Chapter 10: Customizing Search (Progressive Party Problem)

Helmut Simonis

Cork Constraint Computation Centre Computer Science Department University College Cork Ireland

ECLiPSe ELearning Overview





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Outline

- Problem
- 2 Program
- Search





Customizing Search

What we want to introduce

- Problem Decomposition
 - Decide which problem to solve
 - Not always required to solve complete problem in one go
- Modelling with bin packing
- Customized search routines can bring dramatic improvements
- Understanding what is happening important to find improvements





Outline

- Problem
 - Phase 1
 - Phase 2
- 2 Program
- Search





Problem Definition

Progressive Party

The problem is to timetable a party at a yacht club. Certain boats are to be designated hosts, and the crews of the remaining boats in turn visit the host boats for several successive half-hour periods. The crew of a host boat remains on board to act as hosts while the crew of a guest boat together visits several hosts. Every boat can only host a limited number of guests at a time (its capacity) and crew sizes are different. The party lasts for 6 time periods. A guest boat cannot not revisit a host and guest crews cannot meet more than once. The problem facing the rally organizer is that of minimizing the number of host boats.

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Data

Boat	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Capacity	6	8	12	12	12	12	12	10	10	10	10	10	8	8
Crew	2	2	2	2	4	4	4	1	2	2	2	3	4	2
Boat	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Capacity	8	12	8	8	8	8	8	8	7	7	7	7	7	7
Crew	3	6	2	2	4	2	4	5	4	4	2	2	4	5
Boat	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Capacity	6	6	6	6	6	6	6	6	6	6	9	0	0	0
Crew	2	4	2	2	2	2	2	2	4	5	7	2	3	4



Problem Decomposition

- Phase 1: Select minimal set of host boats
 - Manually
- Phase 2: Create plan to assign guest boats to hosts in multiple periods
 - Done as a constraint program





Idea

- Decompose problem into multiple, simpler sub problems
- Solve each sub problem in turn
- Provides solution of complete problem
- Challenge: How to decompose so that good solutions are obtained?
- How to show optimality of solution?





Selecting Host boats

- Some additional side constraints
 - Some boats must be hosts
 - Some boats may not be hosts
- Reason on total or spare capacity
- No solution with 12 boats



Solution to Phase 1

- Select boats 1 to 12 and 14 as hosts
- Many possible problem variants by selecting other host boats



Phase 2 Sub-problem

- Host boats and their capacity given
- Ignore host teams, only consider free capacity
- Assign guest teams to host boats



Model

- Assign guest boats to hosts for each time period
- Matrix of domain variables (size NrGuests × NrPeriods)
- Variables range over possible hosts 1..NrHosts



Constraints

- Each guest boat visits a host boat atmost once
- Two guest boats meet at most once
- All guest boats assigned to a host in a time period fit within spare capacity of host boat



Each guest visits a hosts atmost once

- The variables for a guest and different time periods must be pairwise different
- alldifferent constraint on rows of matrix



Two guests meet at most once

- The variables for two guests can have the same value for atmost one time period
- Constraints on each pair of rows in matrix



All guests assigned to a host in a time period fit within spare capacity of host boat

- Capacity constraint expressed as bin packing for each time period
- Each host boat is a bin with capacity from 0 to its unused capacity
- Each guest is an item to be assigned to a bin
- Size of item given by crew size of guest boat





Bin Packing Constraint

- Global constraint
 bin_packing (Assignment, Sizes, Capacity)
- Items of different sizes are assigned to bins
- Assignment of item modelled with domain variable (first argument)
- Size of items fixed: integer values (second argument)
- Each bin may have a different capacity
- Capacity of each bin given as a domain variable (third argument)





Outline

- Problem
- 2 Program
- 3 Search





Main Program

```
top:-
    top(10,6).

top(Problem, Size):-
    problem(Problem, Hosts, Guests),
    model(Hosts, Guests, Size, Matrix),
    writeln(Matrix).
```



Data

```
problem(10,

[10,10,9,8,8,8,8,8,8,7,6,6,4],

[7,6,5,5,5,4,4,4,4,4,4,4,4,4,3,

3,2,2,2,2,2,2,2,2,2,2,2,2,2]).
```





Creating Variables

```
model(Hosts, Guests, NrPeriods, Matrix):-
   length(Hosts, NrHosts),
   length(Guests, NrGuests),
   dim(Matrix, [NrGuests, NrPeriods]),
   Matrix[1..NrGuests, 1..NrPeriods] :: 1..NrHosts,
   ...
```



Setting up alldifferent constraints

```
(for(I,1,NrGuests),
param(Matrix,NrPeriods) do
    ic:alldifferent(Matrix[I,1..NrPeriods])
),
```



Setting up bin_packing constraints





Each pair of guests meet atmost once



Call search

```
extract_array(col,Matrix,List),
assign(List).
```



Make Bin variables

```
make_bins(HostCapacity,Bins):-
    (foreach(Cap,HostCapacity),
        foreach(B,Bins) do
        B:: 0..Cap
).
```





Each pair of guests meet atmost once

```
card_leq(Vector1, Vector2, Card):-
    collection_to_list(Vector1, List1),
    collection_to_list(Vector2, List2),
    (foreach(X, List1),
     foreach(Y, List2),
     fromto(0, A, A+B, Term) do
        #=(X, Y, B)
    ),
    eval(Term) #=< Card.</pre>
```



Naive Search



Outline

- Problem
- Program
- Search
 - Naive Search
 - First Fail Strategy
 - Layered Search
 - Layered with Credit Search
 - Randomized with Restart





Naive Search First Fail Strategy Layered Search Layered with Credit Search Randomized with Restart

Naive Search (Compact view)







Naive Search
First Fail Strategy
Layered Search
Layered with Credit Search
Randomized with Restart

Observations

- Not too many wrong choices
- But very deep backtracking required to discover failure
- Most effort wasted in "dead" parts of search tree



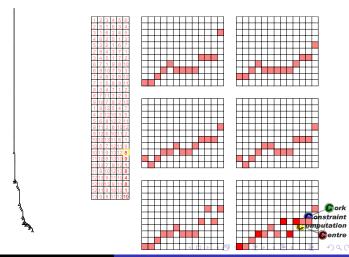


Naive Search
First Fail Strategy
Layered Search
Layered with Credit Search
Randomized with Restart

First Fail strategy



First Fail Search



Observations

- Assignment not done in row or column mode
- Tree consists of straight parts without backtracking
- and nearly fully explored parts



Idea

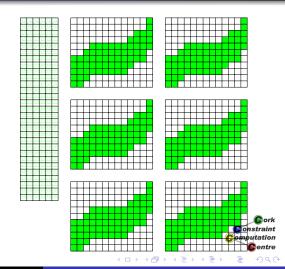
- Assign variables by time period
- Within one time period, use first_fail selection
- Solves bin packing packing for each period completely
- Clearer impact of disequality constraints





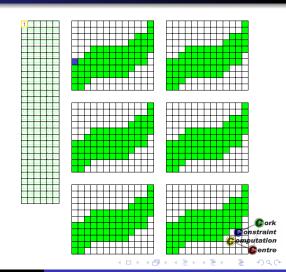
Naive Search
First Fail Strategy
Layered Search
Layered with Credit Search
Randomized with Restart

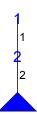


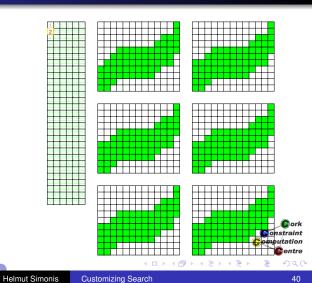


Naive Search
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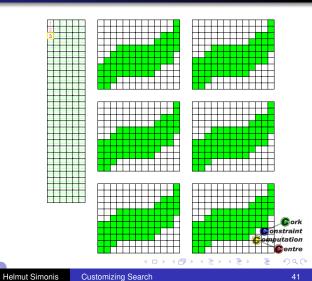




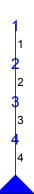


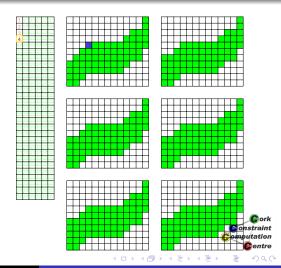
Layered Search

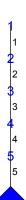
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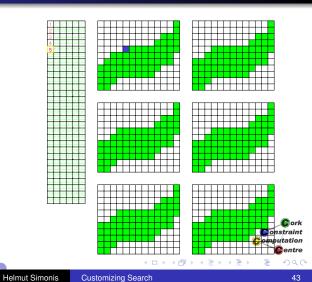


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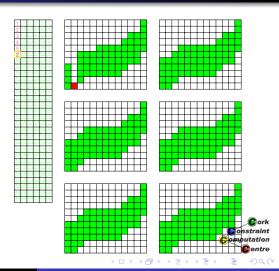




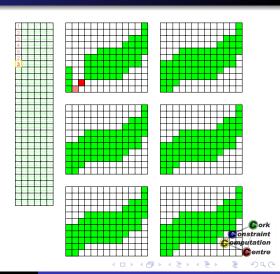




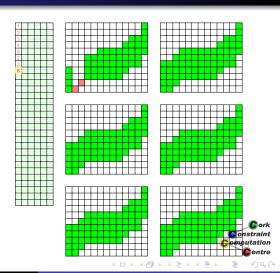




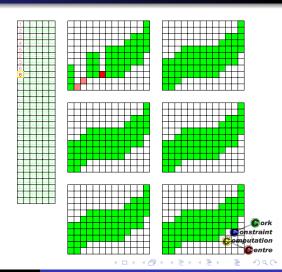




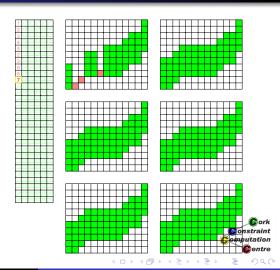






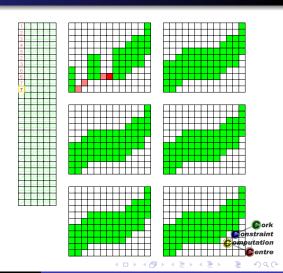




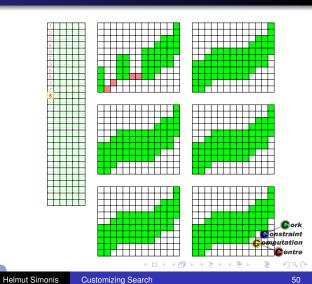


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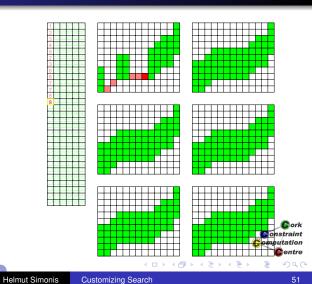




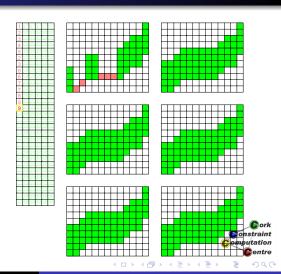






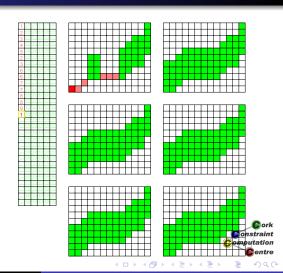




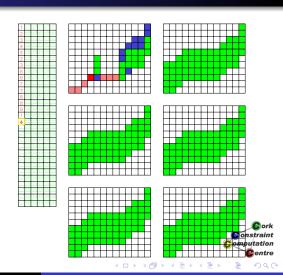


Naive Search
First Fail Strategy
Layered Search
Layered with Credit Search
Randomized with Restart

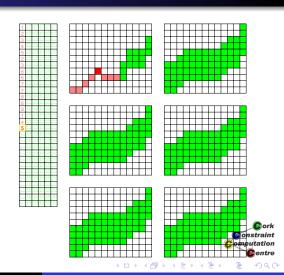




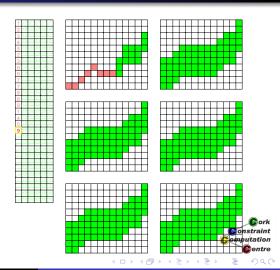




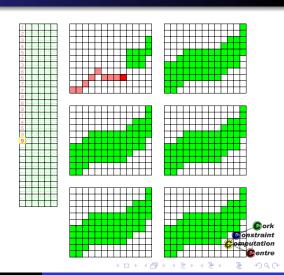




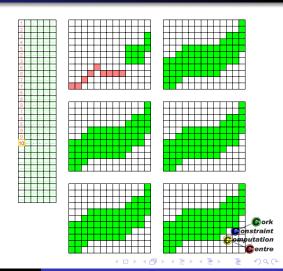




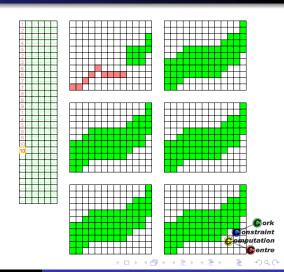


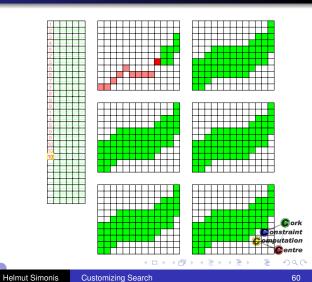




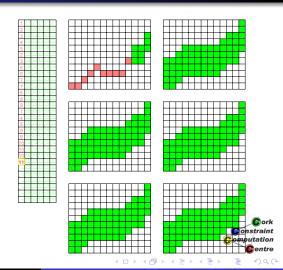




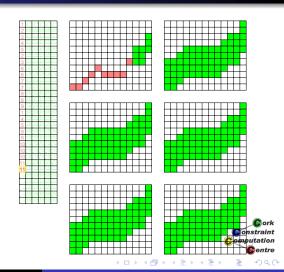




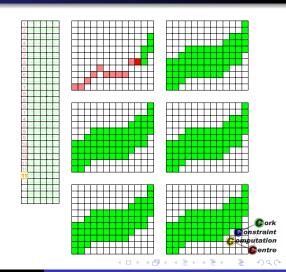


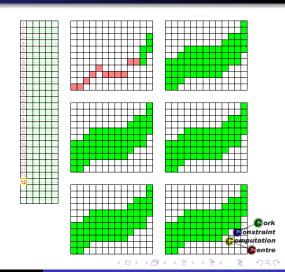


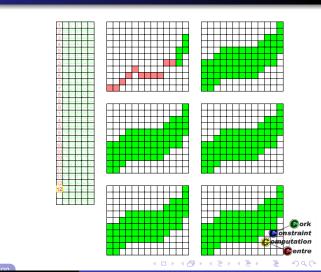




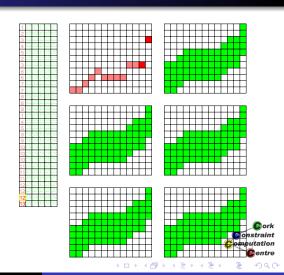


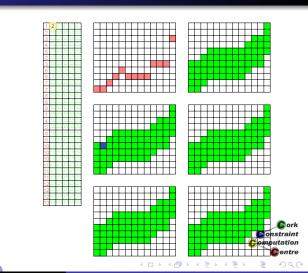


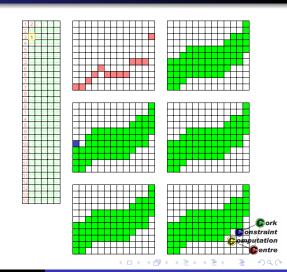


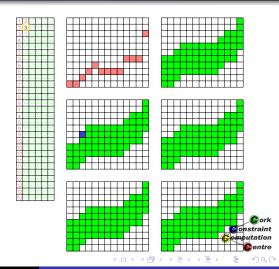


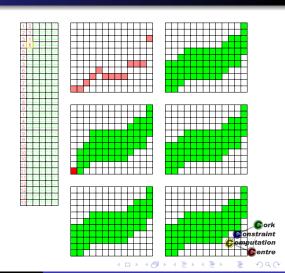


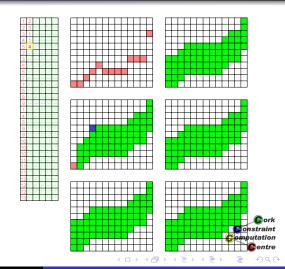


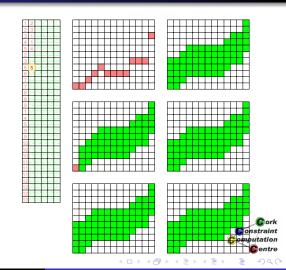


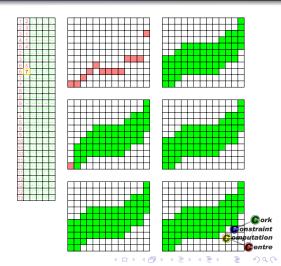


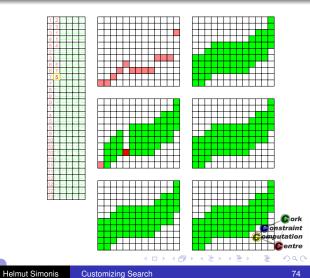


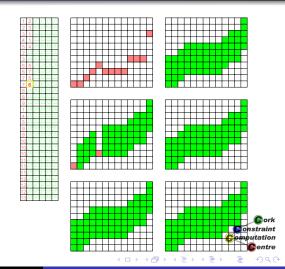


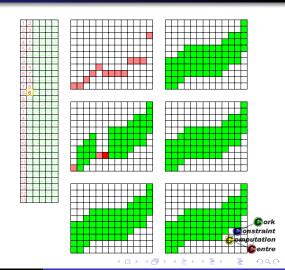


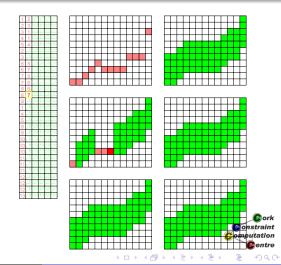


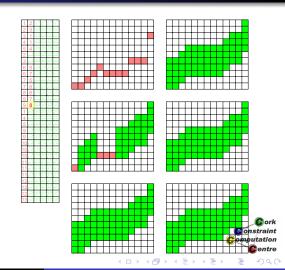


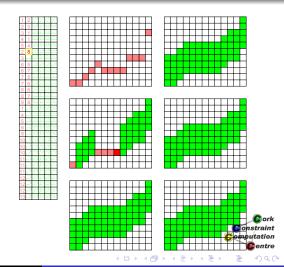


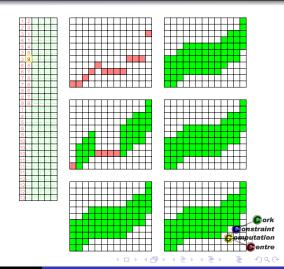


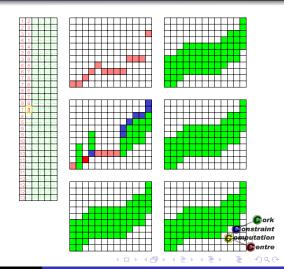


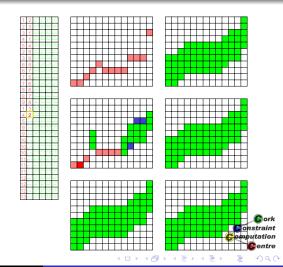


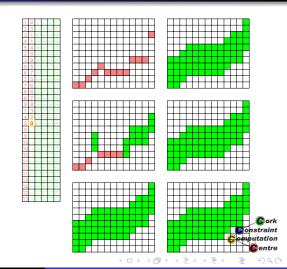




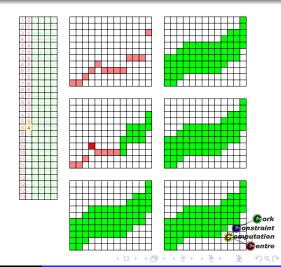




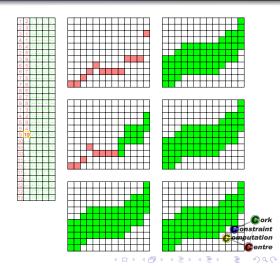


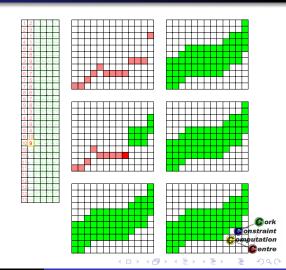


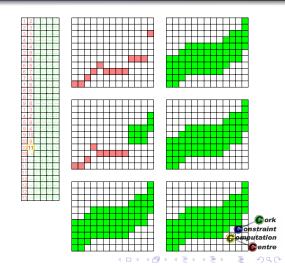
Layered Search

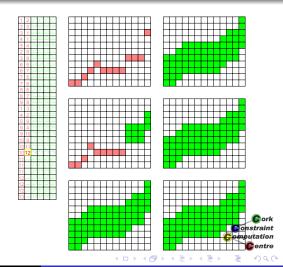


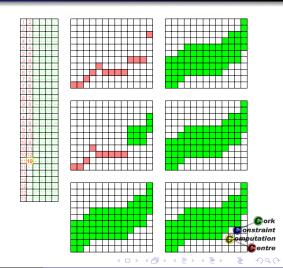
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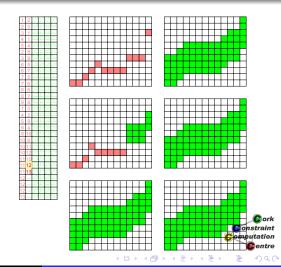


