Chapter 13: Visualization Techniques

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ECLiPSe ELearning Overview

Licence

Outline

What we want to introduce

- Why visualize?
- How to visualize constraint programs
- Visualization Interface
- Visualization Tool

Background

- Gift grant from Cisco Systems/Silicon Valley Community Foundation
- Cisco owns open-sourced ECLiPSe system
- How to expand user-base?
- Self-taught course in constraint programming
- Intended for Cisco engineers/programmers
- Open source/available to community
- Website
  `http://4c.ucc.ie/~hsimonis/ELearning/index.htm`

Format

- Video lectures
- Slides
- Handout
- Exercises

Problems Handled in Course

- Must have puzzles!
- Send+More=Money
- Sudoku
- N-queens
- Shikaku

Practical Example Problems

- Test plan generation (BIBD)
- Progressive party problem
- Routing and wavelength assignment
- Optical network design
- Car sequencing
- Costas arrays
- Sports scheduling
- Still to come
  - Production scheduling
  - Nurse rostering
  - Airport stand allocation

Intention

- Realistic, life like problems
- Must address scalability issues
- Often, problem not completely specified
- Issue: Hard to verify by hand
- Complexity still limited, not real problems
- No attempt at integration

How do we understand behavior?

- Mental model
- Formal analysis
- Debugging
- Tracing
- Life visualization
- Post-mortem analysis

Why Visualize?

- Understand what is done
- Understand what is done in which order
- Understand what is *not* done
- Understand when to give up

Design Choices

- No deep integration with solver
- Post-mortem visualization
- Intermediate file format
- No view of detailed propagation
  - Tool not intended for debugging constraint engine

Conceptual Model

- Stable state at defined program points
- Granularity
  - Assign value
  - Post constraint
- Show stable state after propagation
- Do not show individual propagation steps

