation
- Model-View-Controller paradigm
Switch-technology in visualization

- Proposed by Anatoly Shalyto (1991)
- First application for visualizers Matvey Kazakov (2002)
  - Implementation
  - Block diagrams
  - Automata transition diagram
  - Automata-based visualizer programming
- Visualization and reversing technology Georgiy Korneev (2003)
Switch-technology in Vizi

- Correlated automata systems
- Automata pair for each procedure
- Automata pair
  - Forward transition graph
  - Backward transition graph
  - Shared automata states
Formal program transformations

Algorithm implementation

Structure simplification

Data model extraction

Transformation to automata system
Automated source code generation

XML-Description

Correlated automata system

Source code

Compiled automata
Model-View-Controller paradigm

- Model
  - Auto-generated correlated automata system
- View
  - User interface based on Vizi library
- Controller
  - Vizi library
Algorithm reversing problem

- Backward tracing is very useful for education
- Repeatable forward-backward navigation

- How get one step back?
Algorithm reversing problem solutions

- Per-step save/load technique
  - High memory requirements
- Program re-execution
  - Low execution speed
- Program reverse
  - Average memory requirements
  - High execution speed
Program reversing difficulties

- Two versions of program
  - for forward tracing
  - for backward tracing
- Algorithm development for backward tracing
- Programs must be synchronized
- Complex modification
- Hard debugging
Automated program reversing

- One version of program (XML-source)
- Simple modification
- One-way debugging
Project execution flow

- Algorithm implementation
- Program structure simplification
- Data model extraction
- Transformation to correlated automata system
- Code generation
Algorithm implementation

- Algorithm is implemented using structural language
- Implementation source code is an input for other stages
Program structure simplification

- Most of programming languages are too complicated for automated transformations
- Program should use only simple programming structures
- Structuring theorem

- Formal structure simplification for Java
Allowed structures

- Statements sequence
- Assignment statement
- Short conditional statement
- Full conditional statement
- “While” loop
- Procedure call
Data model extraction

- Data model contains all variables
- Data model fully represents algorithm state
- All data flows going through data model

- Formal data model extraction
Transformation into correlated automata system

- Correlated automata systems
- Pairwise automatas

- Formal and automated program transformation
Project documentation (1)

- Annotation
  - Short project description
- Introduction
  - Brief algorithm description
  - Algorithm applications
  - Usage examples
- Chapter 1. Literature analysis
  - References and comments
Project documentation (2)

- Chapter 2. Algorithm description
  - Complete algorithm descriptions
  - Special cases analysis
- Chapter 3. Algorithm implementation
  - Implementation comments
  - Decision ground
- Chapter 4. Implementation simplification
  - Simplified implementation
● Chapter 5. Data model definition
  ● Descriptions of data model variables
● Chapter 6. “Interesting” stages definition
  ● Implementation is divided into “interesting” stages
  ● Comments for “interesting” stages
● Chapter 7. User Interface Description
  ● Pictures for each “interesting” stage
  ● Controls descriptions
Chapter 8. Configuration Description
- Complete configuration description
- Initial configuration

Conclusions
- Visualizer properties

References
Appendixes

- Algorithm Implementations Source Code
- Transformed Implementation
- Visualizer XML-description
- Generated Source Codes
- User Interfaces Source Codes
Simple algorithm example

“FindMaximum” algorithm

max = 39

21 27 10 39 8 20 65
FindMaximum
Algorithm implementation

```java
int max = 0;
for (int i = 0; i < a.length; i++) {
    if (max < a[i]) {
        max = a[i];
    }
}
```
FindMaximum
Simplified implementation

```java
int max = 0;
int i = 0;
while (i < a.length) {
    if (max < a[i]) {
        max = a[i];
    }
    i++;
}
```
public final static class Data {
    public int max;
    public int a[];
    public int Main_i;
}

FindMaximum

Transformed implementation

d.max = 0;
d.i = 0;
while (d.i < d.a.length) {
    if (d.max < d.a[d.i]) {
        d.max = d.a[d.i];
    }
    d.i++;
}
FindMaximum

Transformation to automata (1)

- Initialization

1. Initialization
   - d.max = 0

2. Loop initialization
   - d.i = 0
FindMaximum
Transformation to automata (2)

- If statement

4. If

6. Update
  stack.push(d.max)
  d.max = d.a[d.i]

5. End if

If statement

stack.push(false)

d.max >= d.a[d.i]
FindMaximum
Transformation to automata (3)

- Full automata

0. Start

1. Initialization
   d.max=0

d.i < d.a.length

2. Loop initialization
   d.i=0

3. Loop

   d.i >= d.a.length

8. Finish

4. If

   d.max < d.a[d.i]

   d.max = d.a[d.i]

   stack.push(true)

5. End if

6. Update

   stack.push(d.max)

7. Increment

   d.i++
FindMaximum

Reversed automata

0'. Start

1'. Initialization

2'. Loop initialization

3'. Loop

4'. If

5'. End if

6'. Update

7'. Инкремент

8'. Finish
FindMaximum

XML-representation

<step>@max @= 0;</step>
<step>@i @= 0;</step>
<while test="@i < @a.length">
  <if test="@max < @a[@i]">
    <then>
      <step>@max @= @a[@i];</step>
    </then>
  </if>
  <step>@i @= @i + 1;</step>
</while>
switch (state) {
    case 0: { // Start state
        state = 1; // Initialization
        break;
    } case 1: { // Initialization
        d.max = 0;
        state = 2; // Loop init
        break;
    } case 2: { // Loop init
        d.i = 0;
        state = 3; // Loop
        break;
    } case 3: { // Loop
        if (d.Main_i < d.a.length)
            state = 4; // If
        else state = END_STATE;
        break;
    } case 4: { // if
        if (d.max < d.a[d.Main_i])
            state = 6; // Update
            else state = 5; // End if
            break;
        } case 5: { // End if
        state = 7; // Increment
        break;
    } case 6: { // Update
        d.max = d.a[d.Main_i];
        state = 5; // End if
        break;
    } case 7: { // Increment
        d.Main_i++;
        state = 3; // Loop
        break;
    }
}
Find maximum
Statistics

- Automata 2
- States 9
- Transitions 22

- XML-source (with comments) 87 lines
- Automata implementation 326 lines
Complex algorithm example

Malhotra, Kumar, Maheshwari
maximal flow algorithm

Than we will lead flow value 1 from source to vertex number 2, greedily leading lack of flow from previous layer, simultaneously correcting potentials of vertices, which are passed by this flow.
Malhotra, Kumar, Maheshwari

Statistics

- Automata 18
- States 107
- Transitions 228

- XML-source (with comments) 516 lines
- Automata implementation 4069 lines
More examples

- Dinic network flow algorithm
- Hopcroft-Karp Bipartite Matching algorithm
- Chu-Liu shortest arborescence of a directed graph
- Algorithms on 2-3 threes
- Bitonic salesman problem
- Ukkonen suffix tree construction algorithm
- Prim minimum spanning tree algorithm
- Simple strings and de Bruin cycles construction algorithms
- …
Links

- Vizi project homepage
  - [http://ctddev.ifmo.ru/vizi](http://ctddev.ifmo.ru/vizi)

- Old visualizers examples

- Visualizer-related switch-technology information
  - [http://is.ifmo.ru/?i0=vis](http://is.ifmo.ru/?i0=vis)