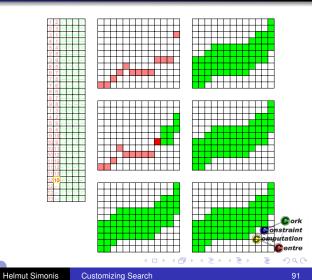


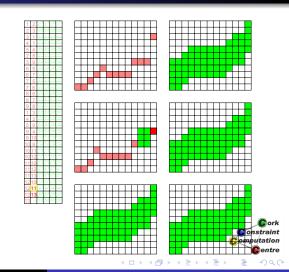


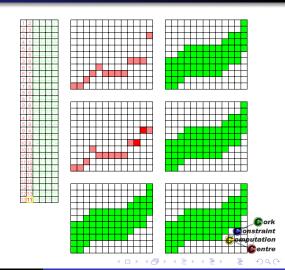


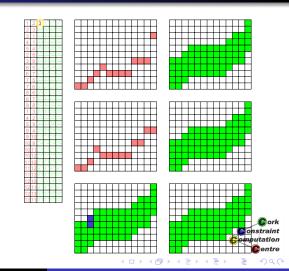


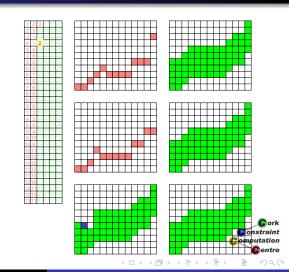


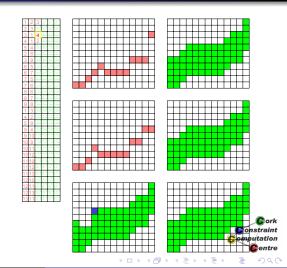


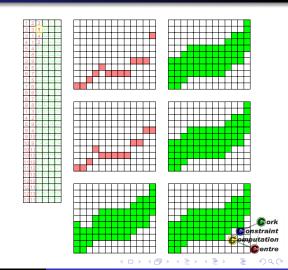


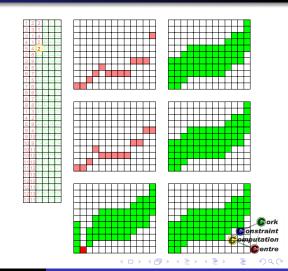


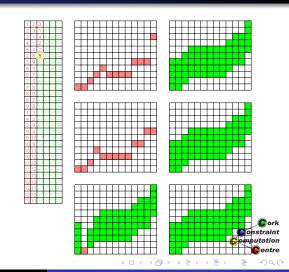


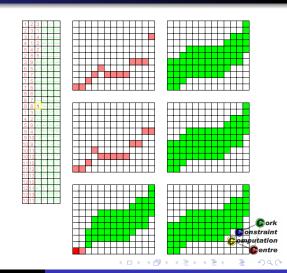


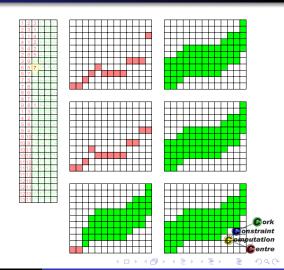


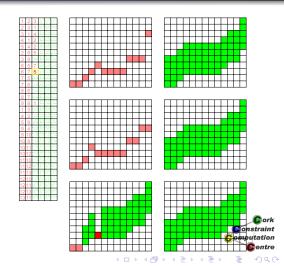


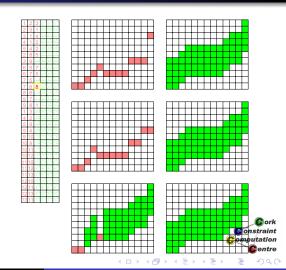


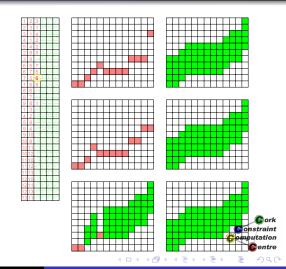


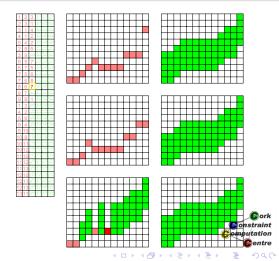


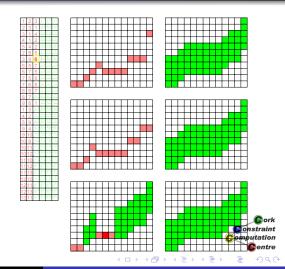


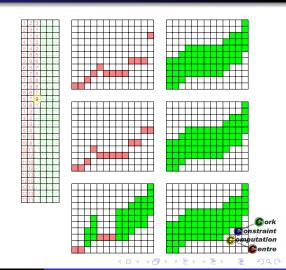


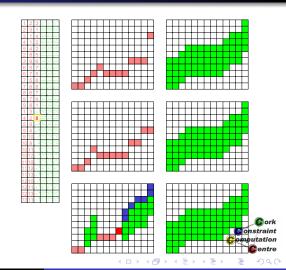


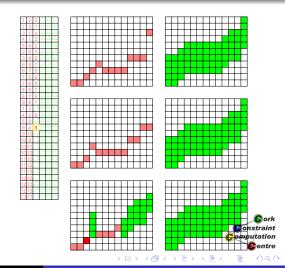


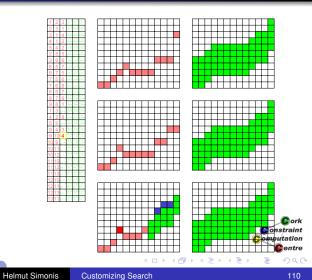


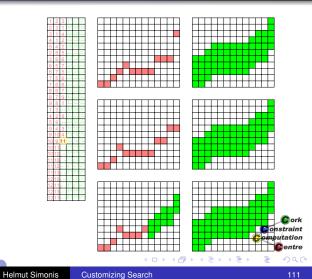


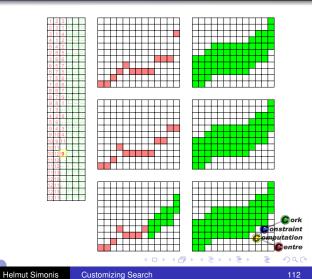


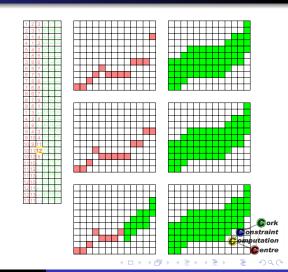


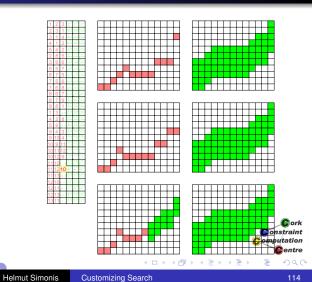


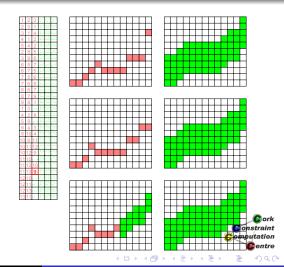


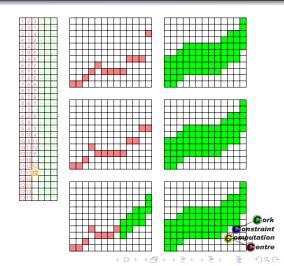


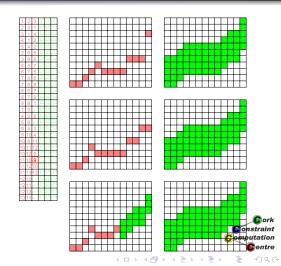


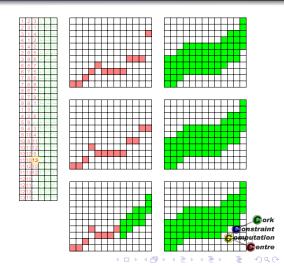


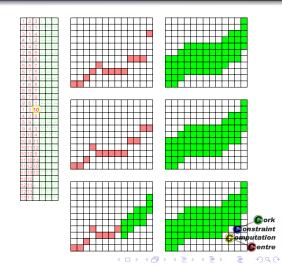


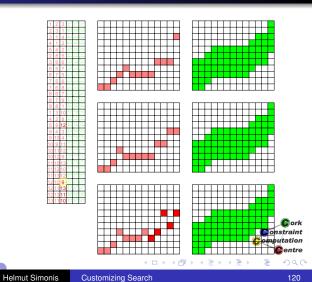


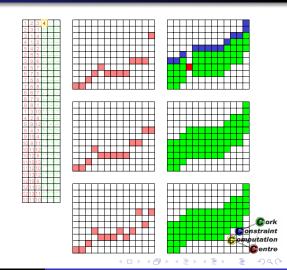


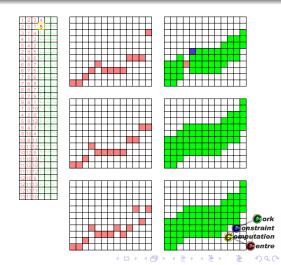


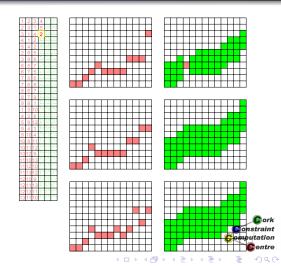


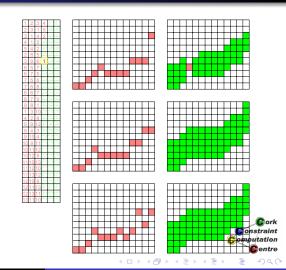


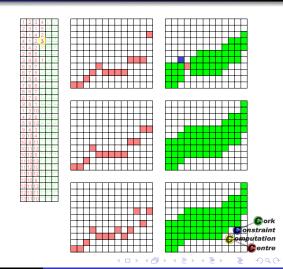


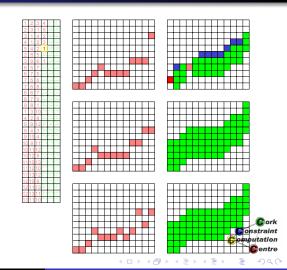


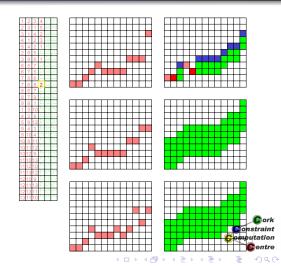


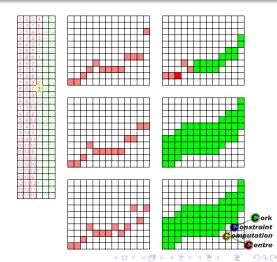


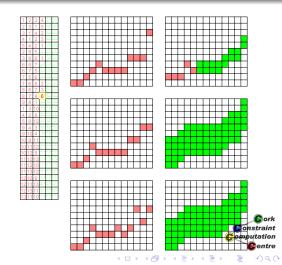


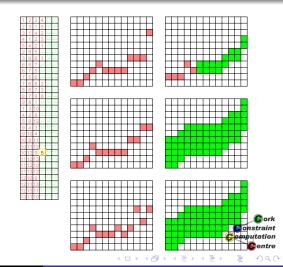


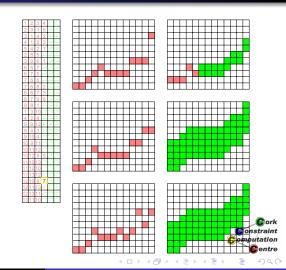


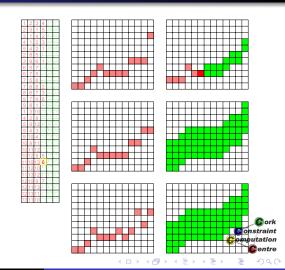


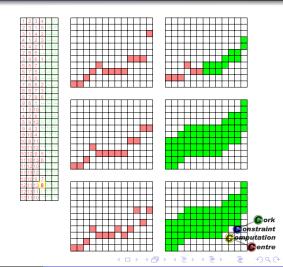


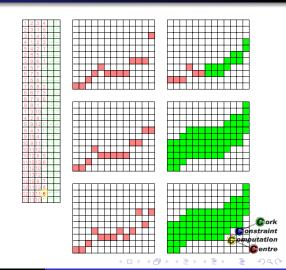


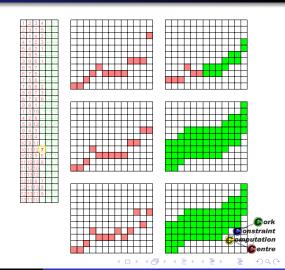


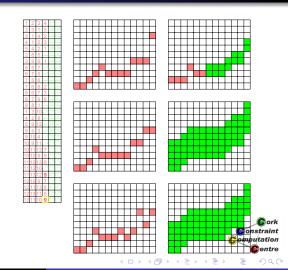


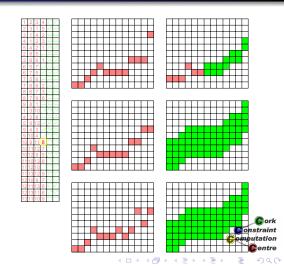


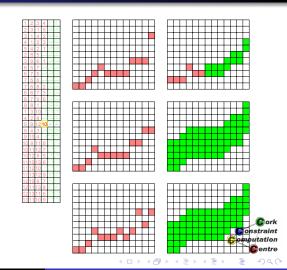


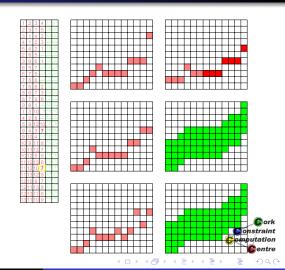


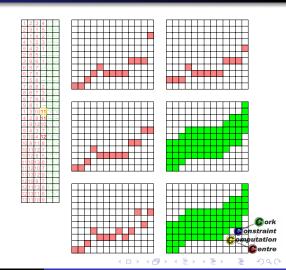


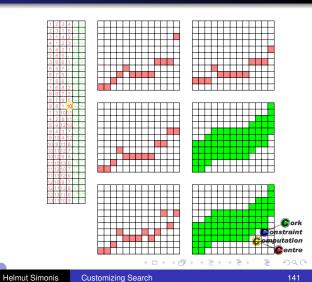


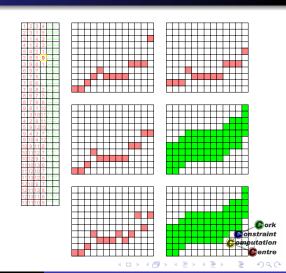


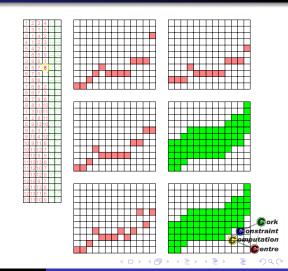


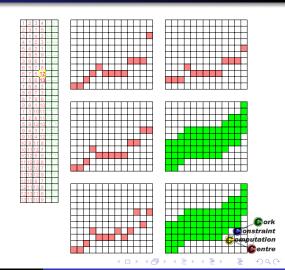


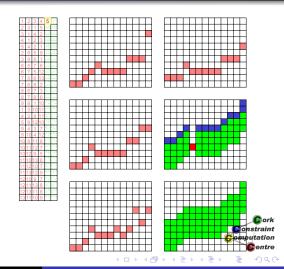


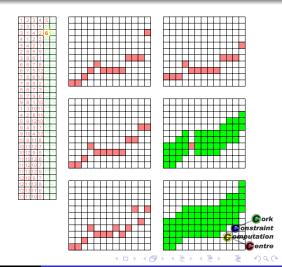


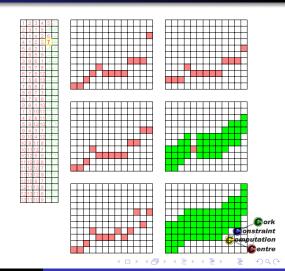


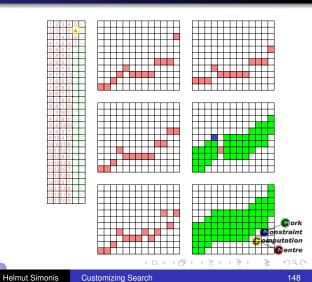


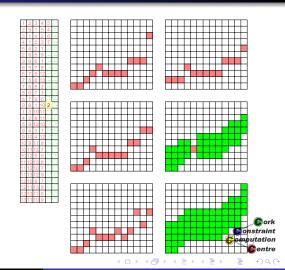


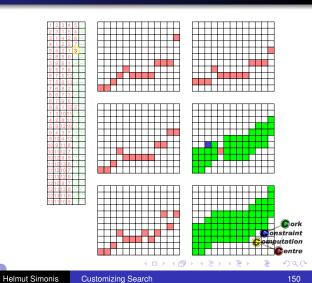


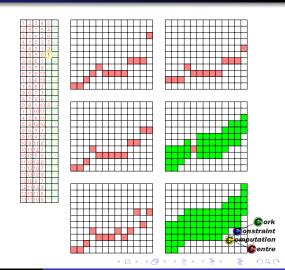


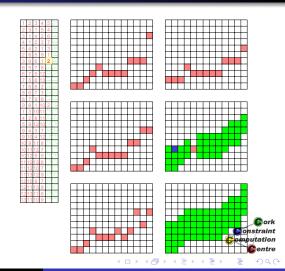


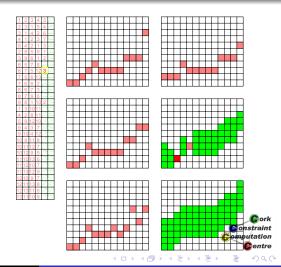


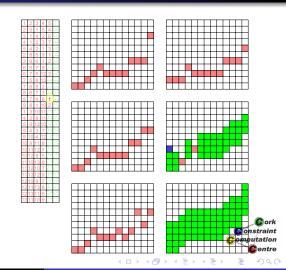


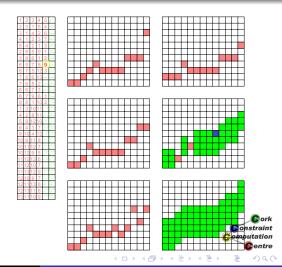


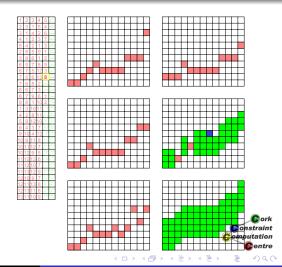


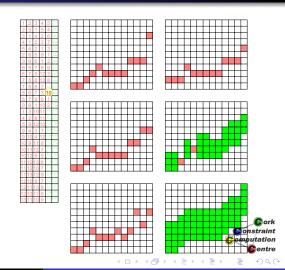


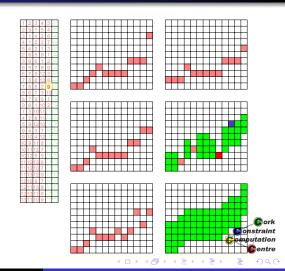


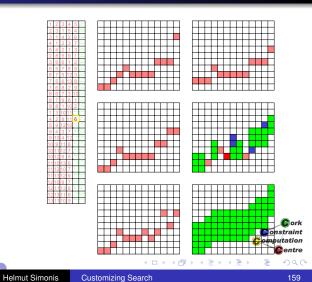


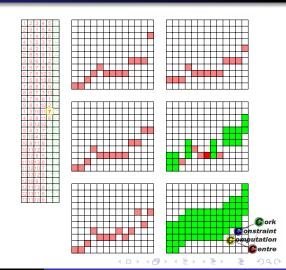


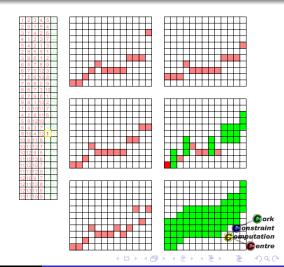


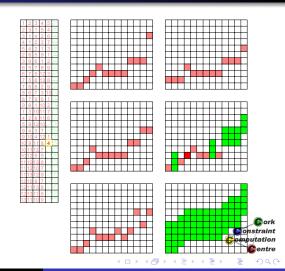


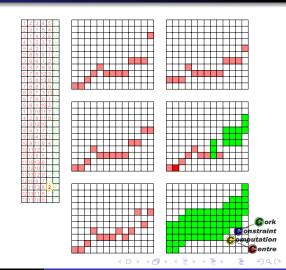


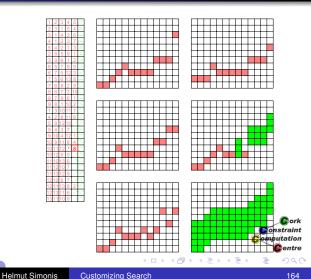


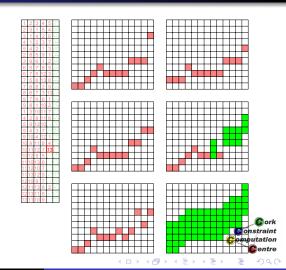


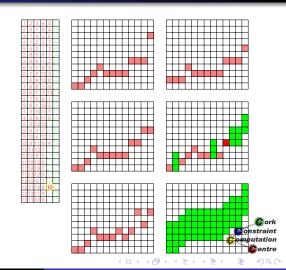


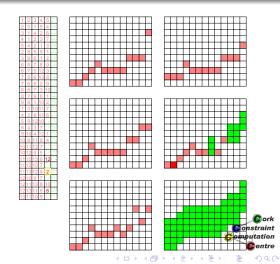


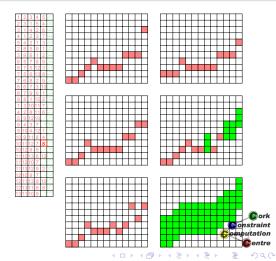


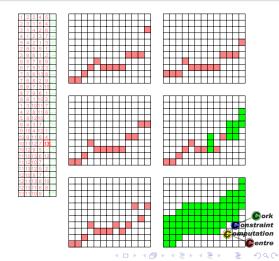


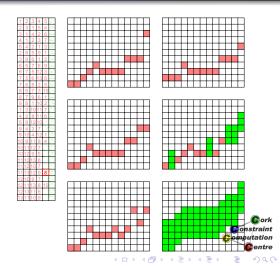


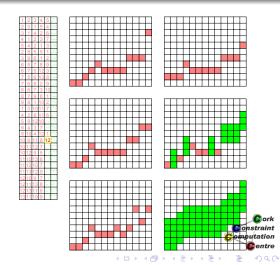


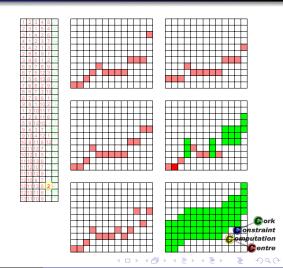


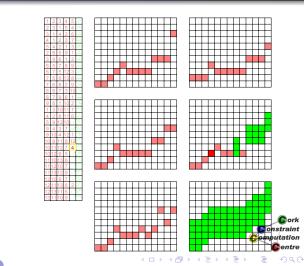


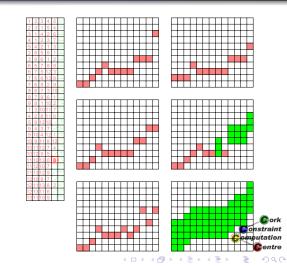