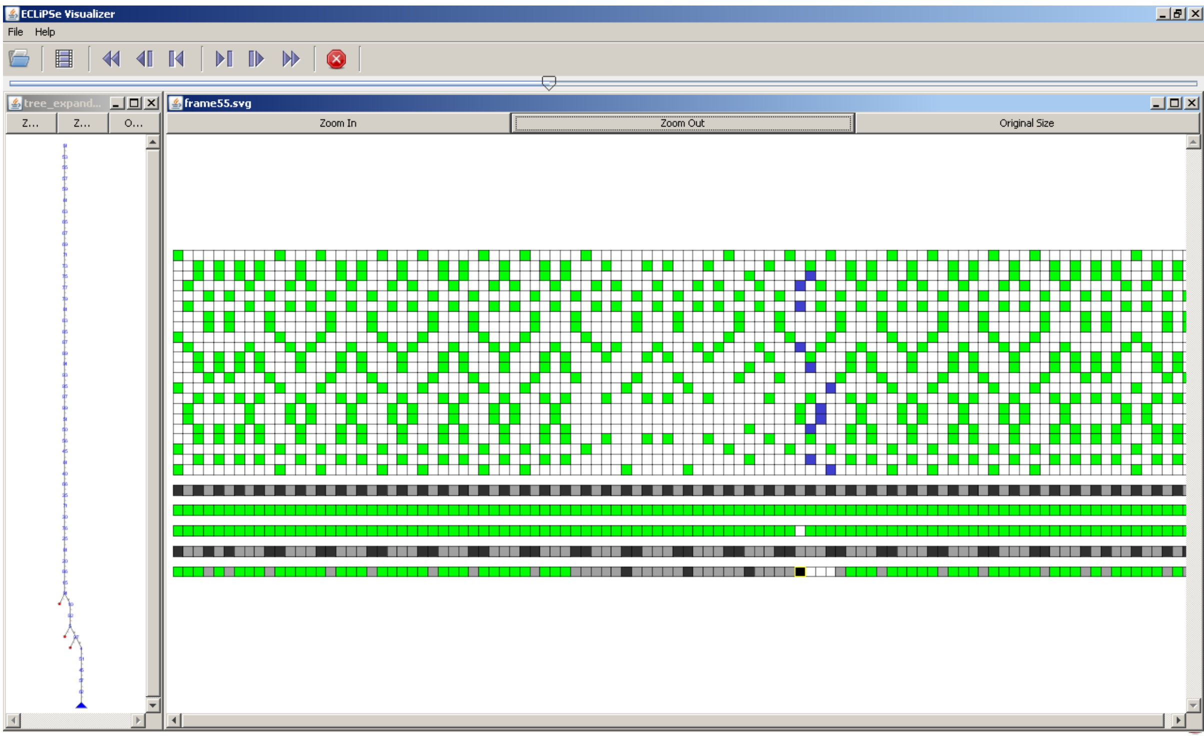
Visualizers

- Search tree
- Variables
- Constraints

Visualization Tool

- Developed in Java
- Show two panes: tree and state
- Navigate along timeline

Visualization Tool: Car Sequencing



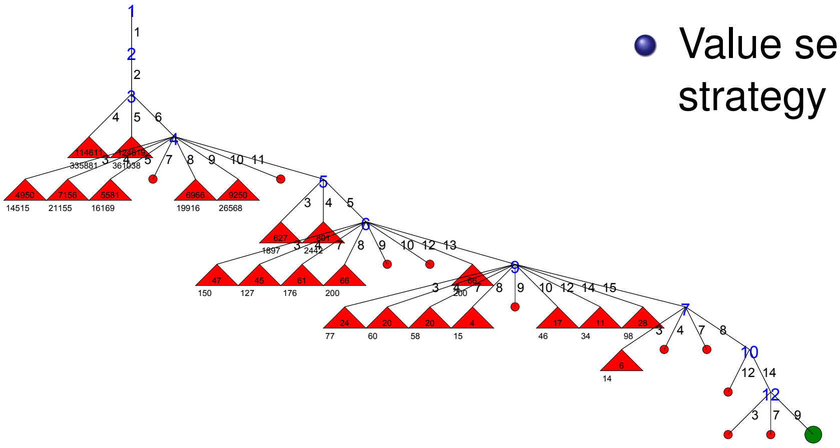
How many visualizers do we need?

- Develop few primitives
  - Cell based view
  - Domain vector
- Allow aggregation
  - Vector/matrix
  - General layout
- Which global constraints require more?
  - Task based view for `cumulative`
  - Matching/flow based representation does not scale

How to Interpret Visualization

- Search tree
  - Good/bad choices
  - Place of backtracking
- State
  - Missing propagation

Costas Array Search tree (Size 16)



- Deep backtracking
- Third choice wrong
- Last choice wrong
- Value selection strategy useless

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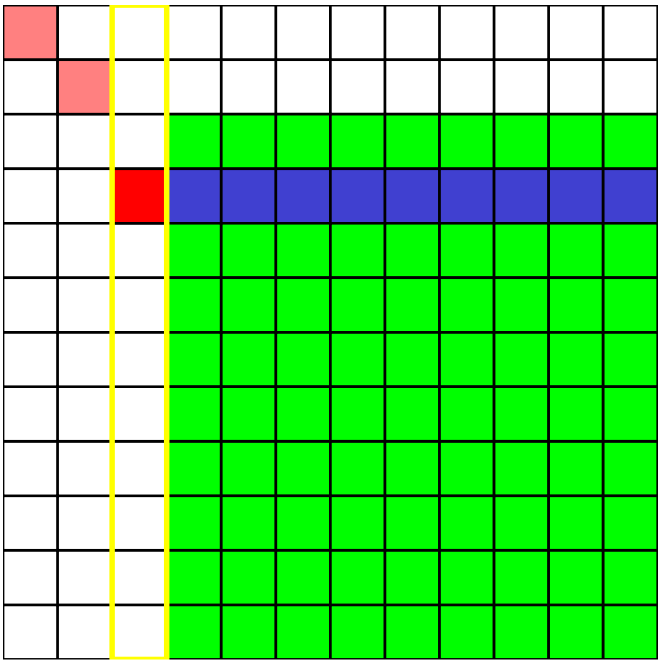
Missing Propagation



The model is doing this

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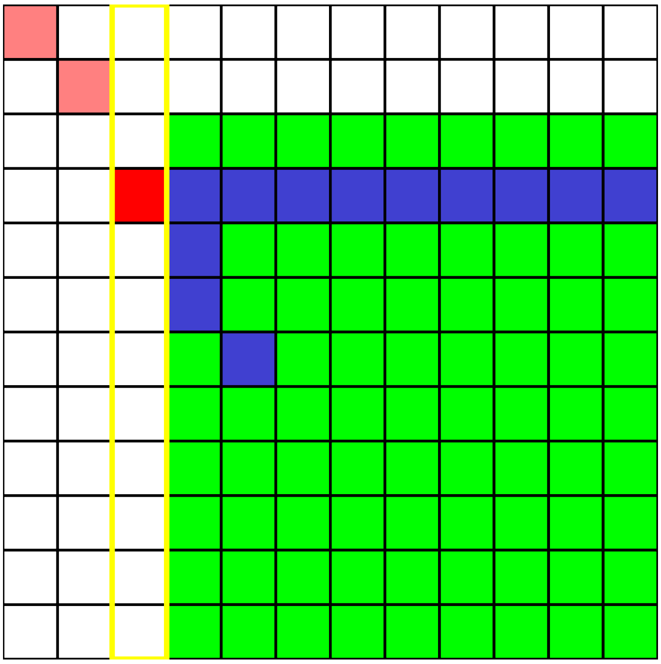
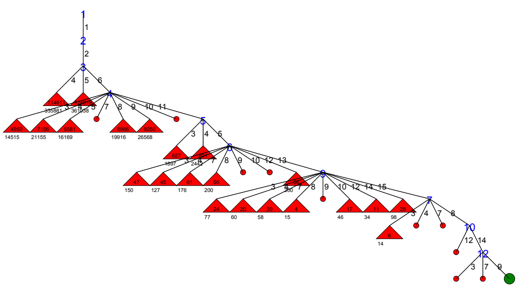
Missing Propagation



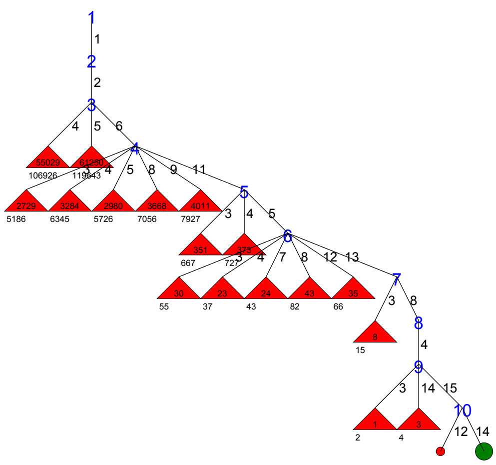
It could be doing that!

Comparison (Search Tree, size 16)

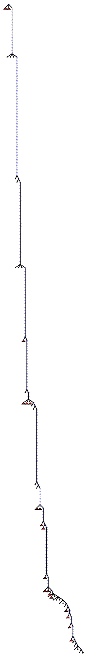
Initial Model



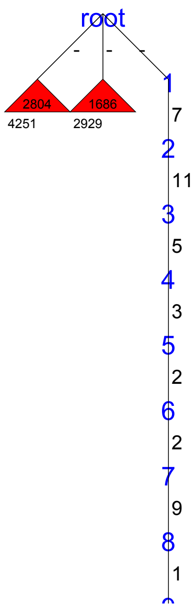
Improved Model



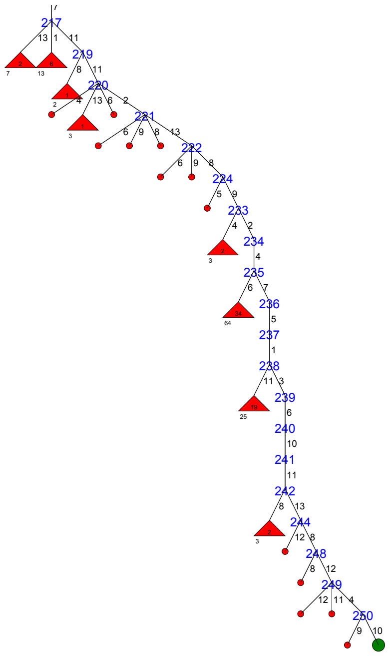
Progressive Party Problem, 9 Time Periods



2 Restarts Before Solution Found



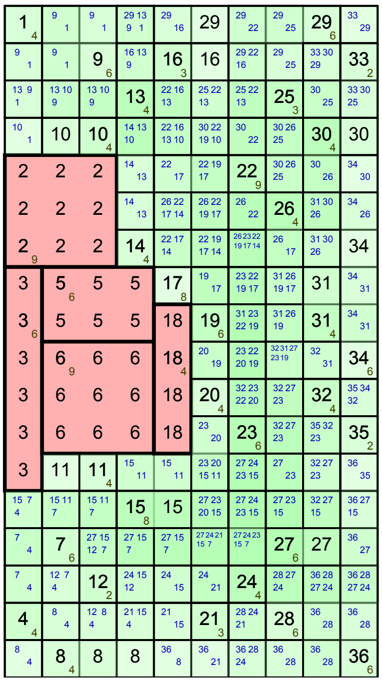
Value Choice Strategy Not Focused



Progressive Party

- Clearly impossible to explore search space
- Either many solutions or good value selection
- Value selection at end rather poor
- Probably many solutions

Missing Propagation: Shikaku



Sendmore Program Annotated

```
sendmory(L,Output,IgnoreFixed):-
  L=[S,E,N,D,M,O,R,Y],
  L :: 0..9,
  create_visualization([output:Output,
                        ignore_fixed:IgnoreFixed,
                        width:8,
                        height:10],Handle),
  add_visualizer(Handle,
                 vector(L),
                 [display:expanded]),
  alldifferent(L),draw_visualization(Handle),
  S #\= 0,draw_visualization(Handle),
  M #\= 0,draw_visualization(Handle),
```

Sendmore Program Annotated

```
1000*S + 100*E + 10*N + D +
1000*M + 100*O + 10*R + E #=
10000*M + 1000*O + 100*N + 10*E + Y,
name_variables(Handle,L,
               ['S','E','N','D','M','O','R','Y'],
               Pairs),
root(Handle),
search(Pairs,1,input_order,
       tree_indomain(Handle,_),
       complete,[]),
solution(Handle),
close_visualization(Handle).
```