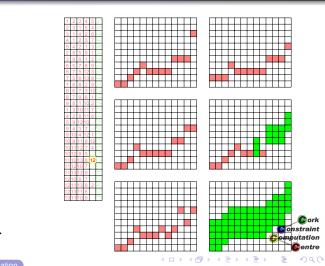


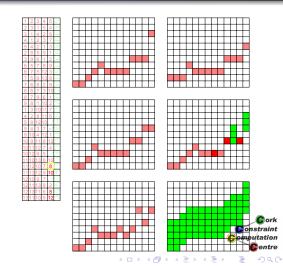


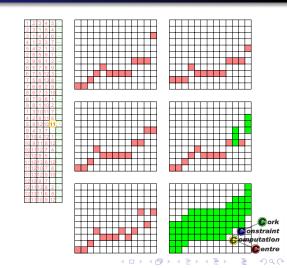


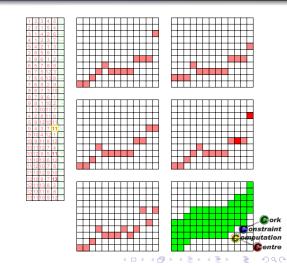


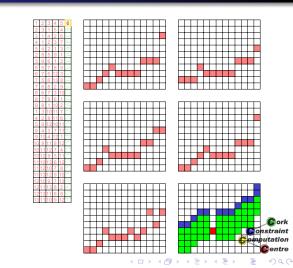


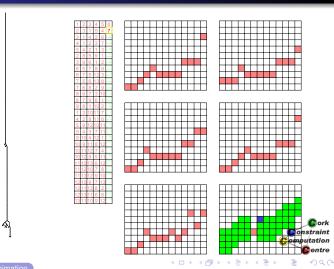


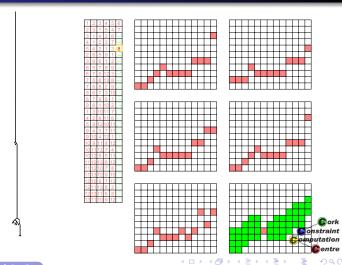


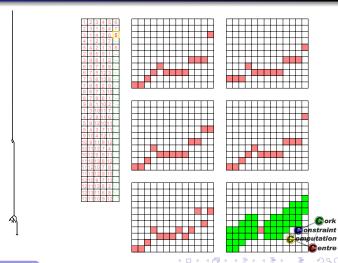


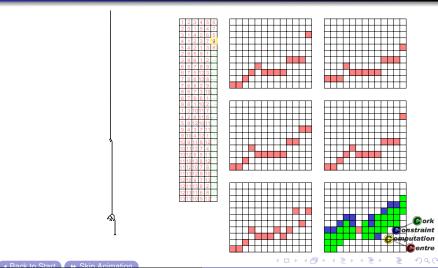


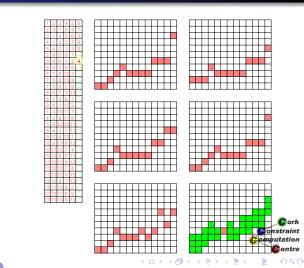


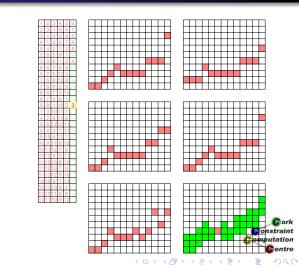


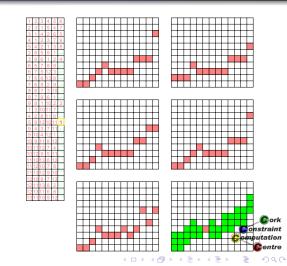


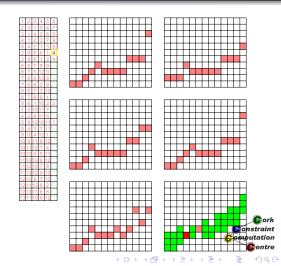


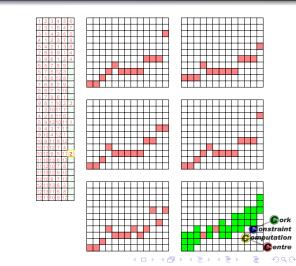


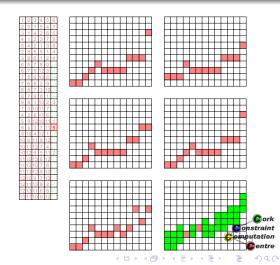


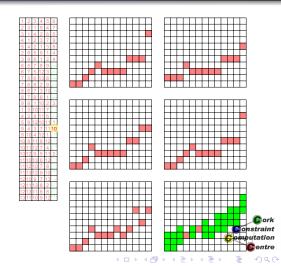


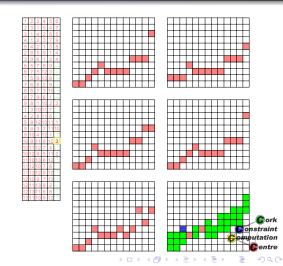


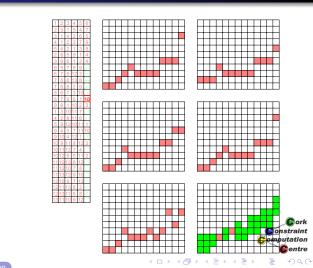


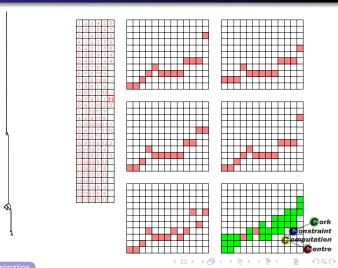


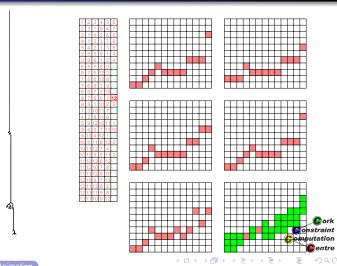


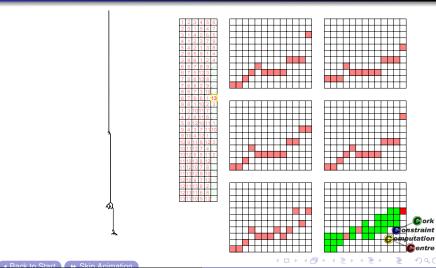


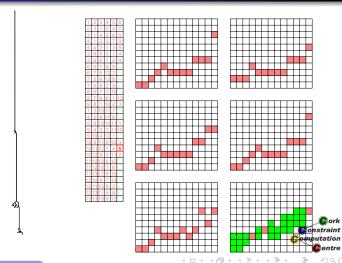


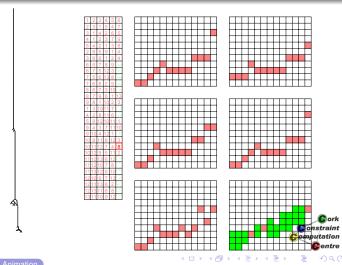


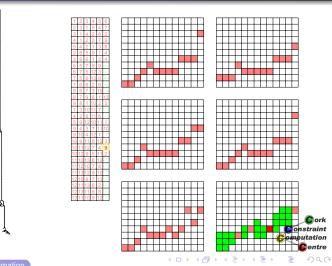


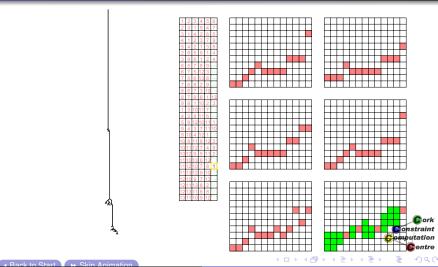


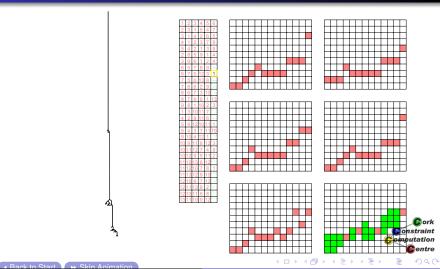


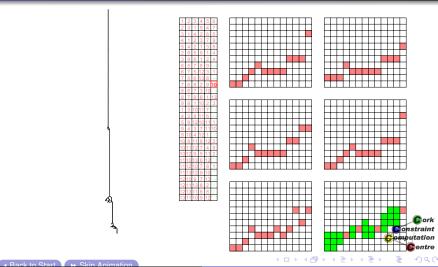


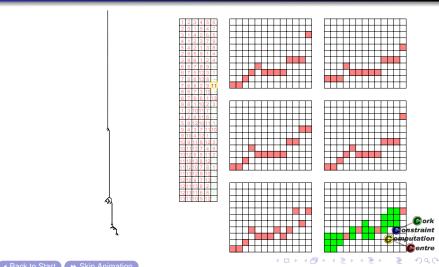


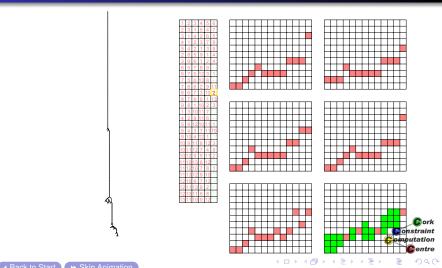


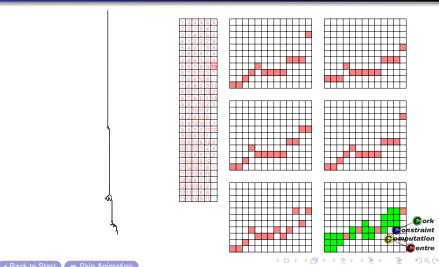


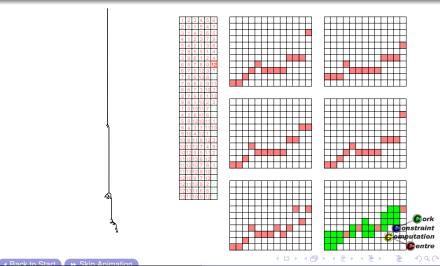


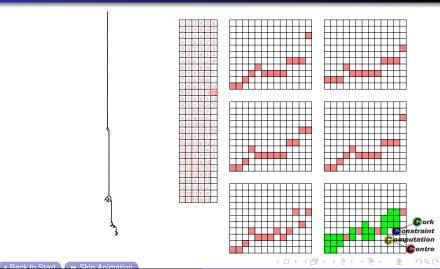


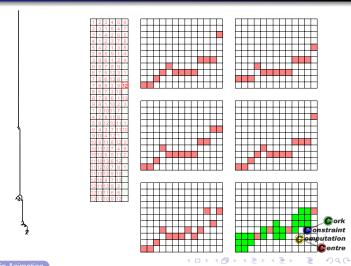


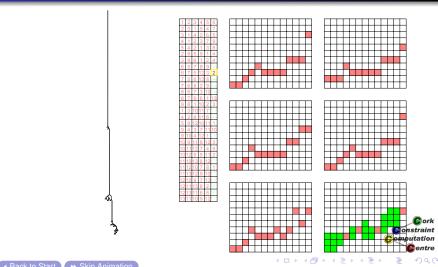


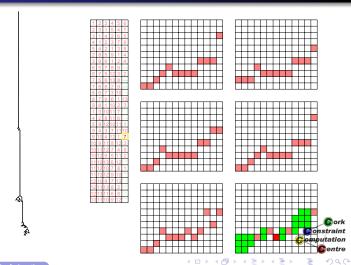


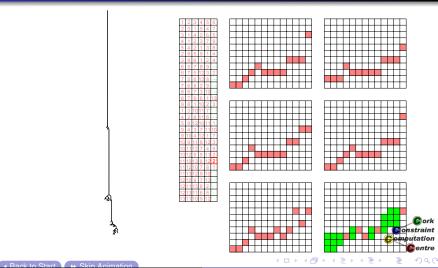


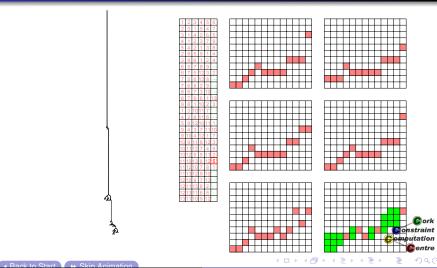


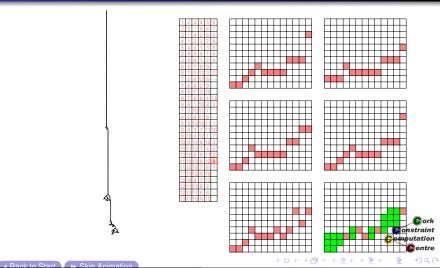


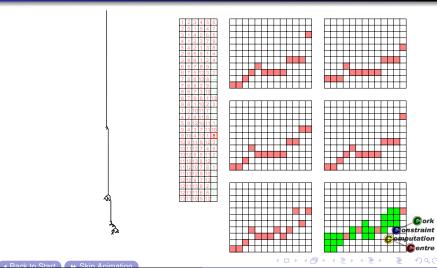


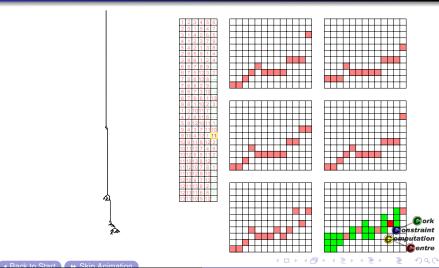


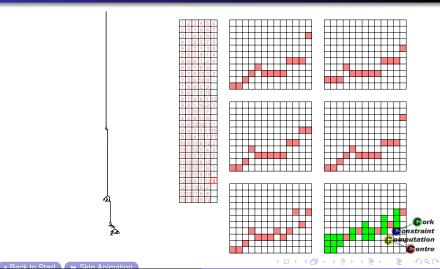


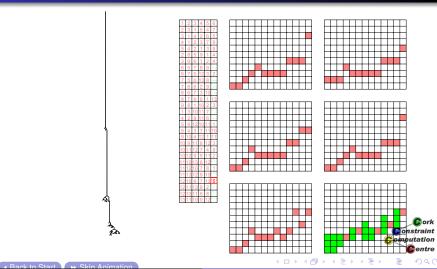


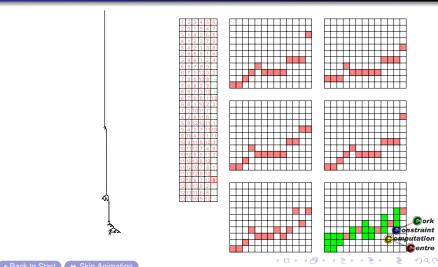


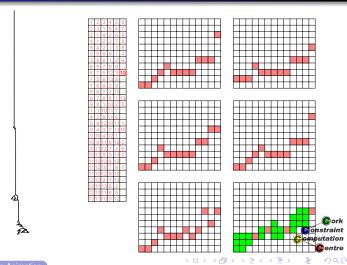


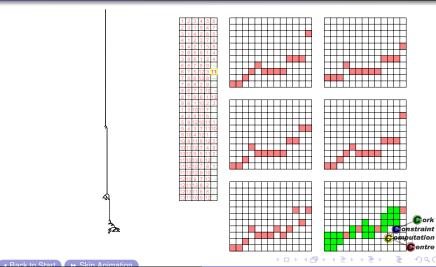


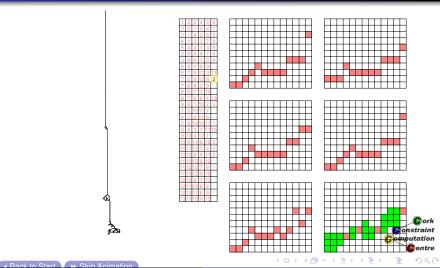


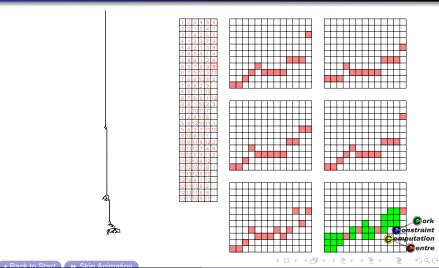


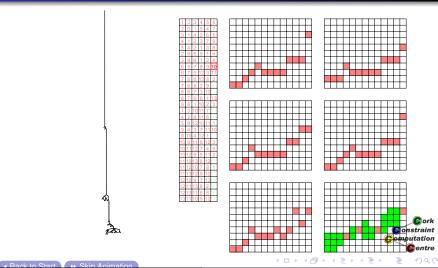


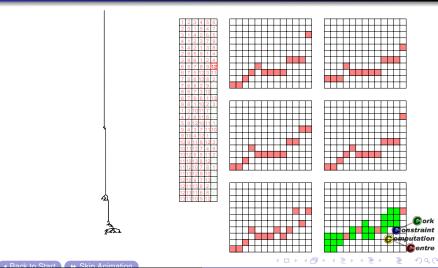


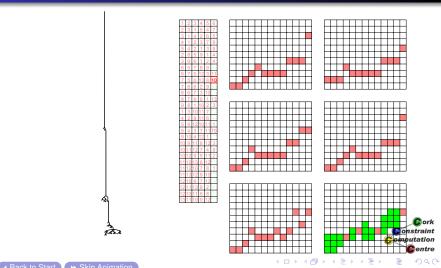


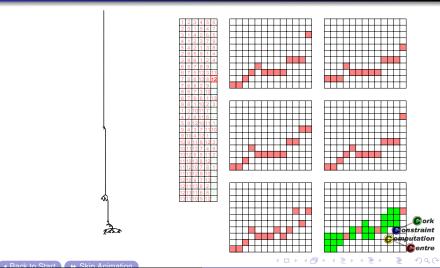


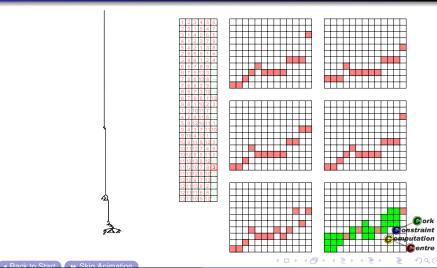


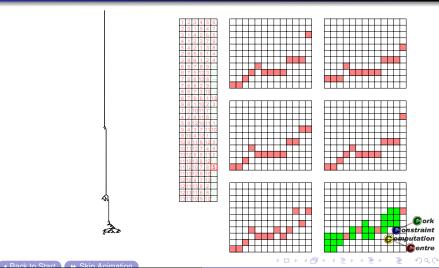


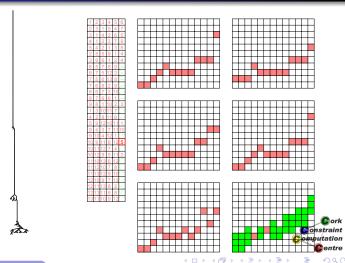


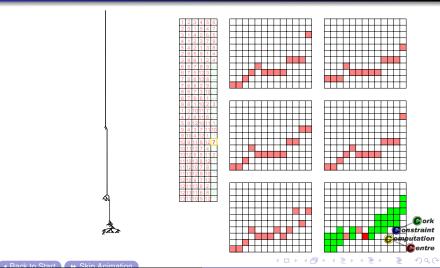


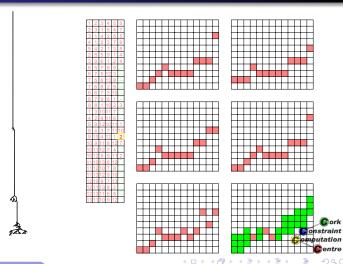


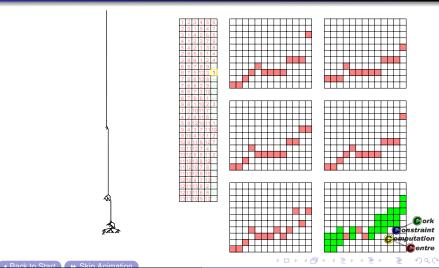


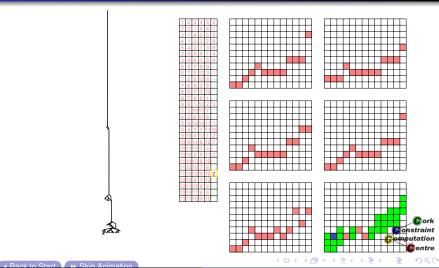


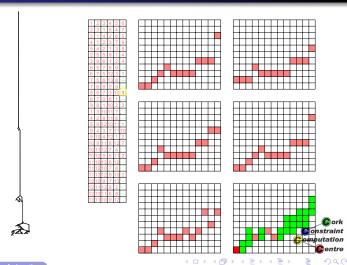


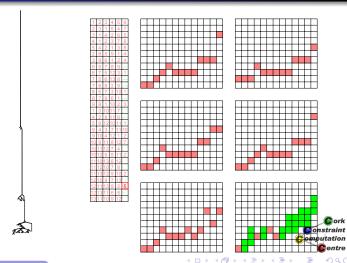


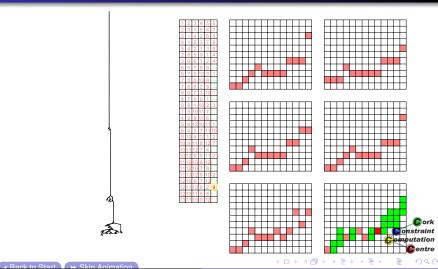


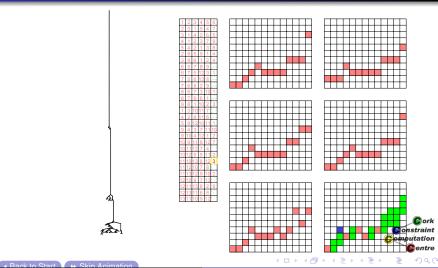


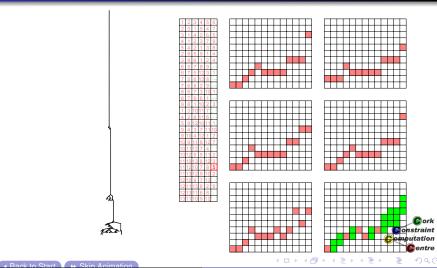


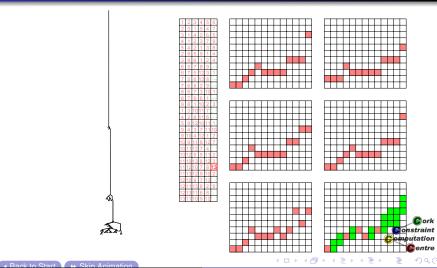


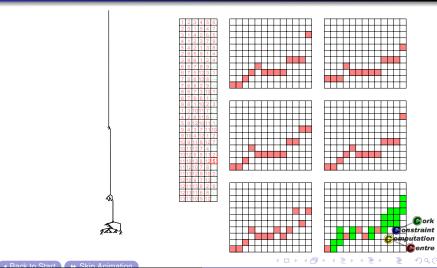


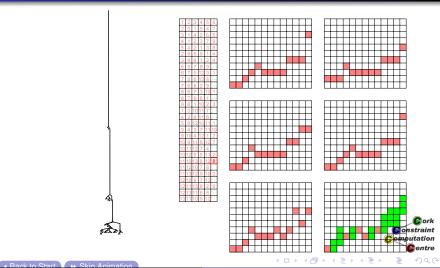


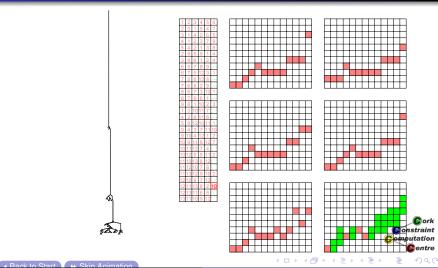


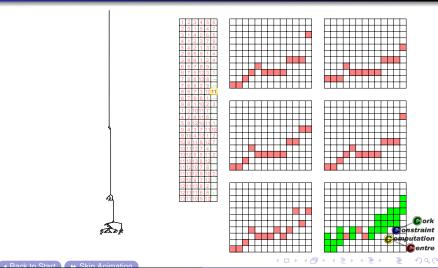


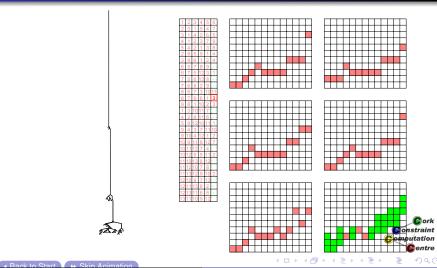


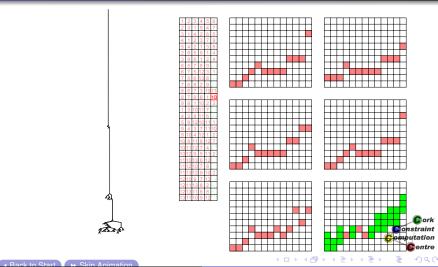


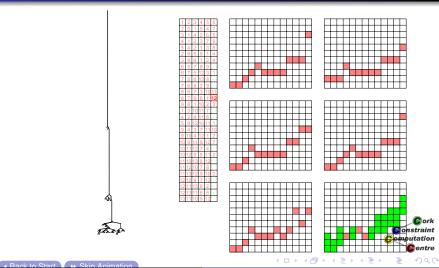


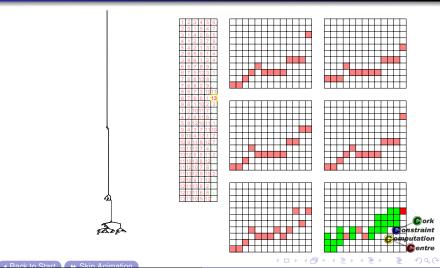


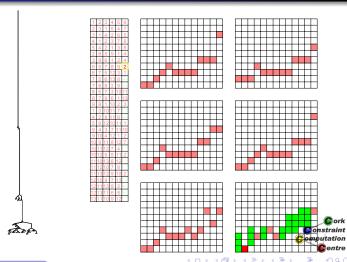


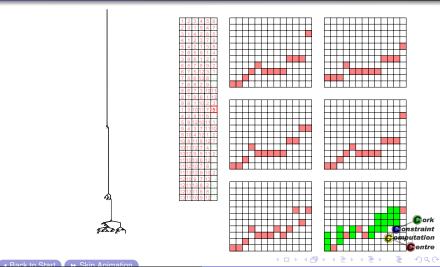


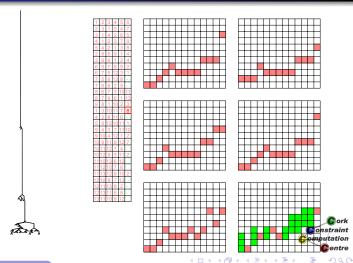


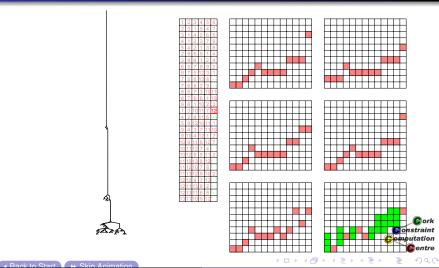




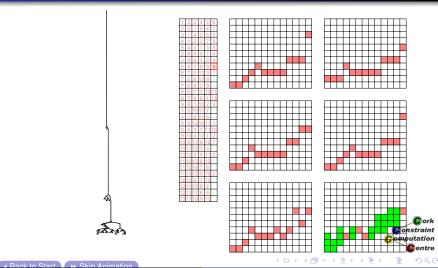




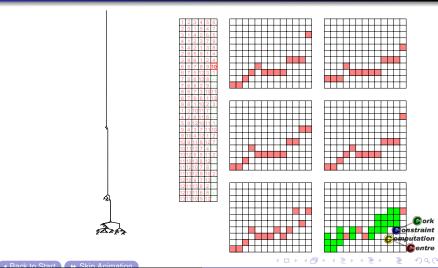


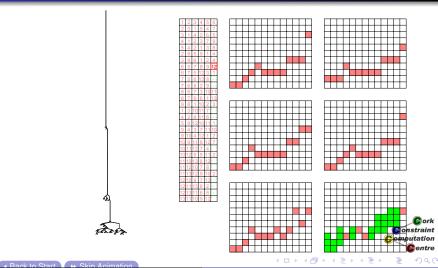


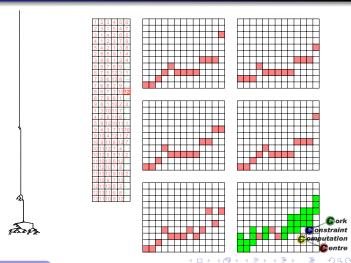
Layered Search

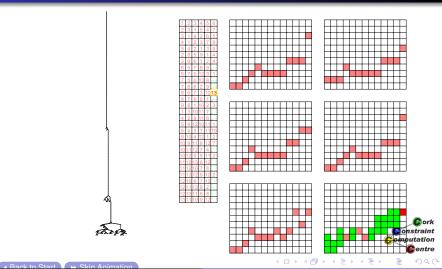


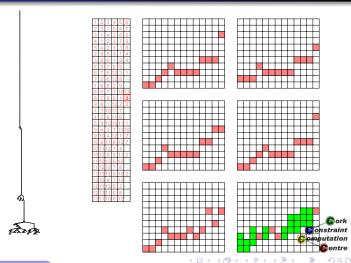
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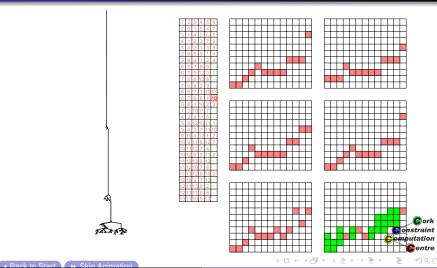