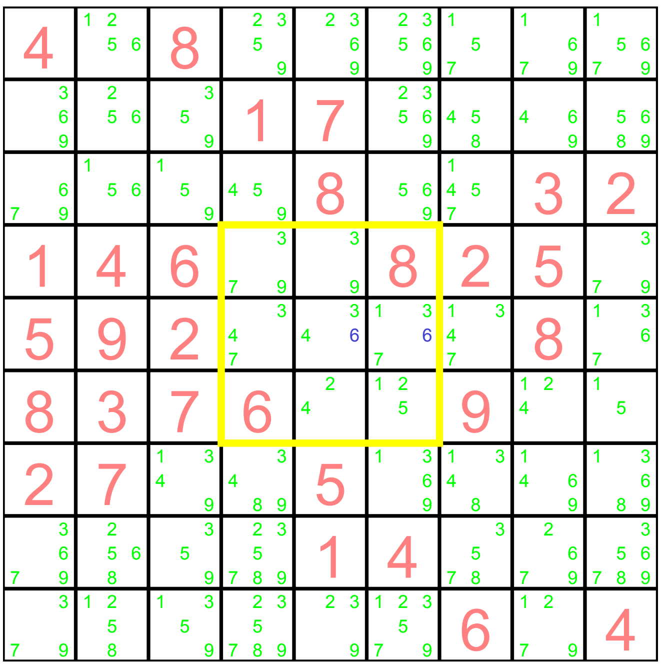

Sudoku Program Annotated

```
model(Matrix,Method,Output):-
  Matrix[1..9,1..9] :: 1..9,
  create_visualization([output:Output,
                        width:9,
                        height:9],Handle),
  add_visualizer(Handle,
                 domain_matrix(Matrix),
                 [display:text]),
  draw_visualization(Handle),
  (for(I,1,9),
   param(Matrix,Method,Handle) do
      Method:alldifferent(Matrix[I,1..9]),
      draw_visualization(Handle,[focus:row(I)]),
      Method:alldifferent(Matrix[1..9,I]),
      draw_visualization(Handle,[focus:col(I)])
  ),
```

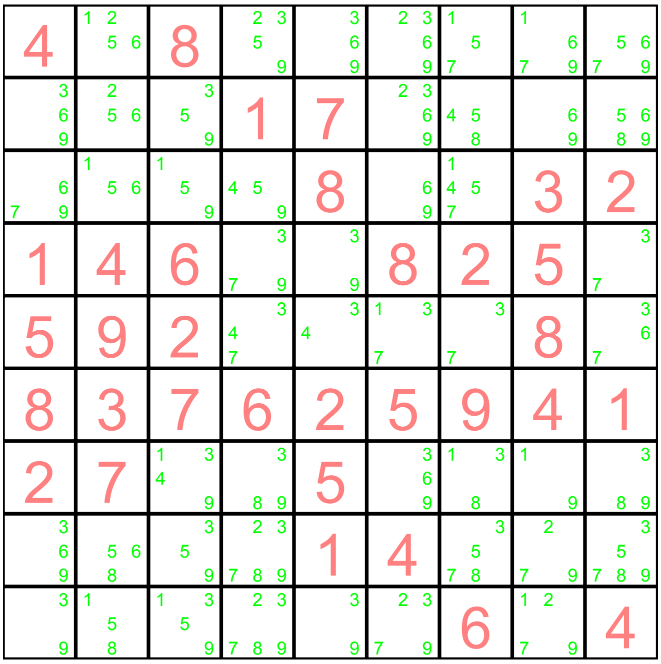
Sudoku Program Annotated

```
(multifor([I,J],[1,1],[7,7],[3,3]),
 param(Matrix,Method,Handle) do
    Method:alldifferent(Matrix[I..I+2,J..J+2]),
    draw_visualization(Handle,
                        [focus:block(I,J,3,3)])
),
extract_array(Handle,row,Matrix,NamedList),
root(Handle),
search(NamedList,1,input_order,
        tree_indomain(Handle,_),
        complete,[]),
solution(Handle),
close_visualization(Handle).
```

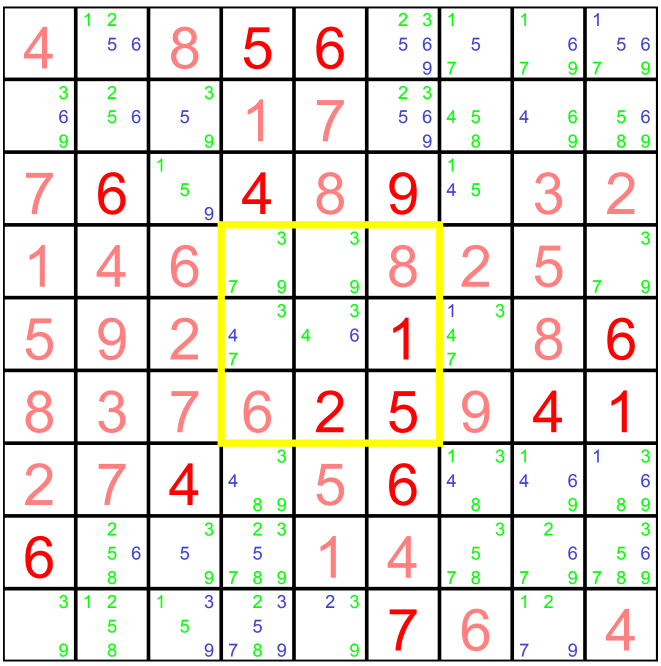

Propagation Steps (Forward Checking)