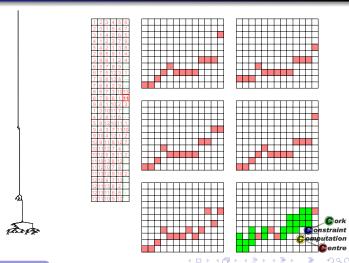


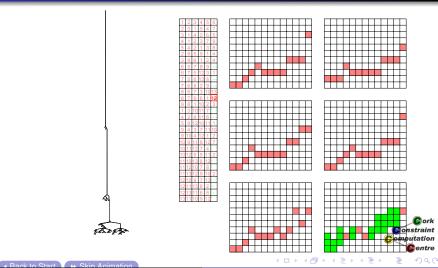


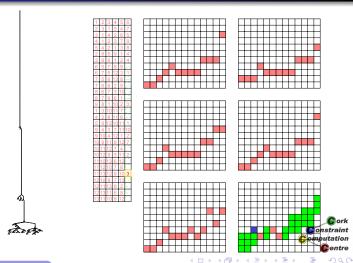


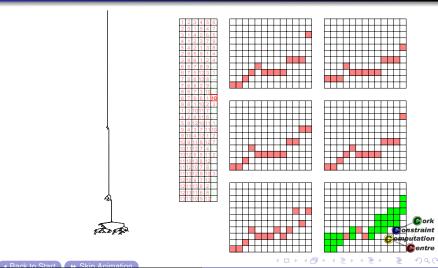


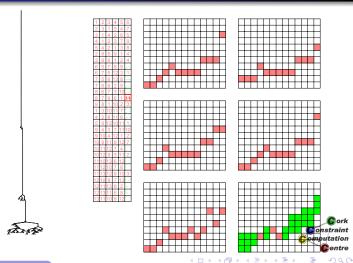


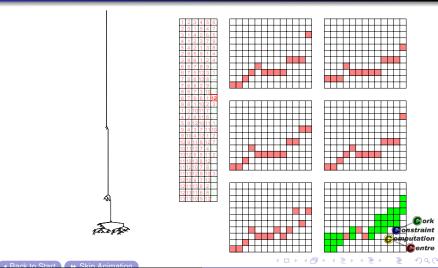


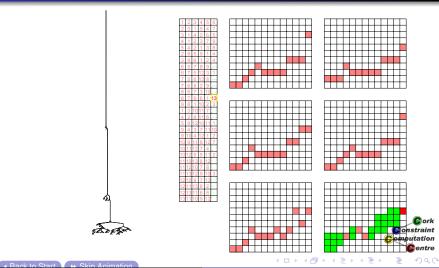


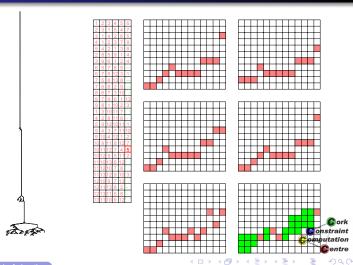


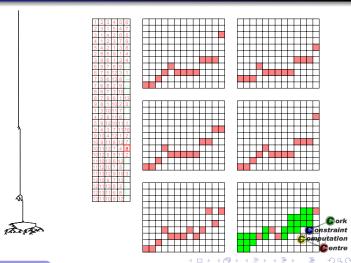


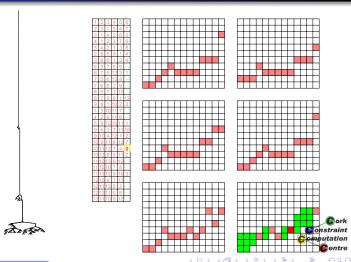


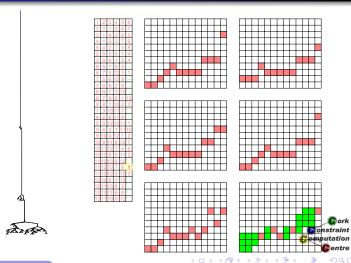


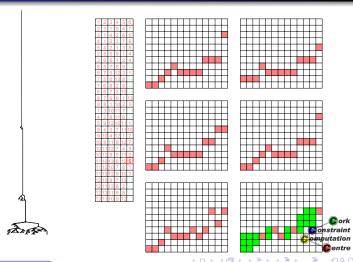


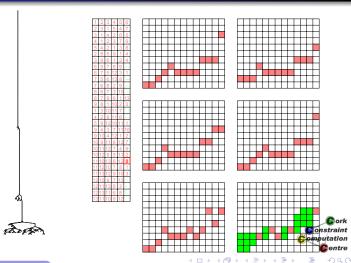


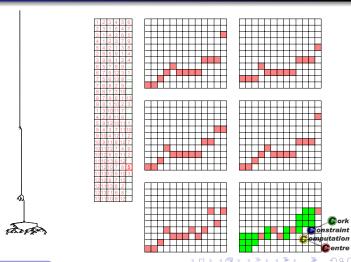


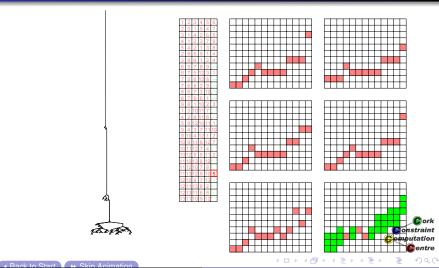


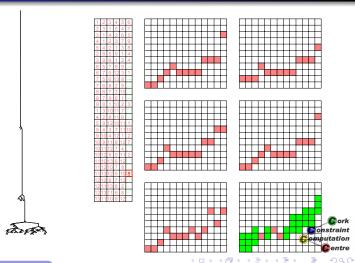


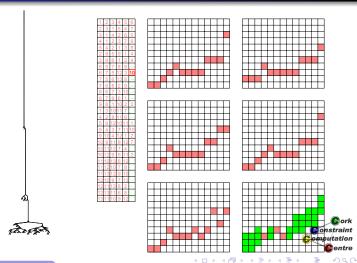


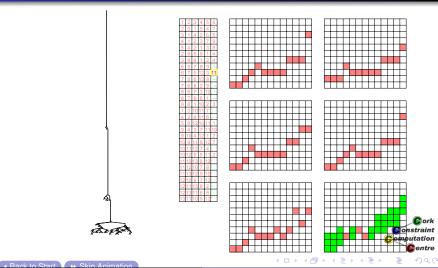


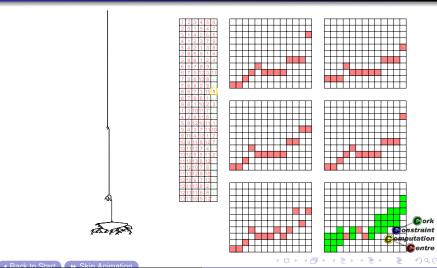


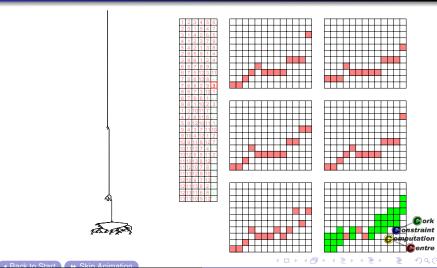


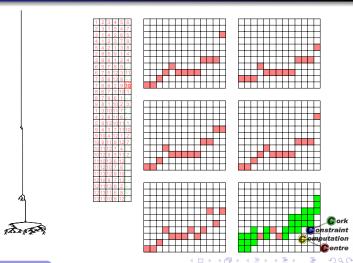


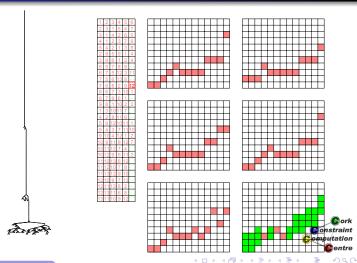


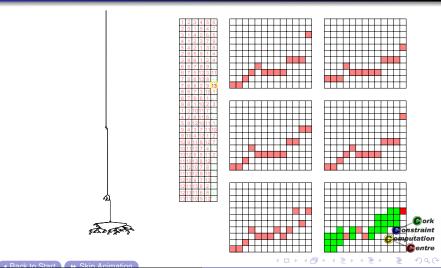


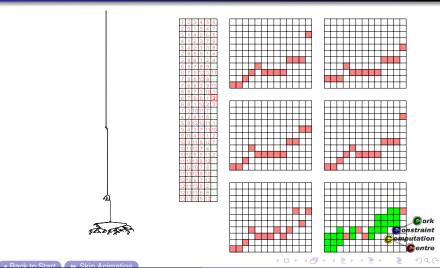


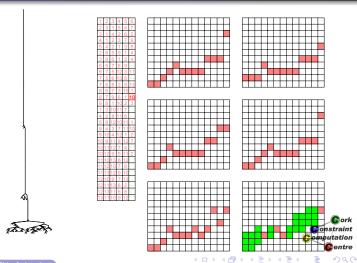


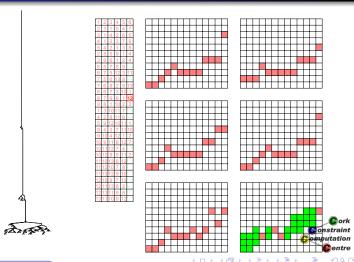


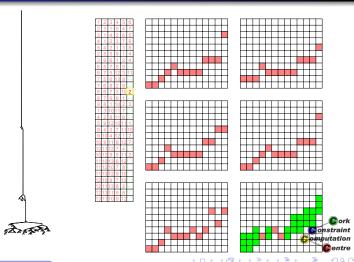


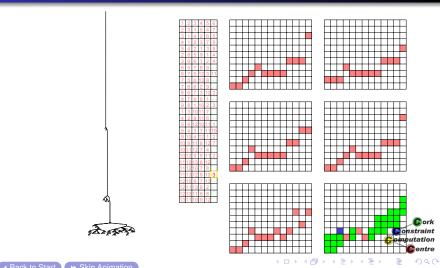


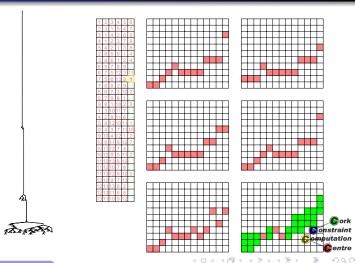


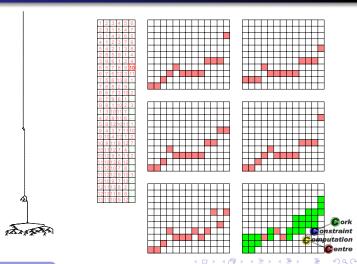


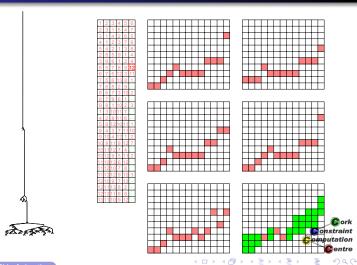


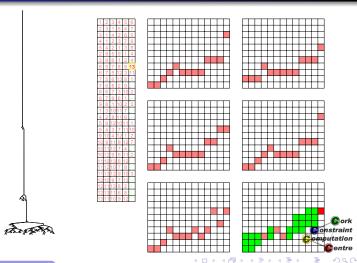


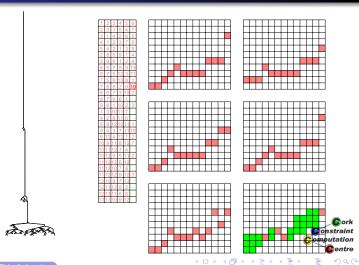


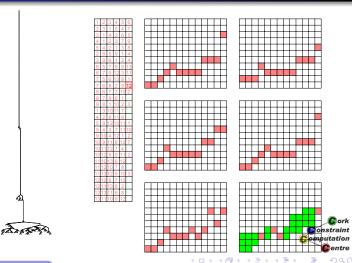


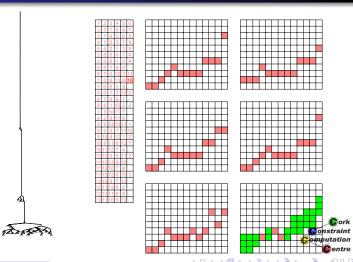


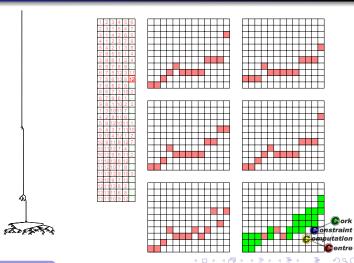


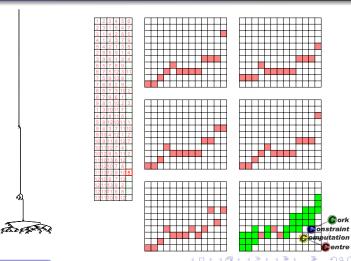


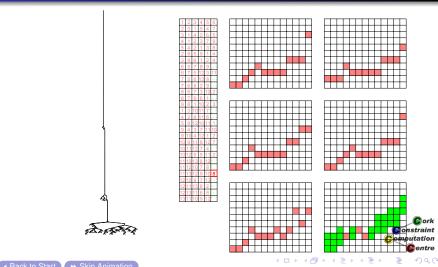


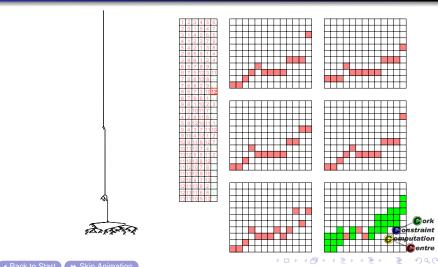


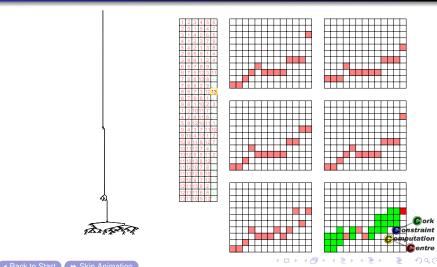


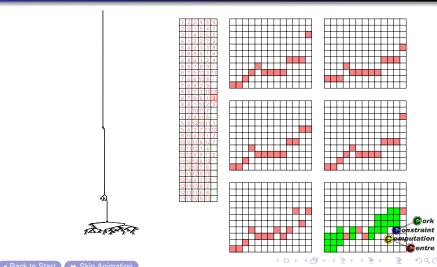


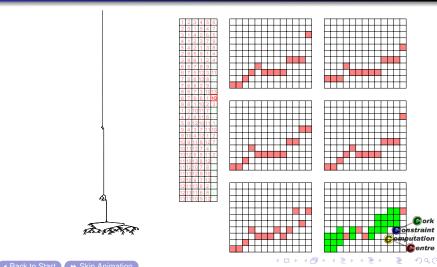


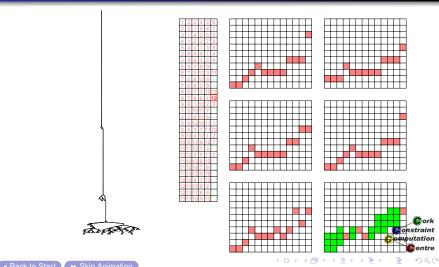


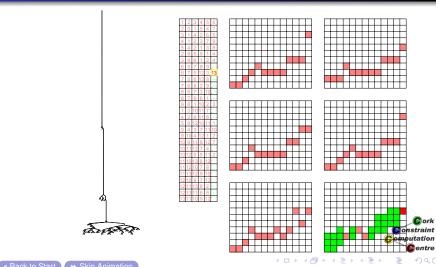


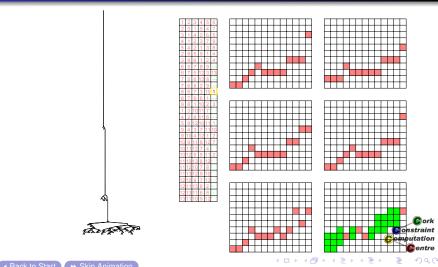


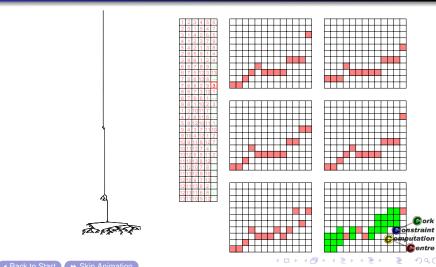


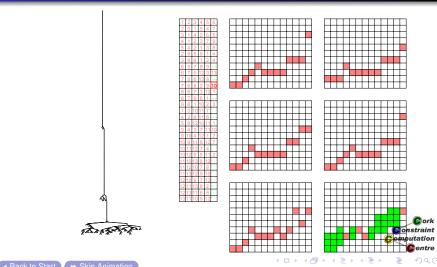


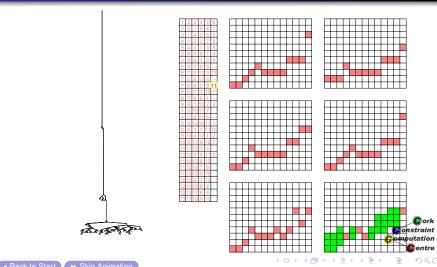


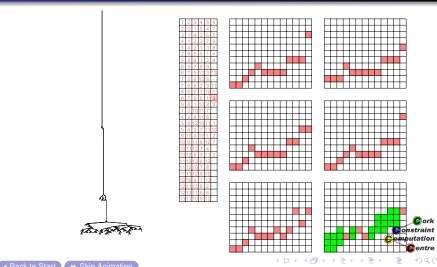


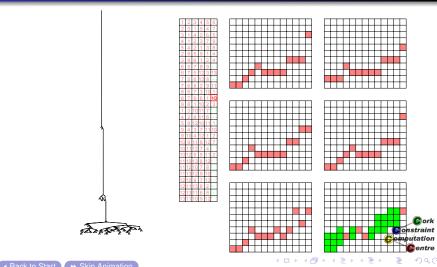


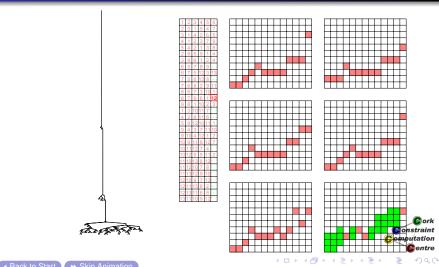


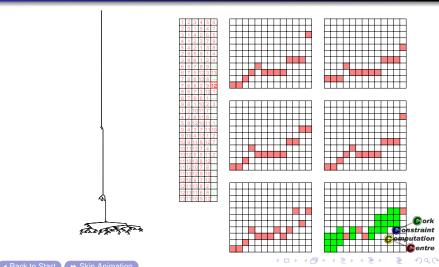


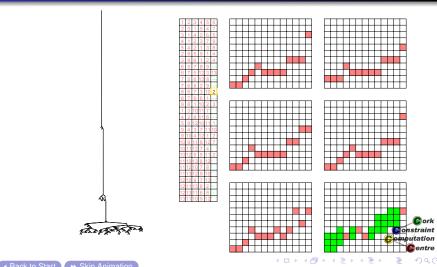


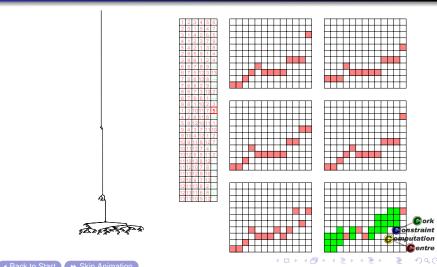


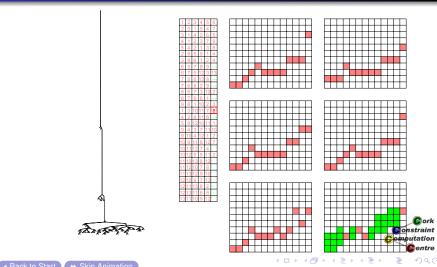


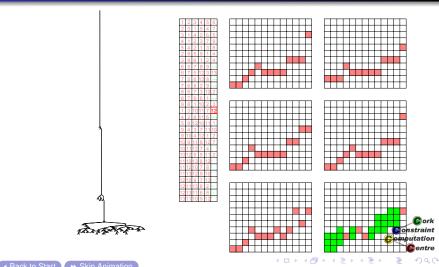


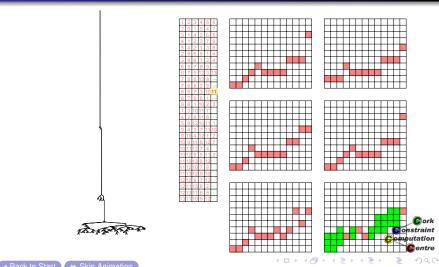


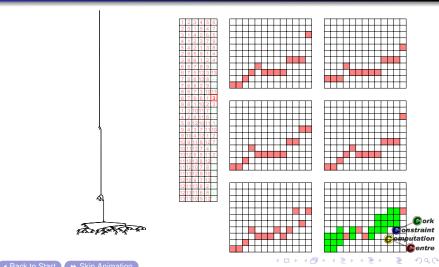


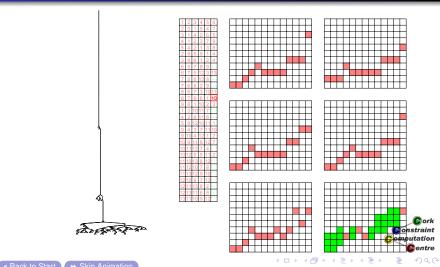


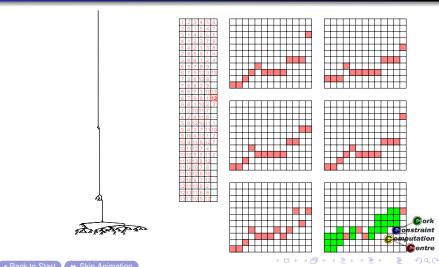


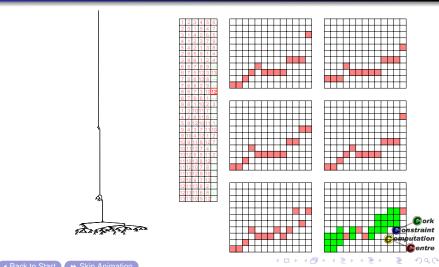


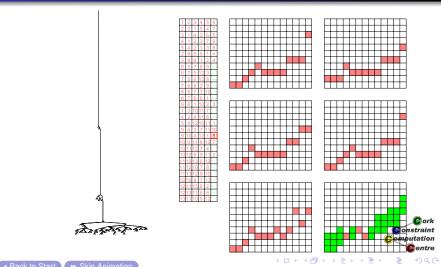


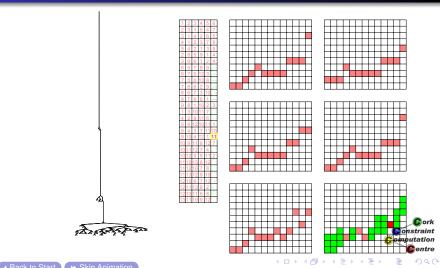


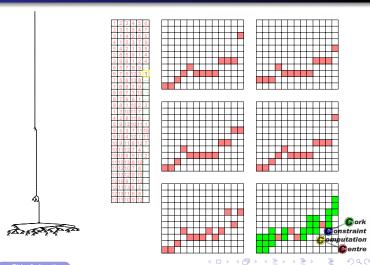


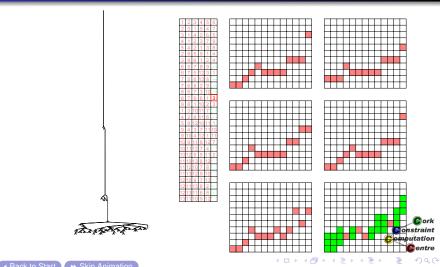


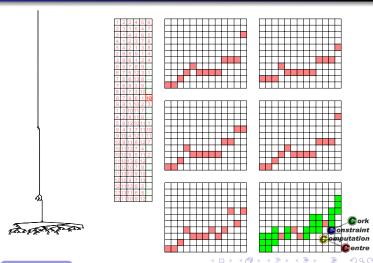


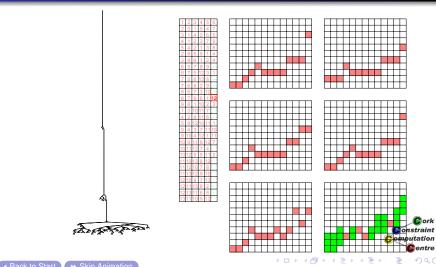


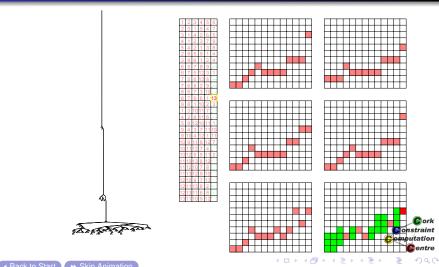


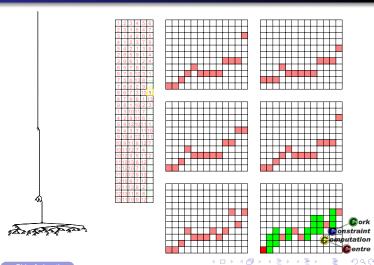


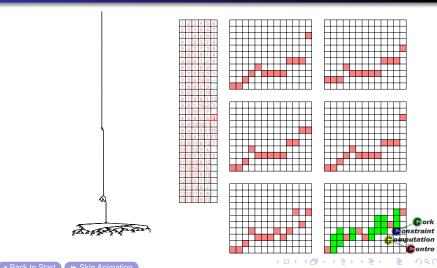


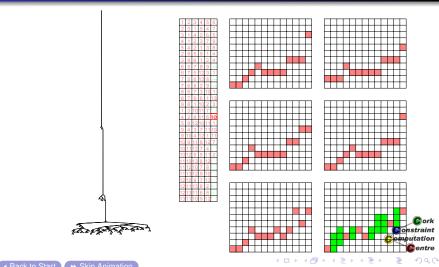


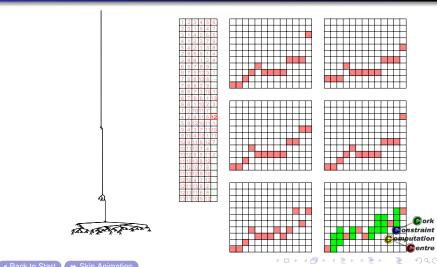


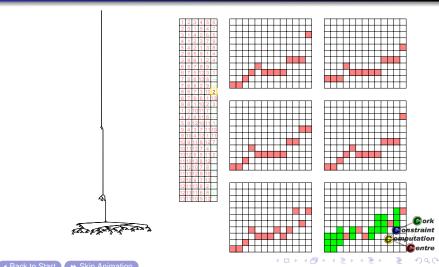


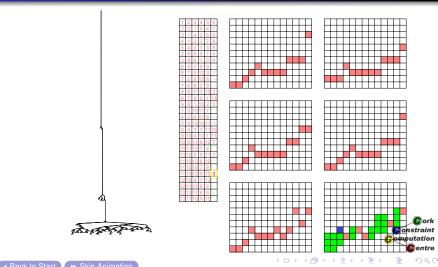


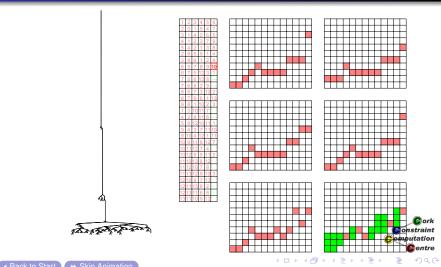