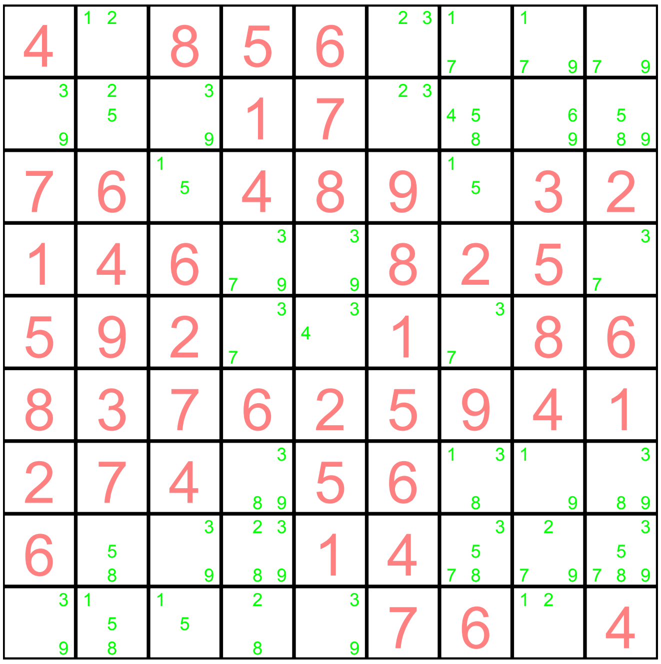
After Setup (Forward Checking)



Propagation Steps (Bounds Consistency)



After Setup (Bounds Consistency)

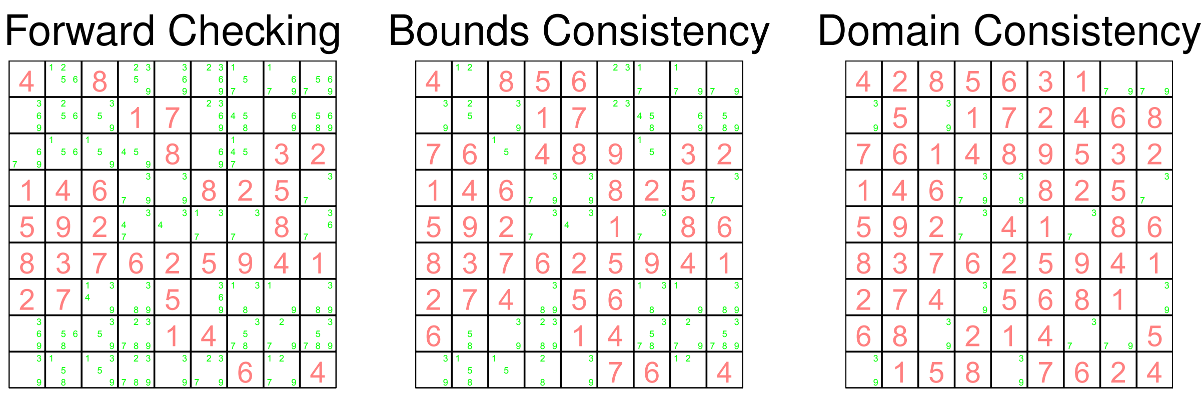


Propagation Steps (Domain Consistency)

After Setup (Domain Consistency)

4	2	8	5	6	3	1	7 9	7 9
3 9	5	3 9	1	7	2	4	6	8
7	6	1	4	8	9	5	3	2
1	4	6	3 7 9	3 9	8	2	5	3 7
5	9	2	3 7	4	1	3 7	8	6
8	3	7	6	2	5	9	4	1
2	7	4	3 9	5	6	8	1	3 9
6	8	3 9	2	1	4	3 7	7 9	5
3 9	1	5	8	3 9	7	6	2	4