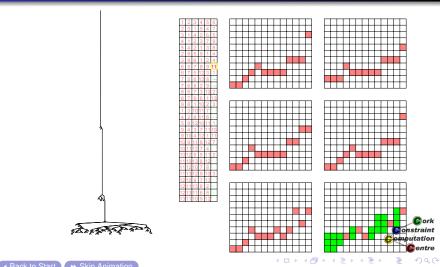


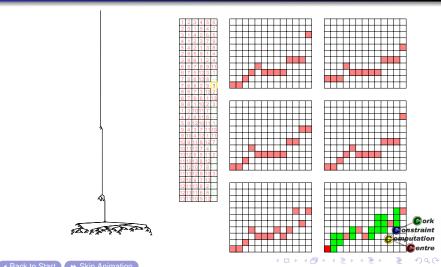


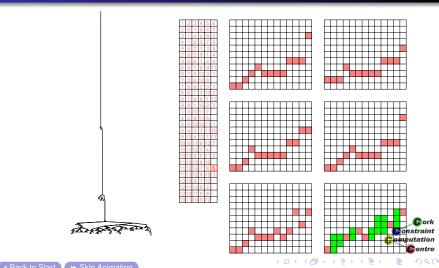


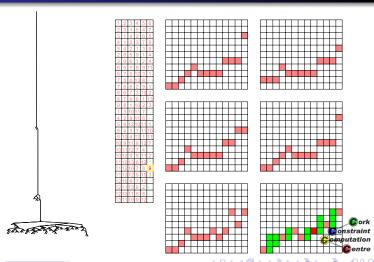


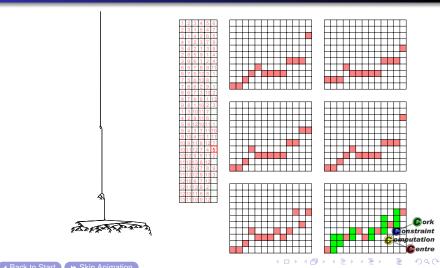


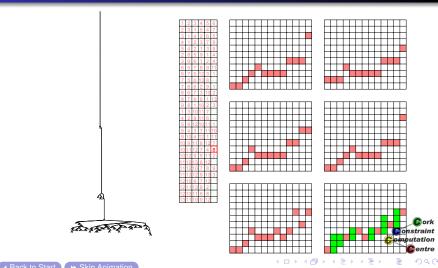


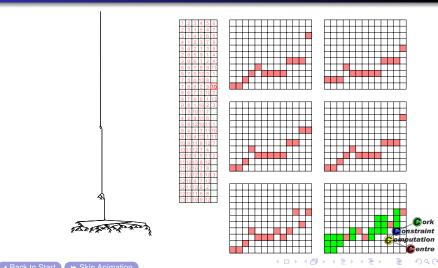


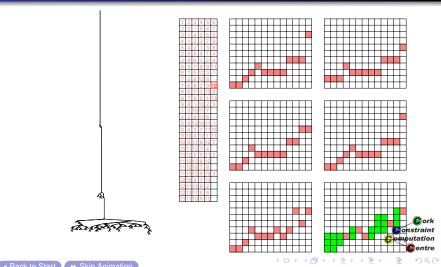


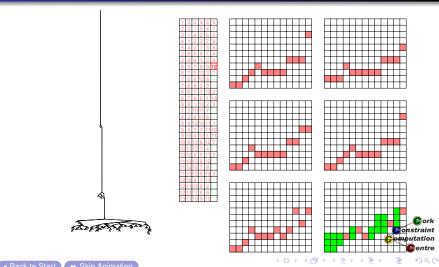


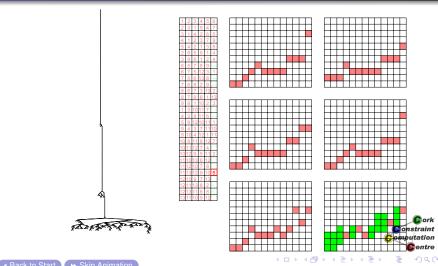


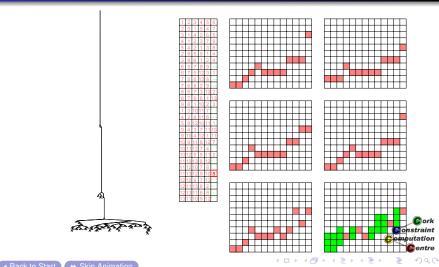


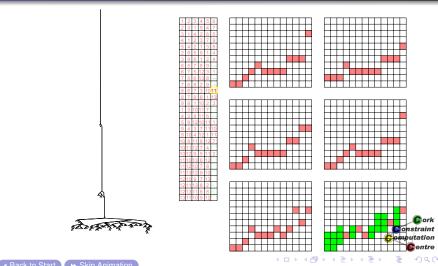


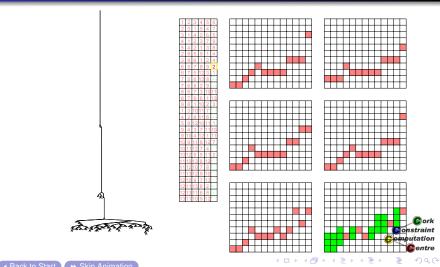


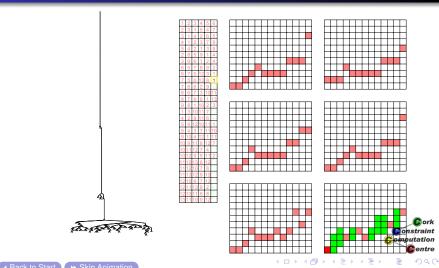


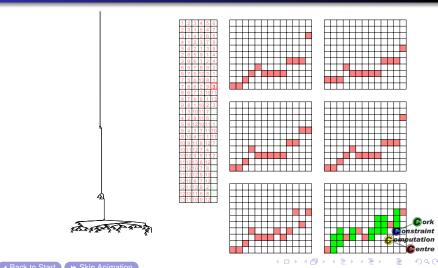


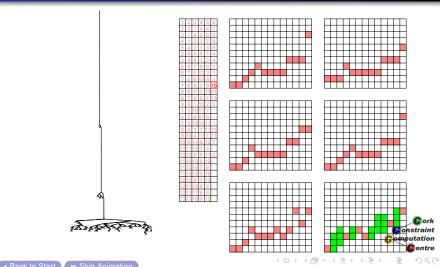


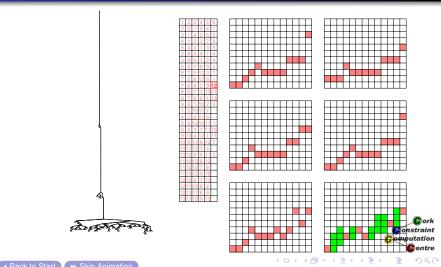


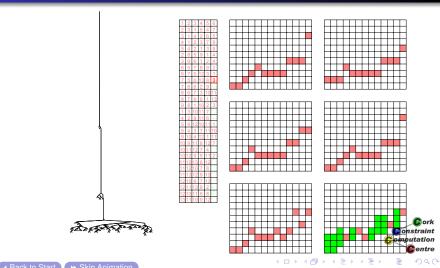


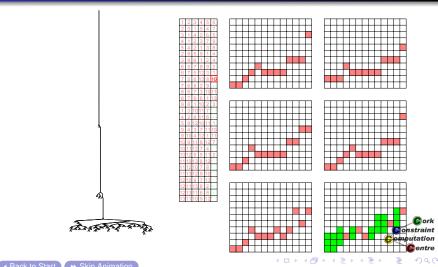


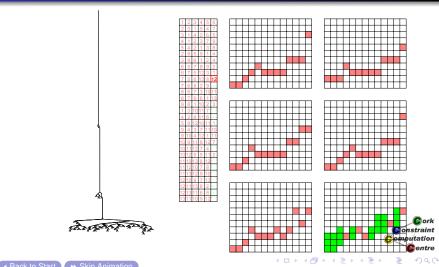


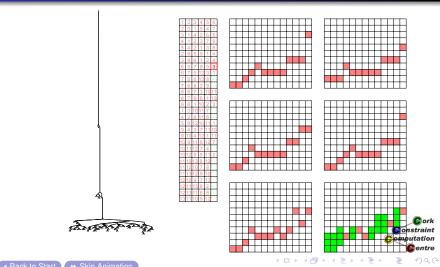


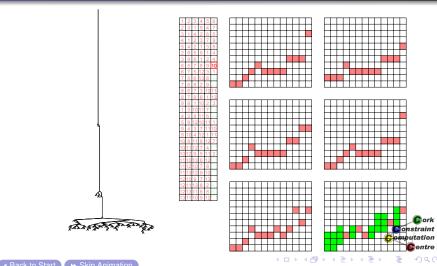


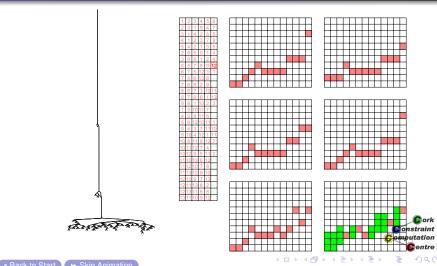


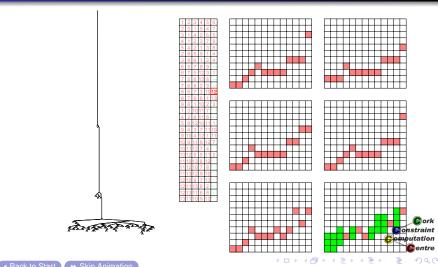


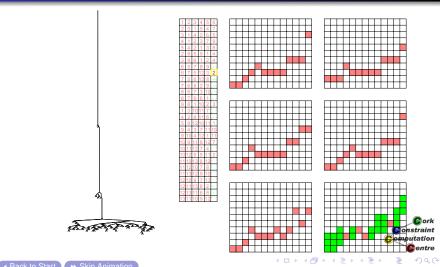


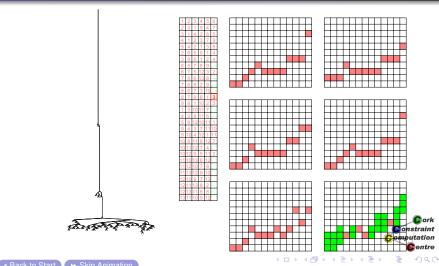


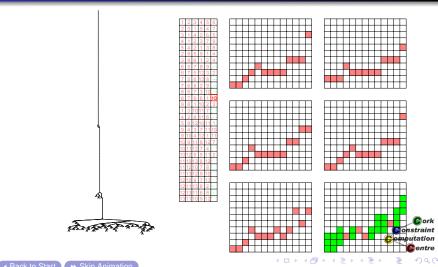


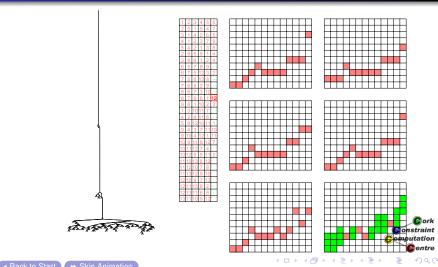


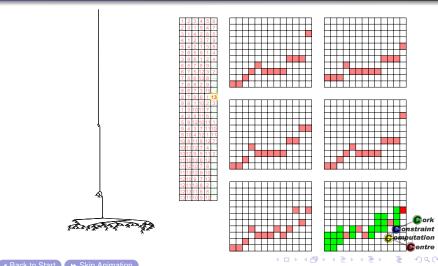


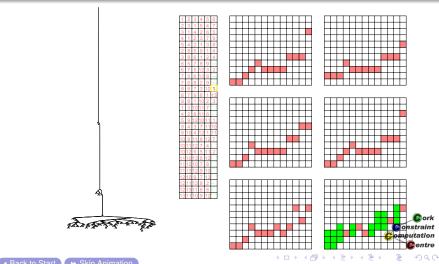


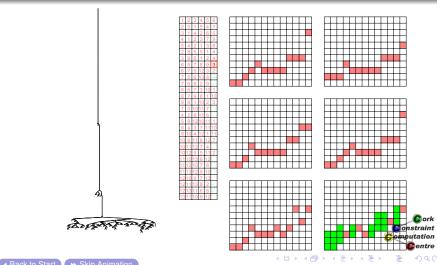


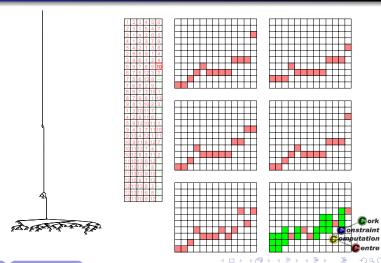


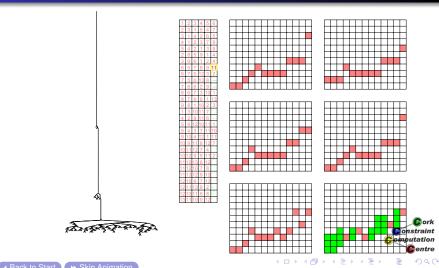


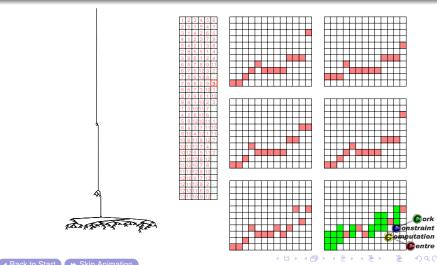


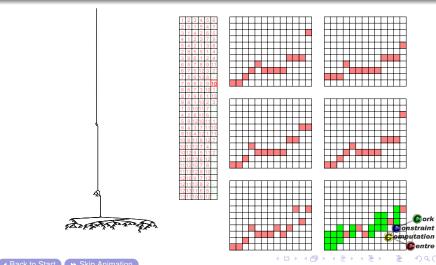


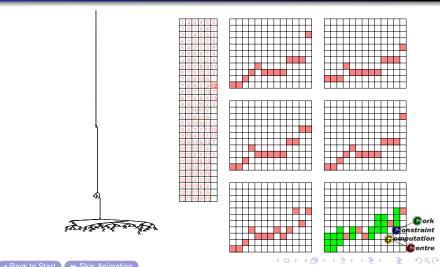


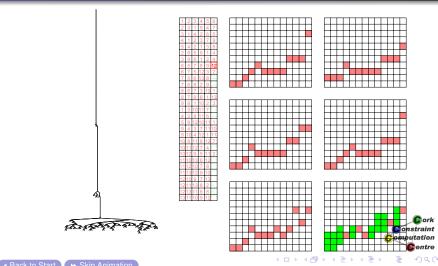


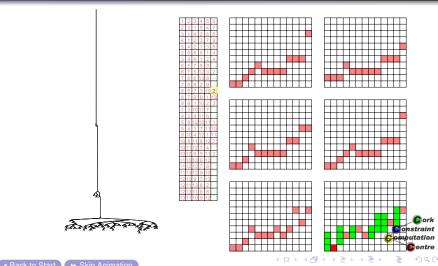


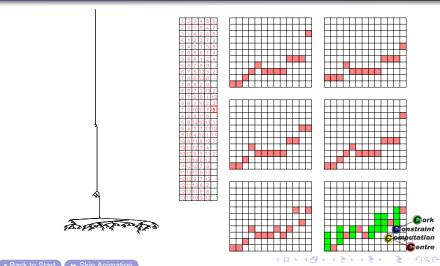


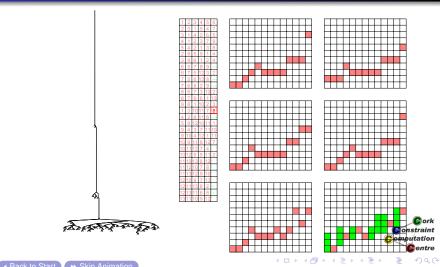


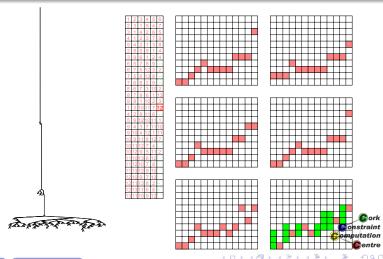


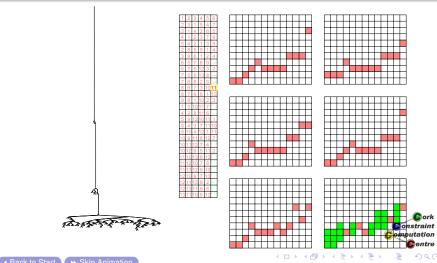


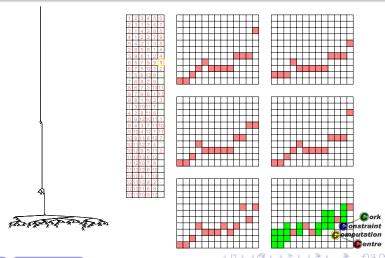


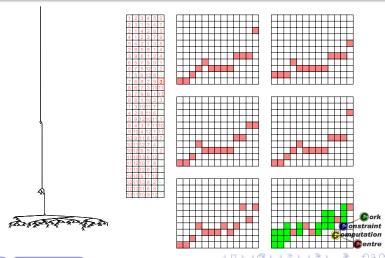


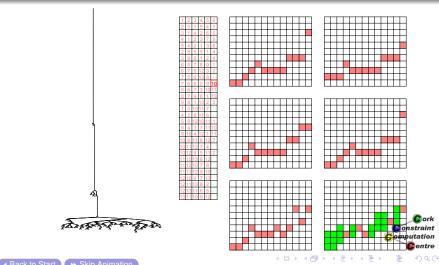


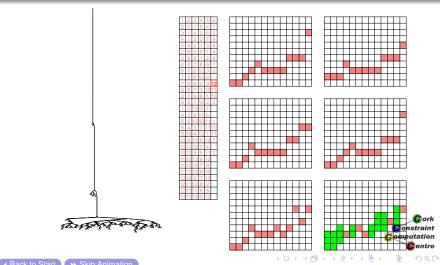


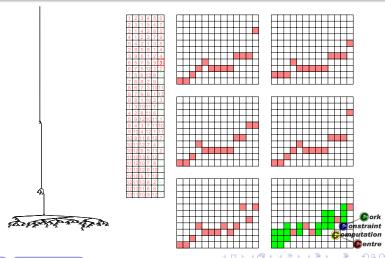


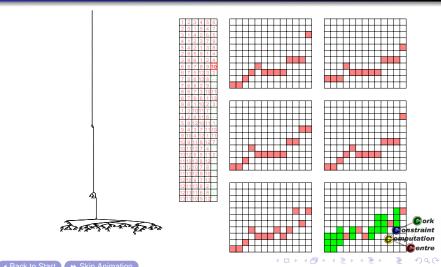


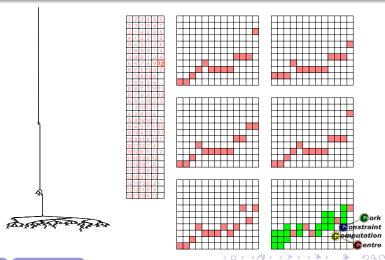


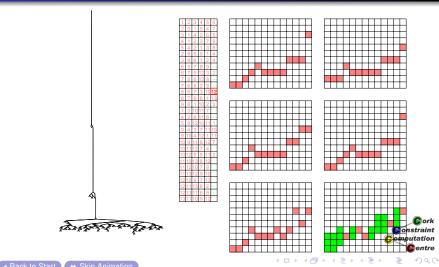


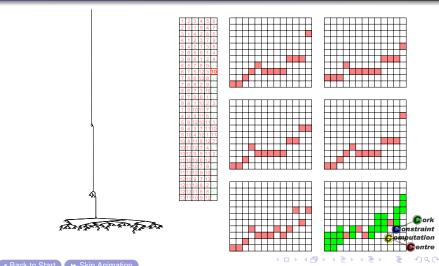


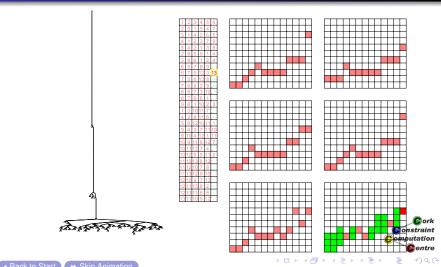


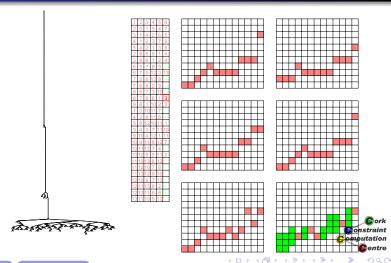


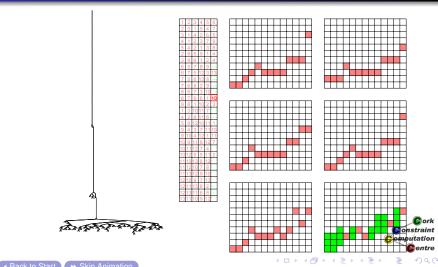


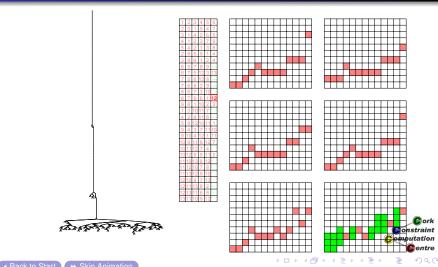


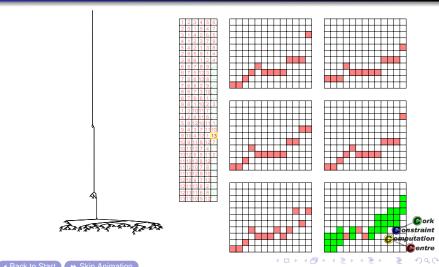


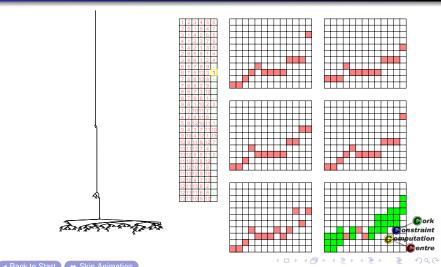


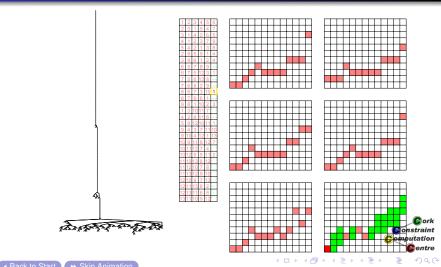


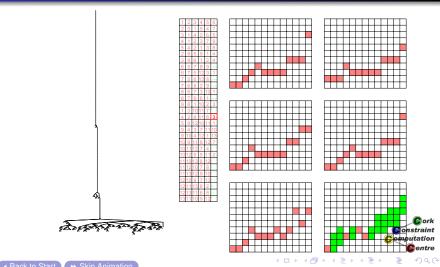


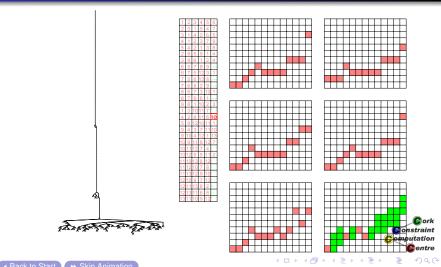


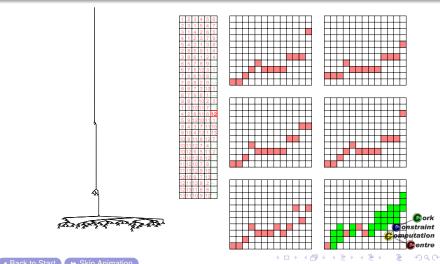


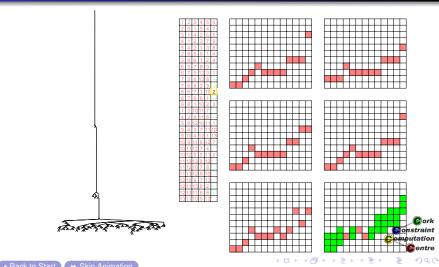


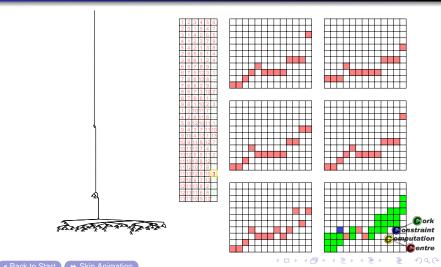


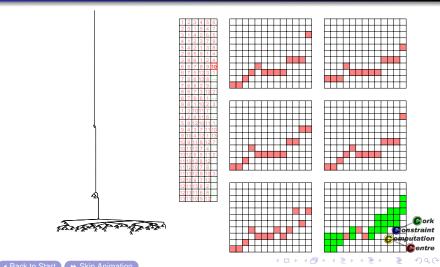


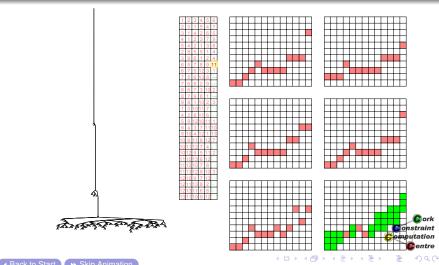


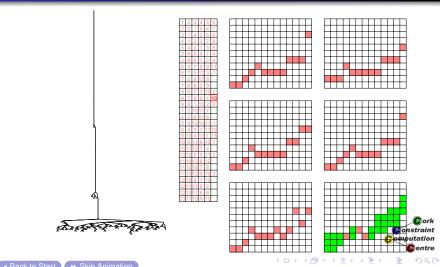


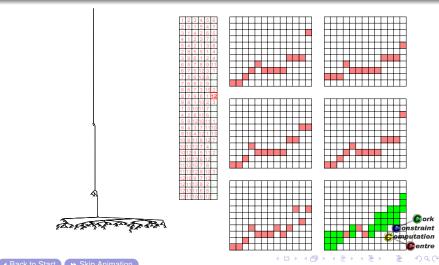




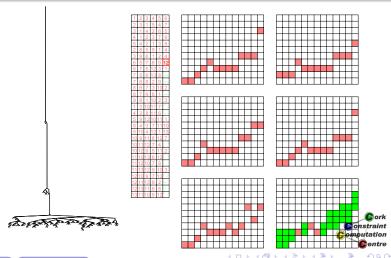




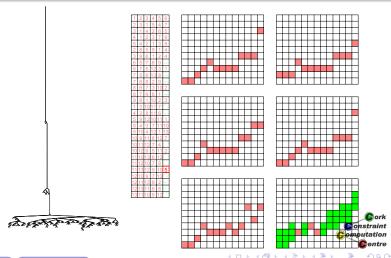


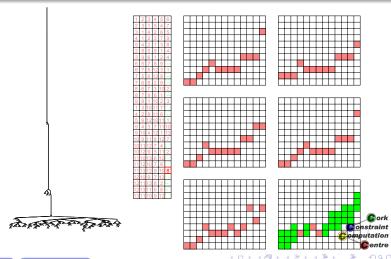


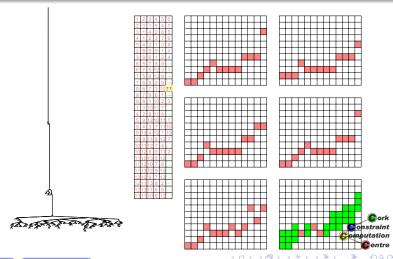
Layered Search

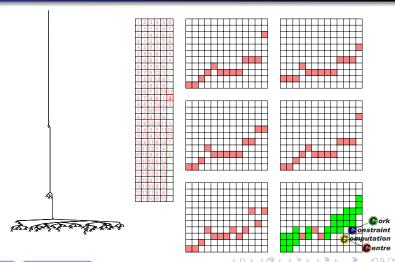


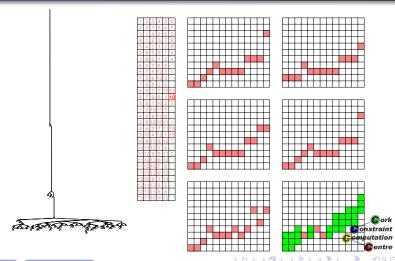
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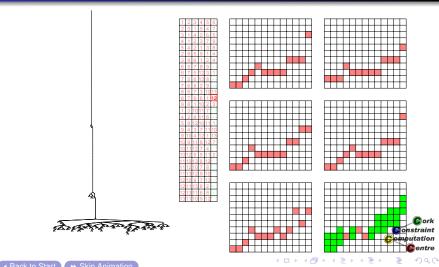


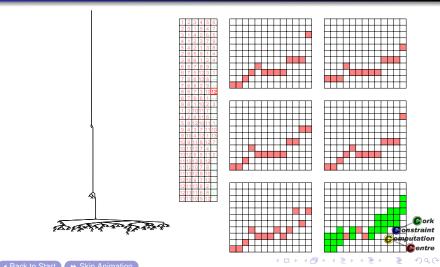


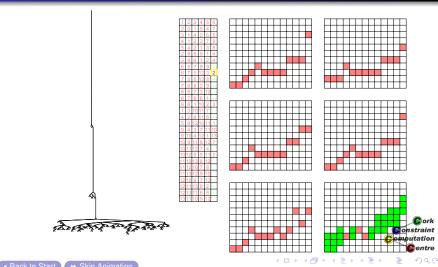


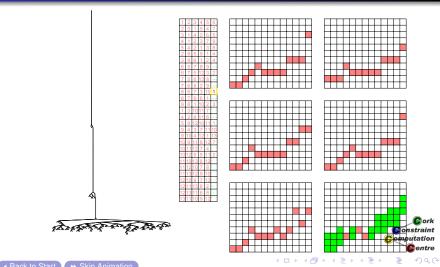


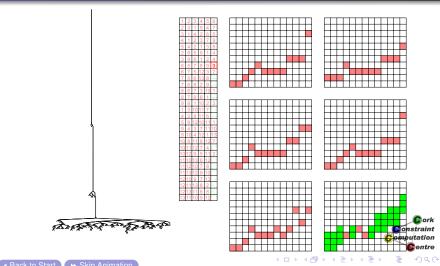


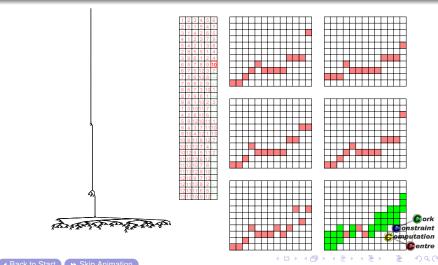


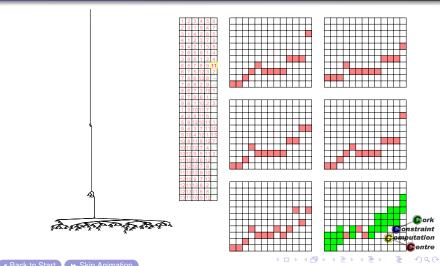


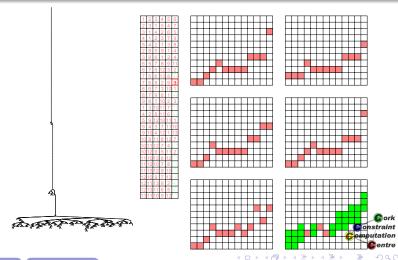


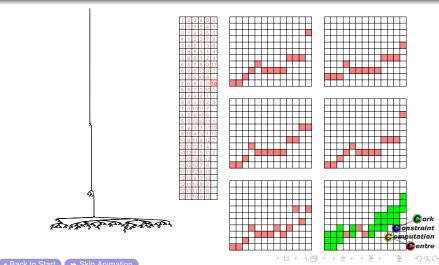


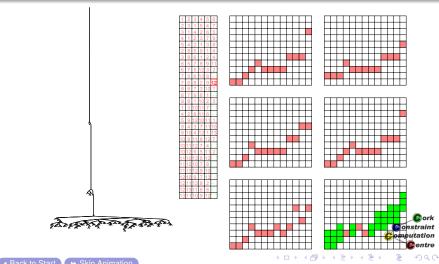


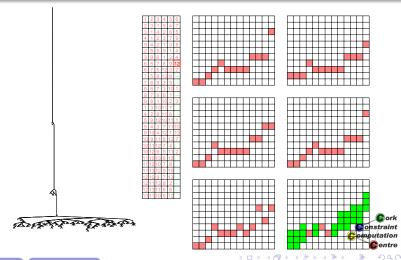


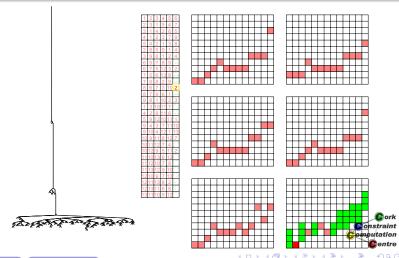


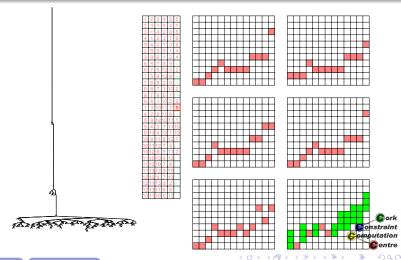




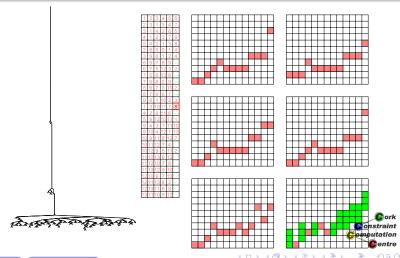




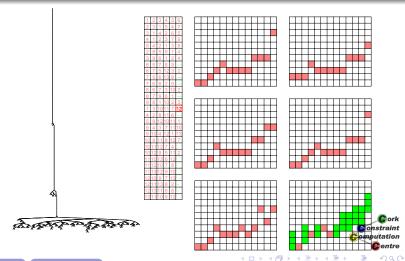


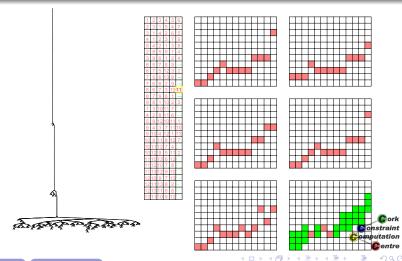


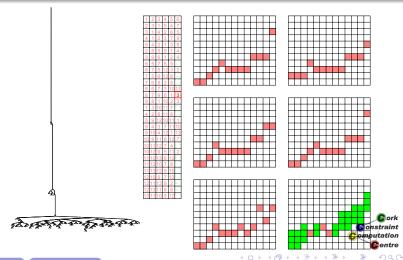
Layered Search

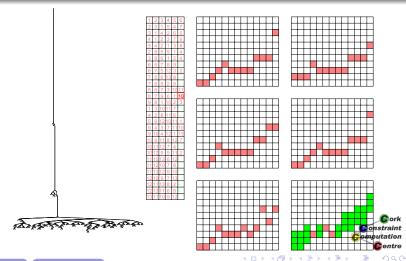


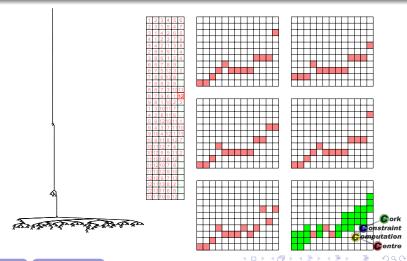
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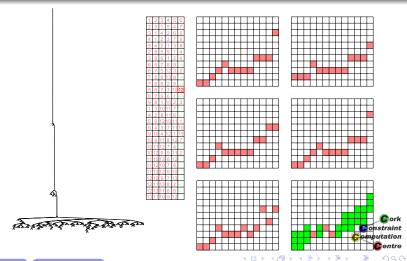


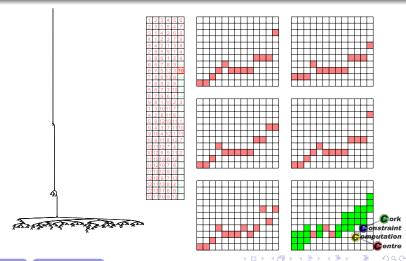


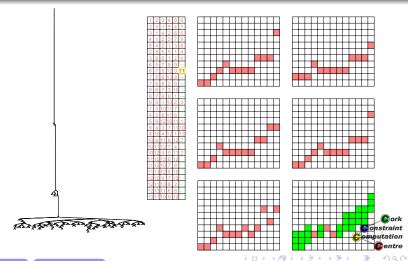


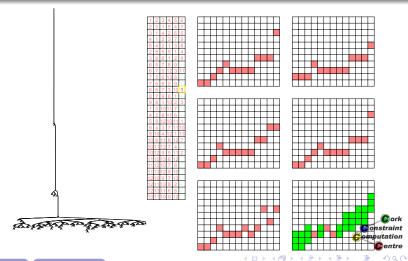


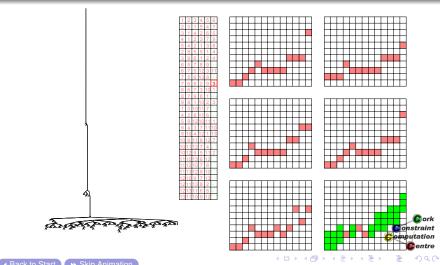


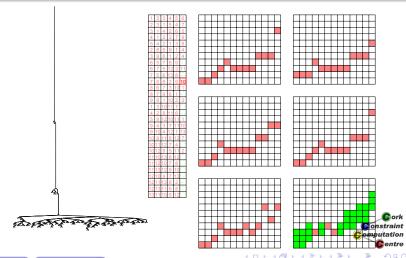


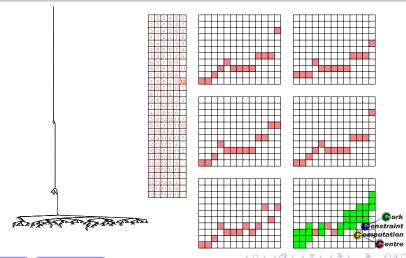


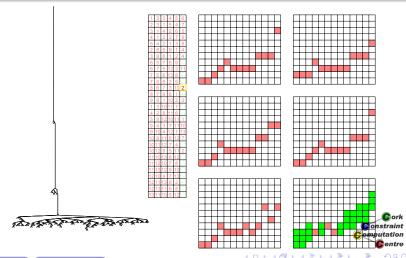




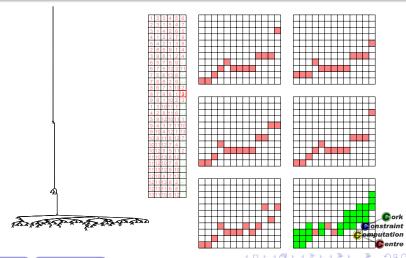






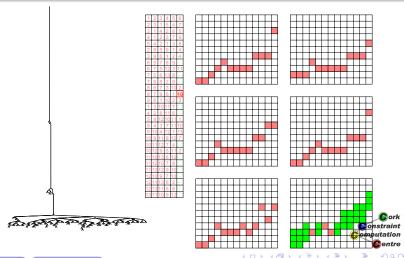


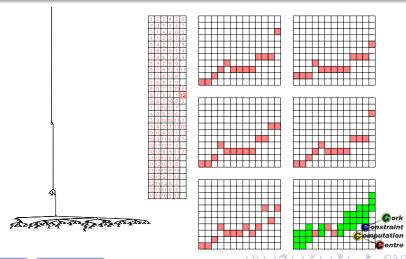
Layered Search

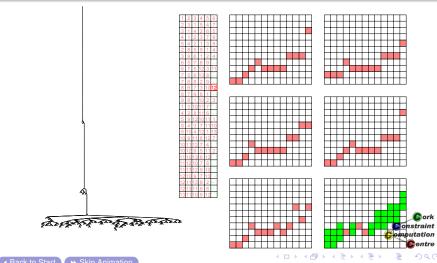


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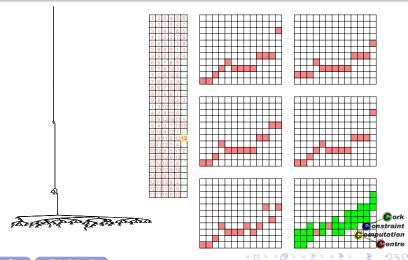
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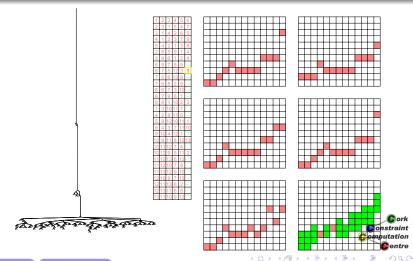


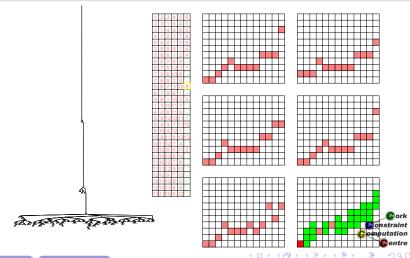


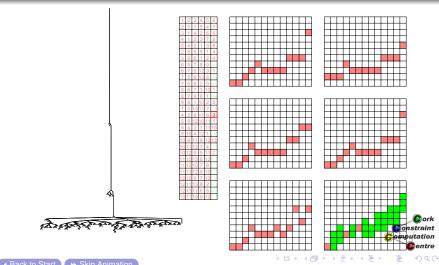
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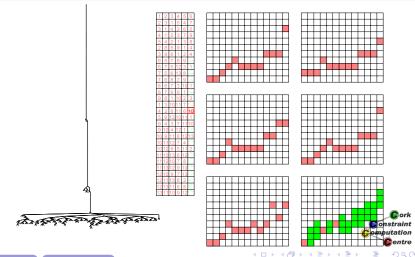


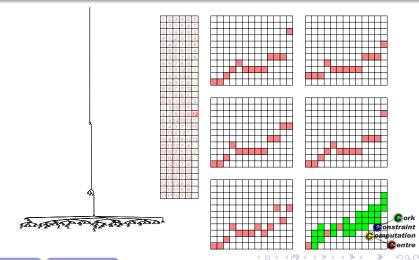
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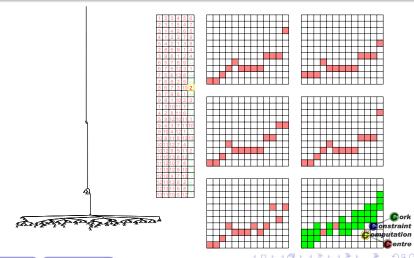