Comparison



Instrumented indomain

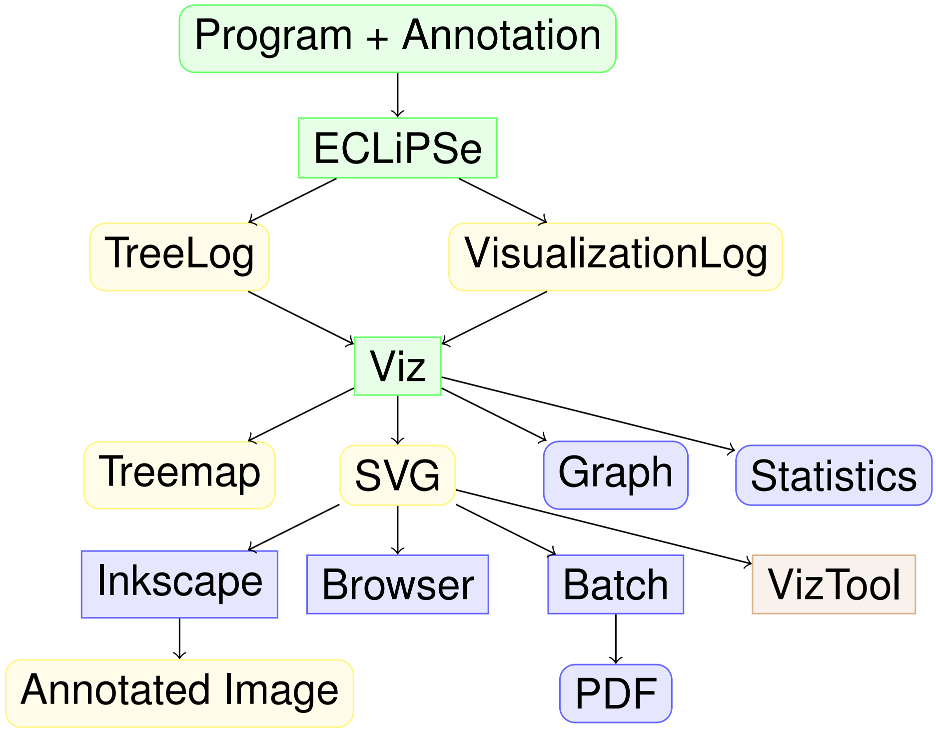
```
tree_indomain_generic(Term,Handle,Handle,Type):-
  Handle = visualization{ignore_fixed:IgnoreFixed,
                          var_arg:VarArg,
                          name_arg:NameArg,
                          focus_arg:FocusArg},
  arg(VarArg,Term,X),
  ((integer(X),IgnoreFixed = yes) ->
      true
  ;
      arg(NameArg,Term,Name),
      arg(FocusArg,Term,Focus),
      get_domain_as_list(X,L),
      get_domain_size(X,Size),
      reorganize_domain(X,L,Type,K),
      try_value(Handle,X,K,Name,Size,Focus)
  ).
```


Introduction
Visualization by Annotation
Visualization Interface
Conclusions

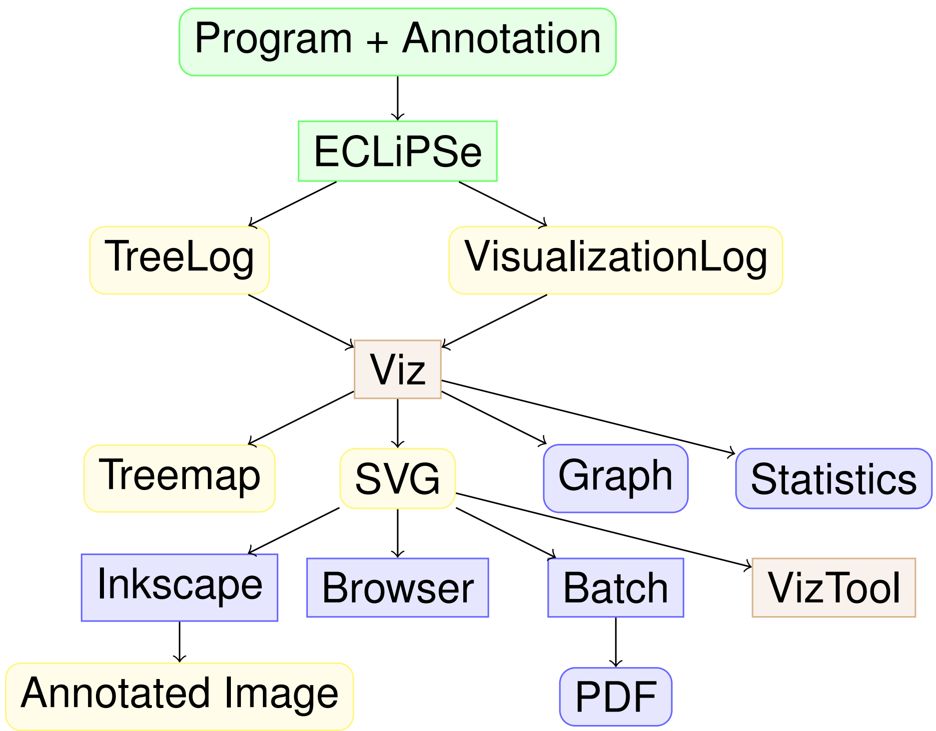
Instrumented indomain

```
try_value(Handle,X,[V|_],Name,Size,Focus):-
  ((X = V, true) ->
      try(Handle,Name,Size,V),
      focus_option(Focus,FocusOption),
      draw_visualization(Handle,FocusOption)
  ;
      failure(Handle,Name,Size,V),
      fail_option(Focus,V,FailOption),
      draw_visualization(Handle,FailOption),
      fail
  ).
try_value(Handle,X,[_|R],Name,Size,Focus):-
  try_value(Handle,X,R,Name,Size,Focus).
```

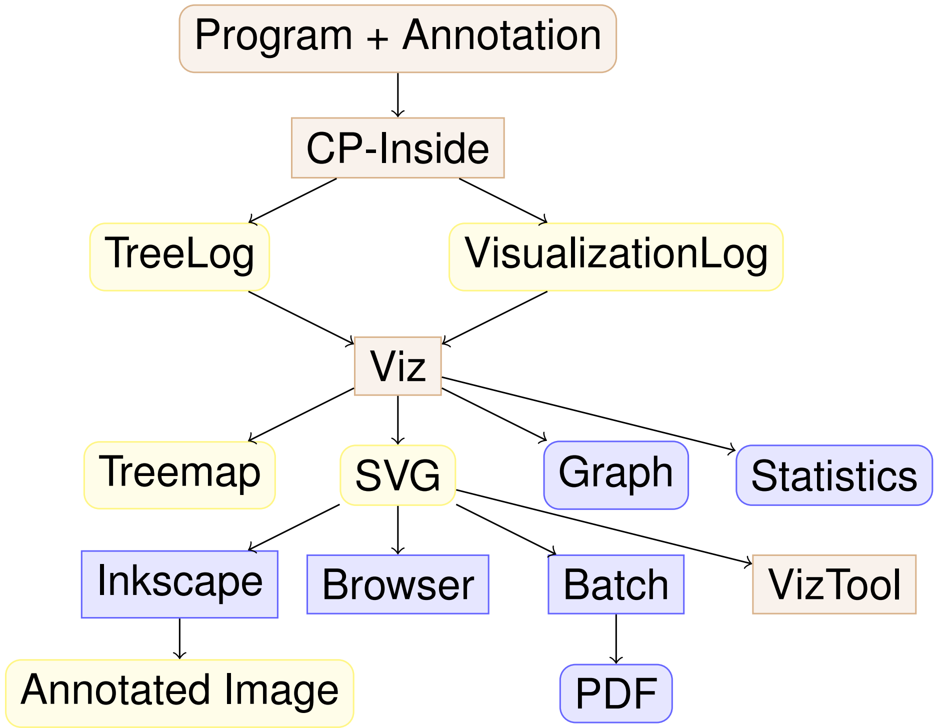
Architecture (Current)



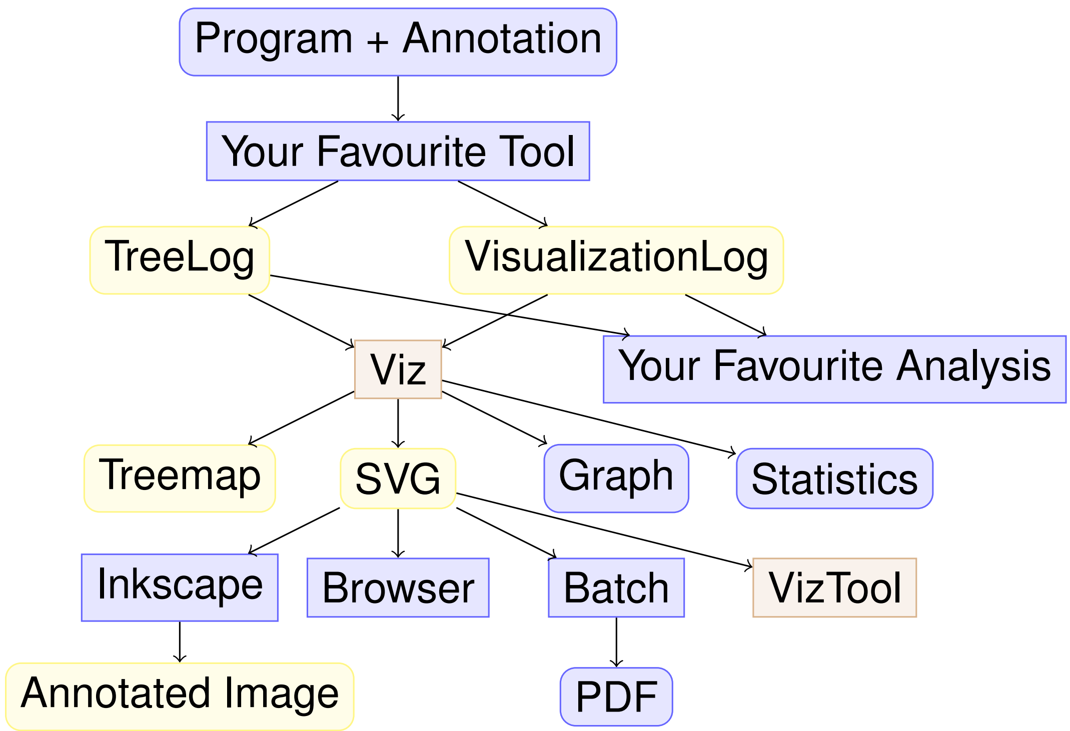
Architecture (Planned)