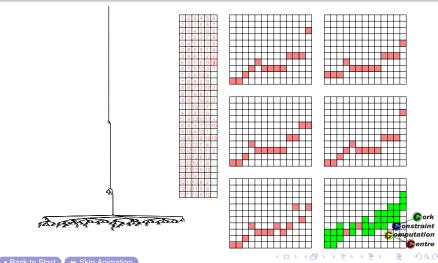


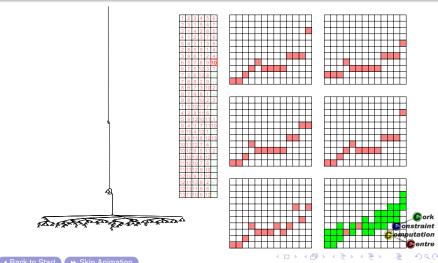


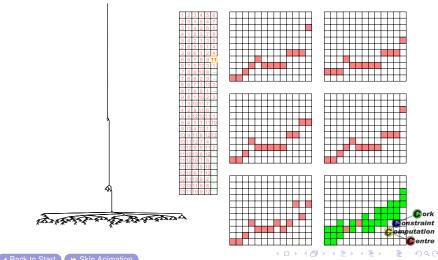


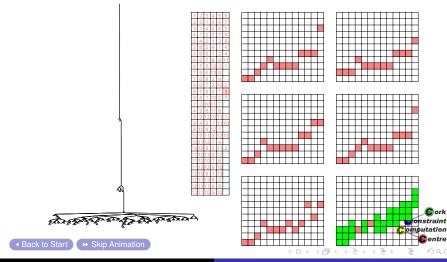


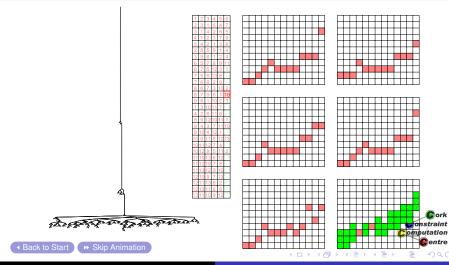


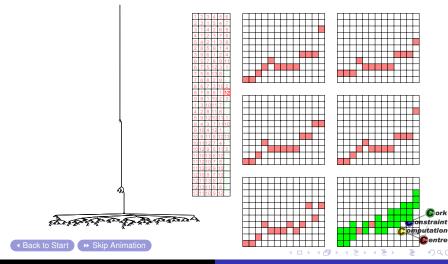


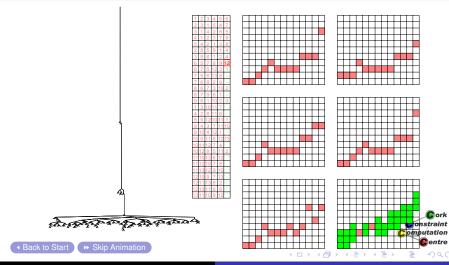


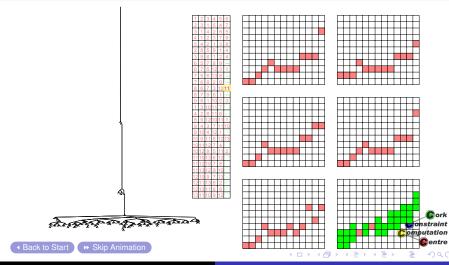


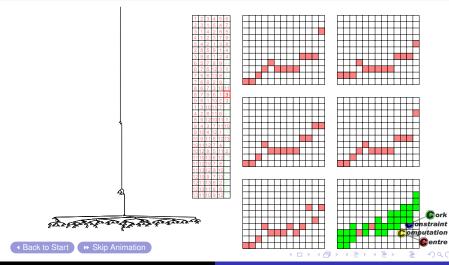


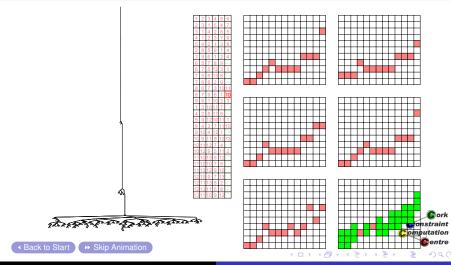


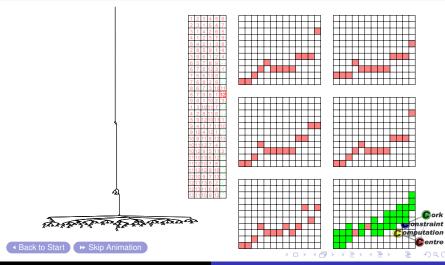


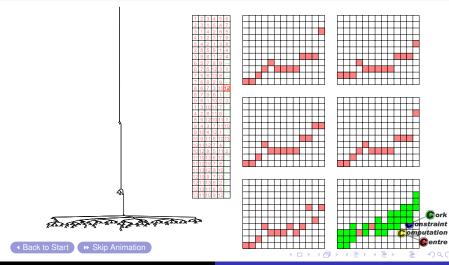


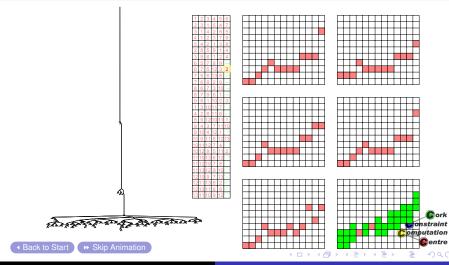


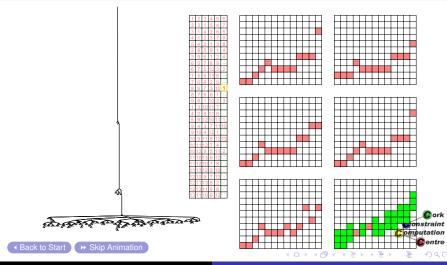


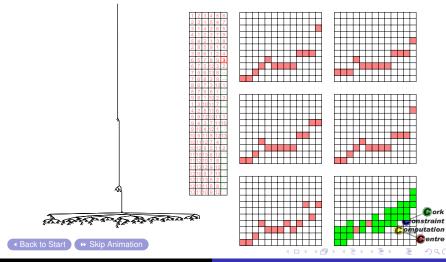


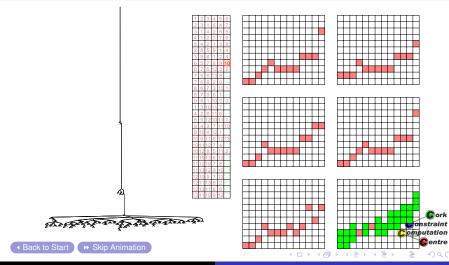


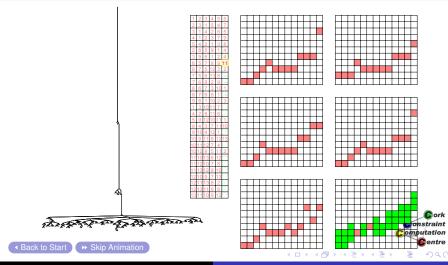


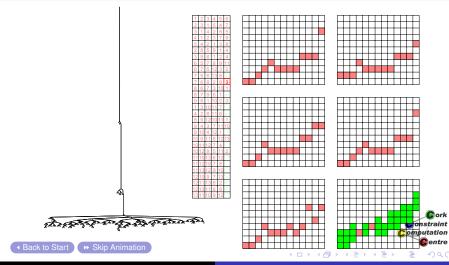


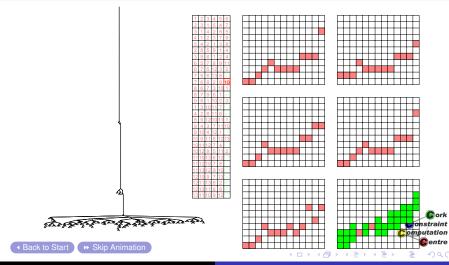


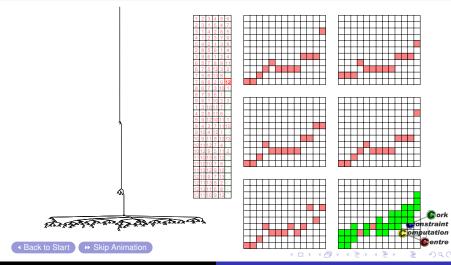


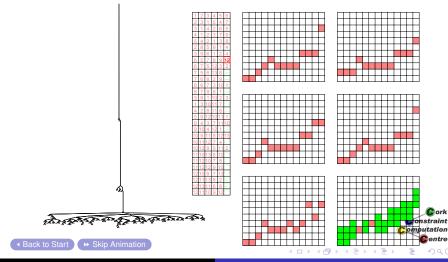


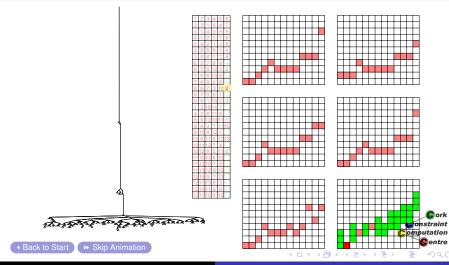


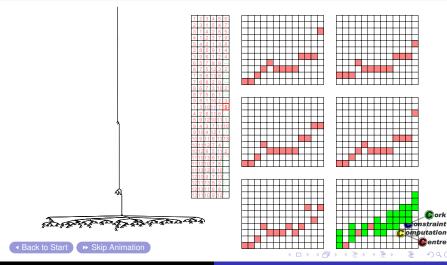


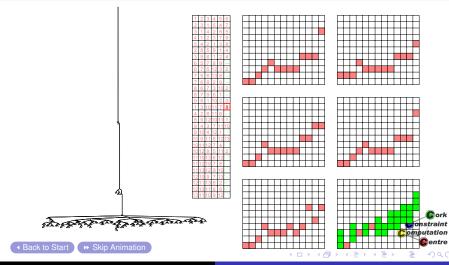


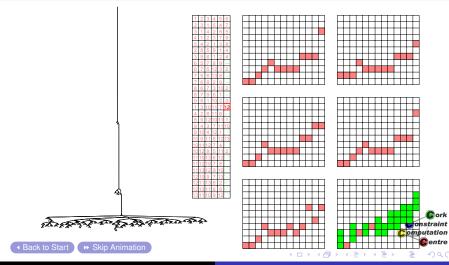


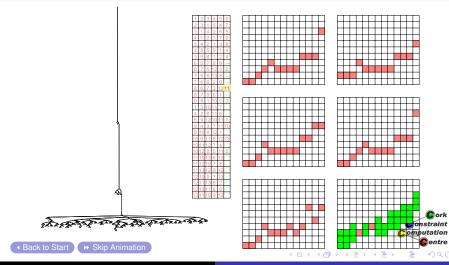


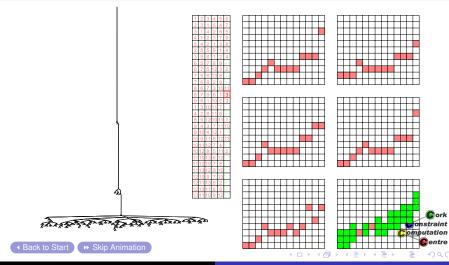


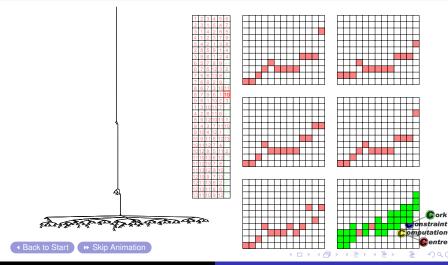


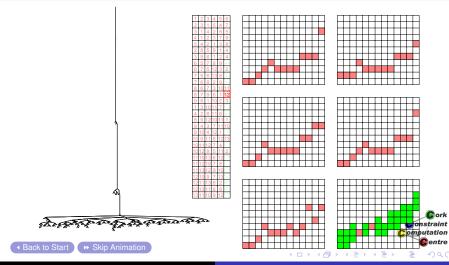


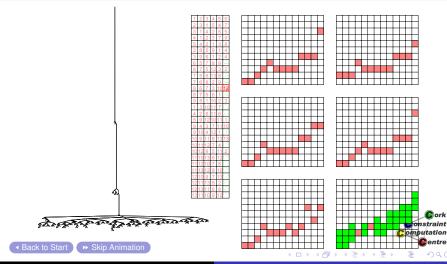


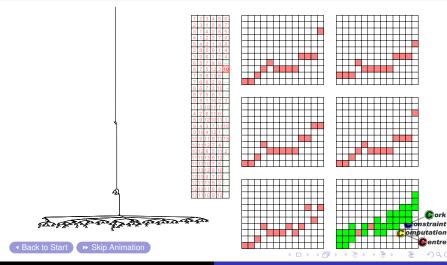


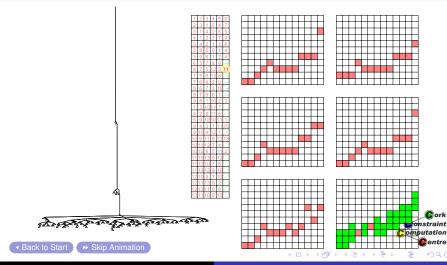


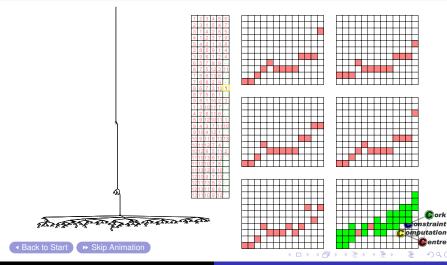


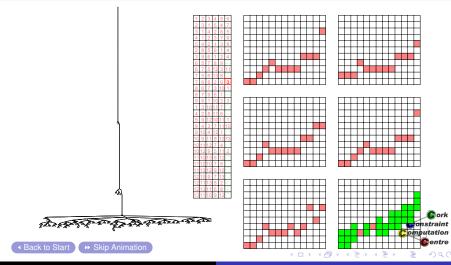


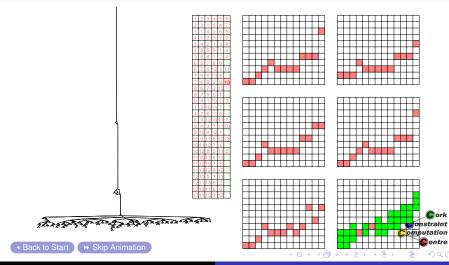


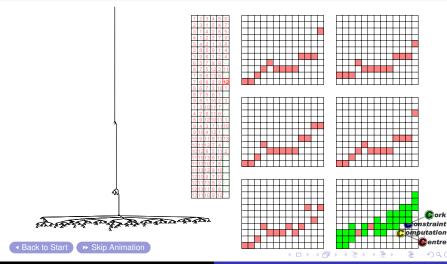


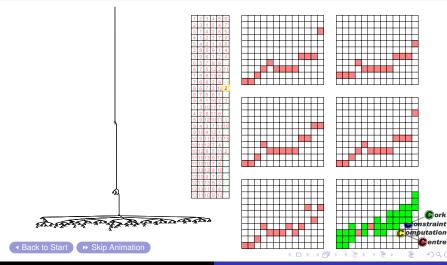


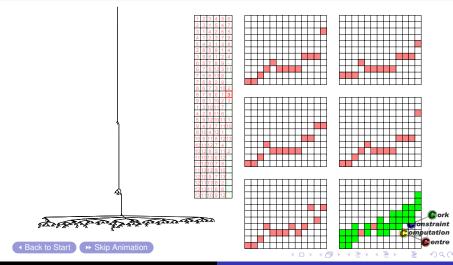


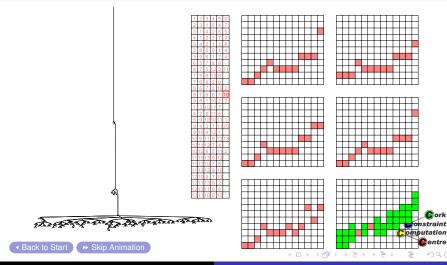


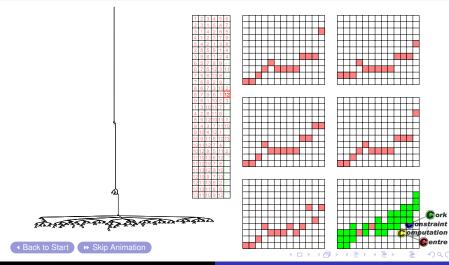


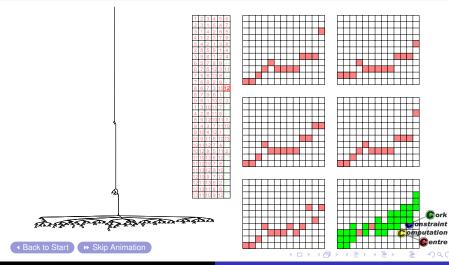


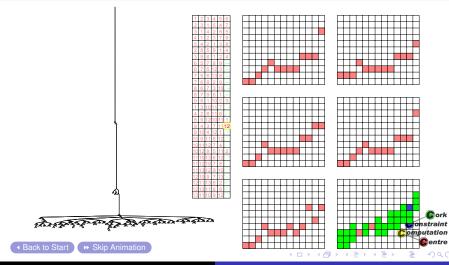


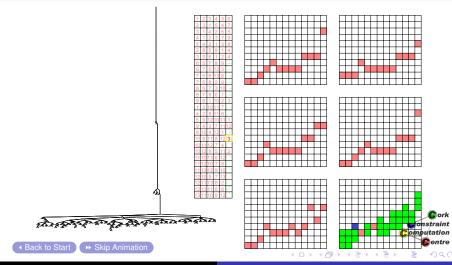


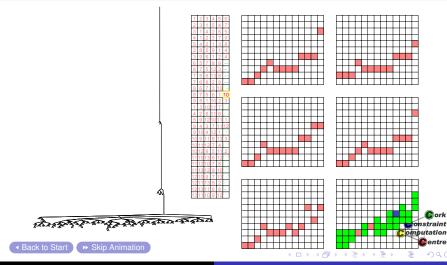


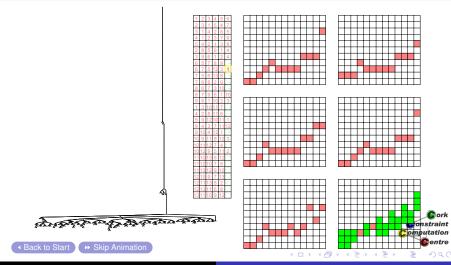


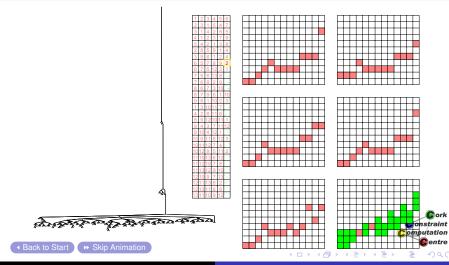


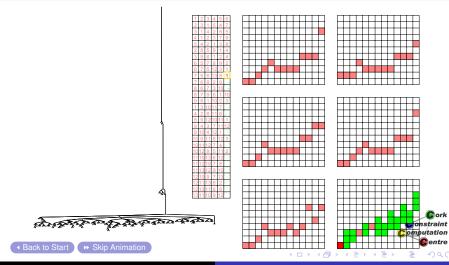


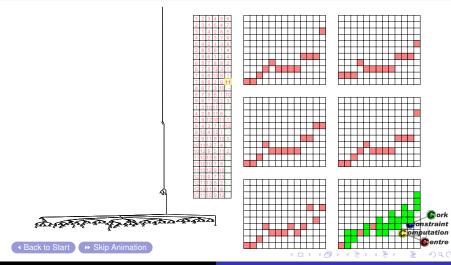


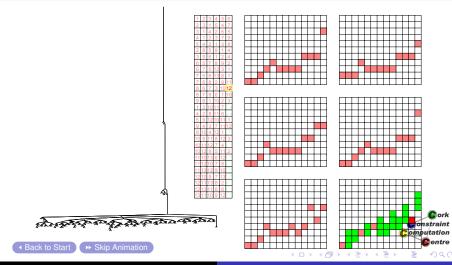


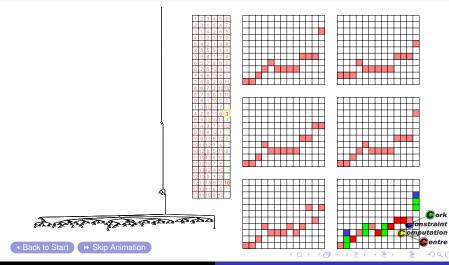


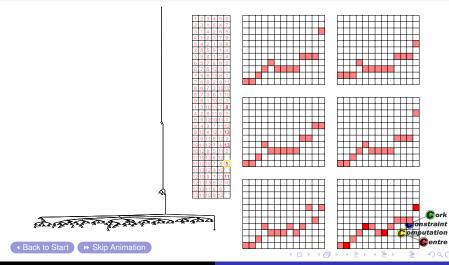


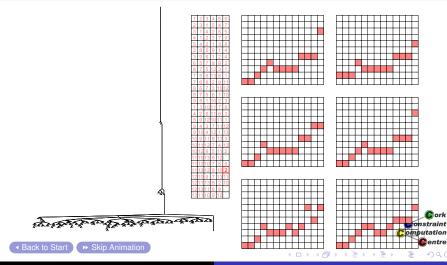


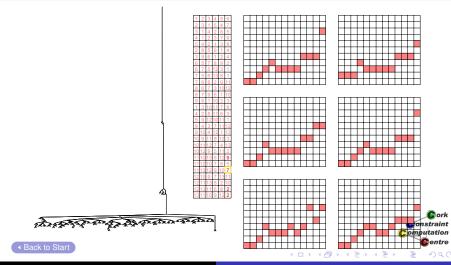












Observations

- Deep backtracking for last time period
- No backtracking to earlier time periods required
- Small amount of backtracking at other time periods



Idea

- Use credit based search
- But not for complete search tree
- Loose too much useful work
- Backtrack independently for each time period
- Hope to correct wrong choices without deep backtracking



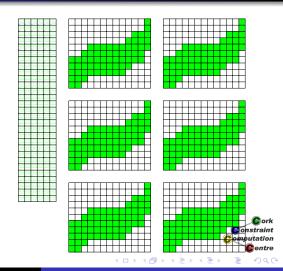
Layered with Credit



Naive Search
First Fail Strategy
Layered Search

Layered with Credit Search Randomized with Restart

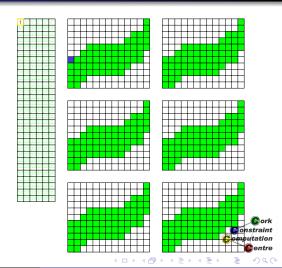




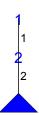
Naive Search
First Fail Strategy
Layered Search
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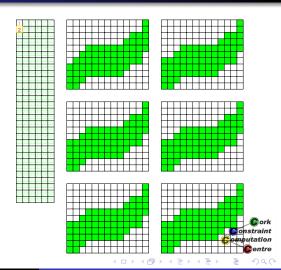
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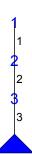