CP-Inside



Generic Tool

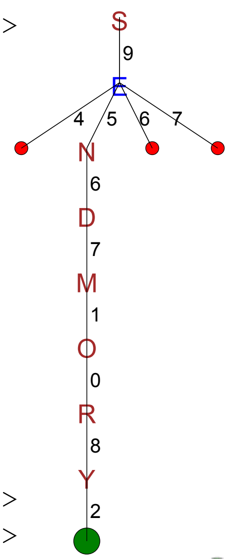


TreeLog Format

- XML based description
- Record information about nodes in search tree
  - Choices
  - Failures
  - Success
- Redundant information to ease generation

TreeLog Example

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<tree version="1.0" >
<root id="0"/>
<try id="1" parent="0" name="S" size="1" value="9" />
<fail id="2" parent="1" name="E" size="4" value="4" />
<try id="3" parent="1" name="E" size="4" value="5" />
<try id="4" parent="3" name="N" size="1" value="6" />
<try id="5" parent="4" name="D" size="1" value="7" />
<try id="6" parent="5" name="M" size="1" value="1" />
<try id="7" parent="6" name="O" size="1" value="0" />
<try id="8" parent="7" name="R" size="1" value="8" />
<try id="9" parent="8" name="Y" size="1" value="2" />
<succ id="9"/>
<fail id="10" parent="1" name="E" size="4" value="6" />
<fail id="11" parent="1" name="E" size="4" value="7" />
</tree>
```



VisualizerLog Format

- XML based description
- Describe state of variables and/or constraints at specific stages
  - Where annotated in program
  - For every node in tree
- Linked to search tree log

VisualizerLog Example

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<visualization version="1.0" >
<visualizer id="1" type="vector" display="expanded" x="0" y="0"
  width="8" height="10" group="1" min="0"  max="9" />
<state id="1" tree_node="-1" >
<visualizer_state id="1" >
<dvar index="1" domain="0 .. 9" />
<dvar index="2" domain="0 .. 9" />
<dvar index="3" domain="0 .. 9" />
<dvar index="4" domain="0 .. 9" />
<dvar index="5" domain="0 .. 9" />
<dvar index="6" domain="0 .. 9" />
<dvar index="7" domain="0 .. 9" />
<dvar index="8" domain="0 .. 9" />
</visualizer_state>
</state>
...
```

VisualizerLog Example

```
...
<state id="2" tree_node="-1" >
<visualizer_state id="1" >
<dvar index="1" domain="1 .. 9" />
<dvar index="2" domain="0 .. 9" />
<dvar index="3" domain="0 .. 9" />
<dvar index="4" domain="0 .. 9" />
<dvar index="5" domain="0 .. 9" />
<dvar index="6" domain="0 .. 9" />
<dvar index="7" domain="0 .. 9" />
<dvar index="8" domain="0 .. 9" />
</visualizer_state>
</state>
...
```


VisualizerLog Example

```
...
<state id="5" tree_node="1" >
<visualizer_state id="1" >
<integer index="1" value="9" />
<dvar index="2" domain="4 .. 7" />
<dvar index="3" domain="5 .. 8" />
<dvar index="4" domain="2 .. 8" />
<integer index="5" value="1" />
<integer index="6" value="0" />
<dvar index="7" domain="2 .. 8" />
<dvar index="8" domain="2 .. 8" />
<focus group="-" index="1" />
</visualizer_state>
</state>
...
```

VisualizerLog Example

```
...
<state id="6" tree_node="2" >
<visualizer_state id="1" >
<integer index="1" value="9" />
<dvar index="2" domain="4 .. 7" />
<dvar index="3" domain="5 .. 8" />
<dvar index="4" domain="2 .. 8" />
<integer index="5" value="1" />
<integer index="6" value="0" />
<dvar index="7" domain="2 .. 8" />
<dvar index="8" domain="2 .. 8" />
<failed group="-" index="2" value="4" />
</visualizer_state>
</state>
...
```

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VisualizerLog Example

```
...
<state id="14" tree_node="9" >
<visualizer_state id="1" >
<integer index="1" value="9" />
<integer index="2" value="5" />
<integer index="3" value="6" />
<integer index="4" value="7" />
<integer index="5" value="1" />
<integer index="6" value="0" />
<integer index="7" value="8" />
<integer index="8" value="2" />
</visualizer_state>
</state>
...
</visualization>
```

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Conclusions

- New ELearning course for ECLiPSe
- Open source material, Creative Commons BY-NC-SA license
  - Application driven
  - Modelling with global constraints
  - Customizing search
- Effort only justifiable through Cisco grant

Visualization

- Design choice: System independent
- Provide enough information to user of system, not to tool developer
- Relatively few primitives, extensible for specific global constraints
- XML intermediate format, open for specific analysis