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First Fail Strategy
Layered Search
Layered with Credit Search

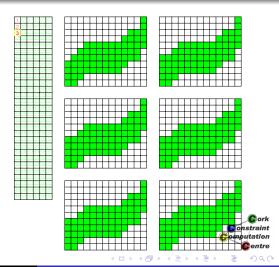




Naive Search
First Fail Strategy
Layered Search
Layered with Credit Search

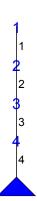
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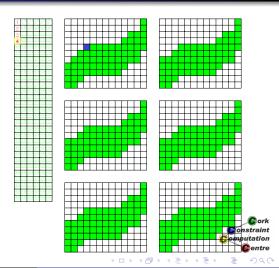




Layered with Credit Search

Layered with Credit Search

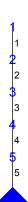


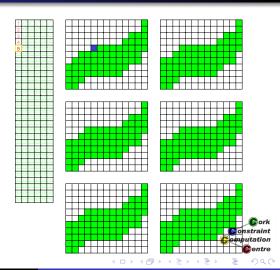


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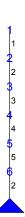
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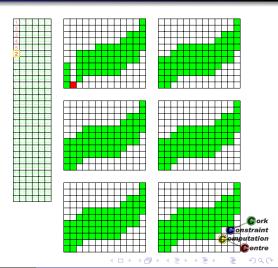




Naive Search First Fail Strategy Layered Search Layered with Credit

Layered with Credit Search Randomized with Restart

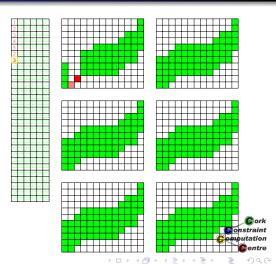




Naive Search First Fail Strategy Layered Search Layered with Credil

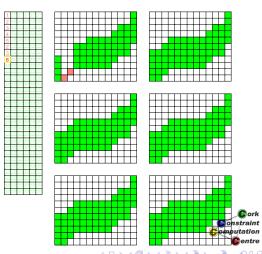
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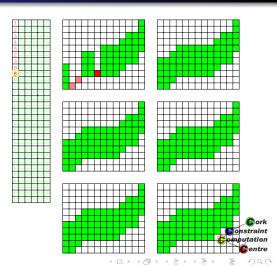
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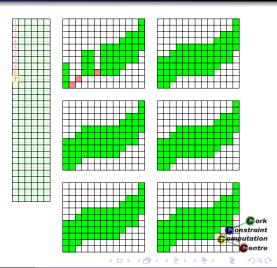


Customizing Search





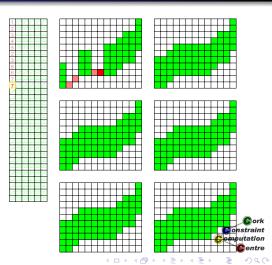




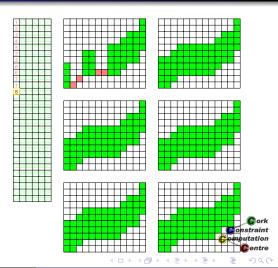
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First Fail Strategy
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Layered with Credit Search Randomized with Restart

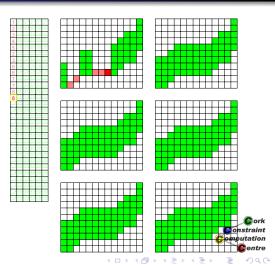




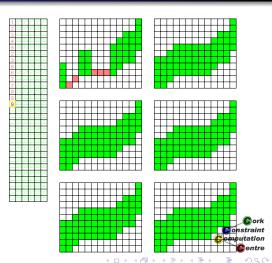




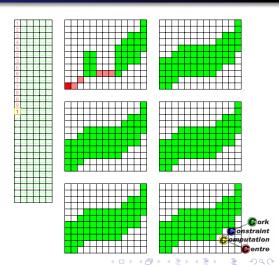






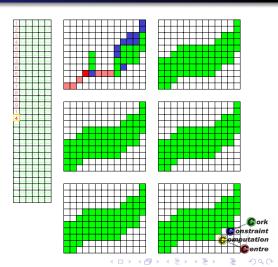




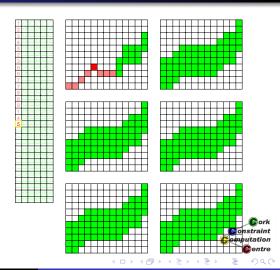


Naive Search
First Fail Strategy
Layered Search
Layered with Credit Search

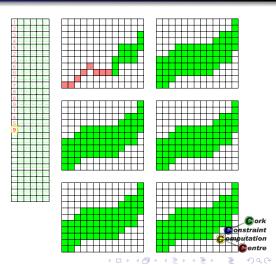




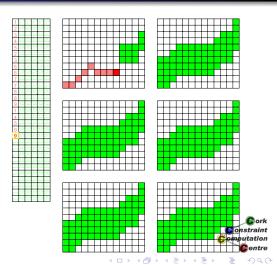


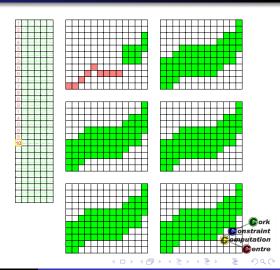




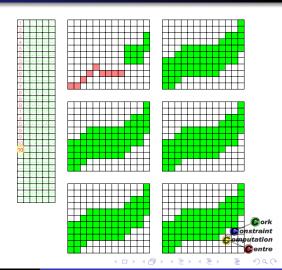


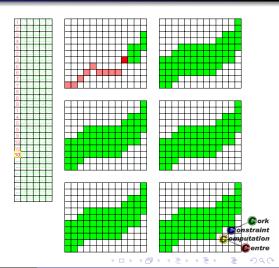




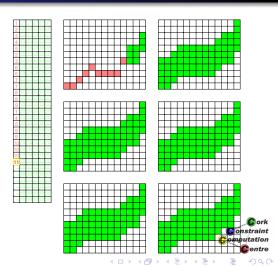




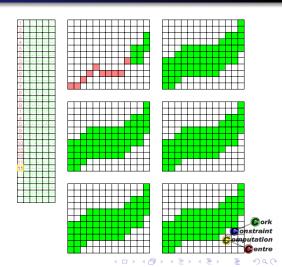




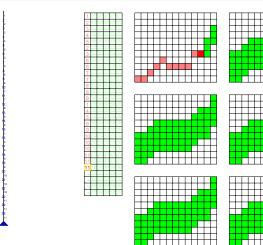






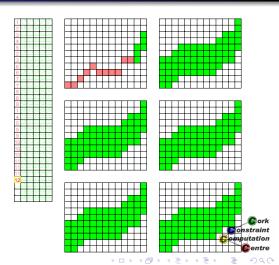


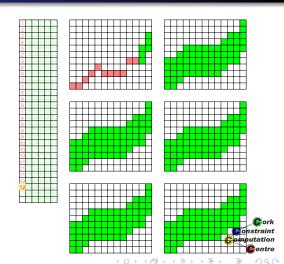
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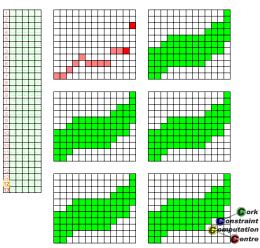


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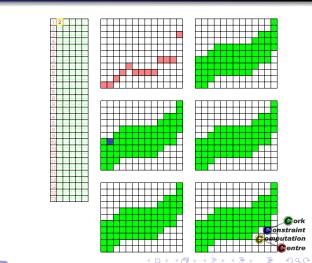




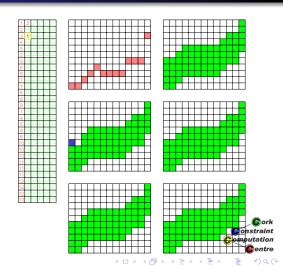


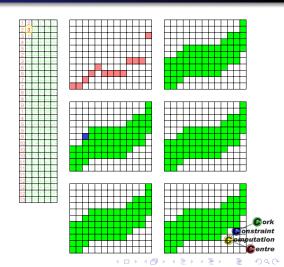


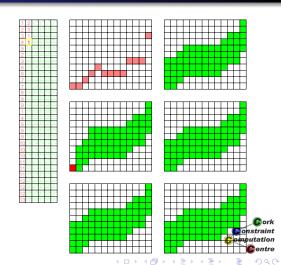
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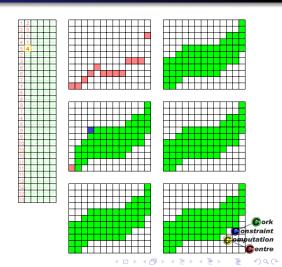


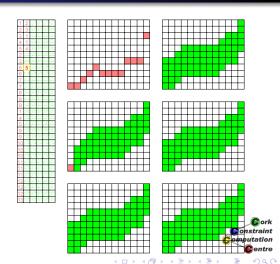
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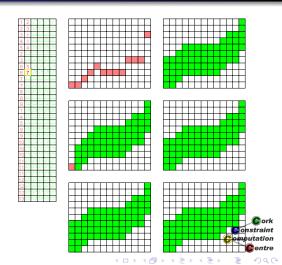


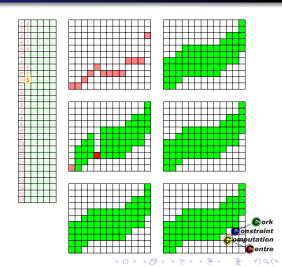


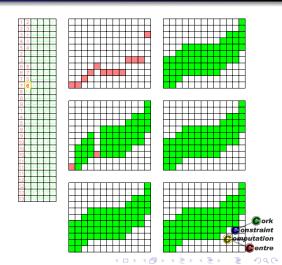


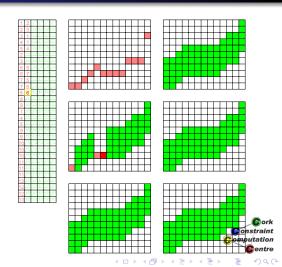


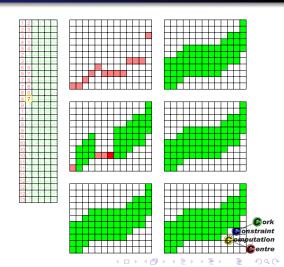


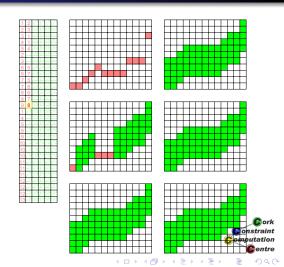


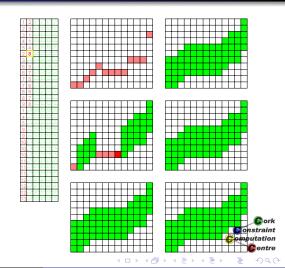


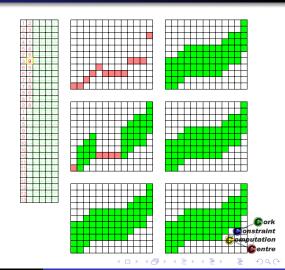


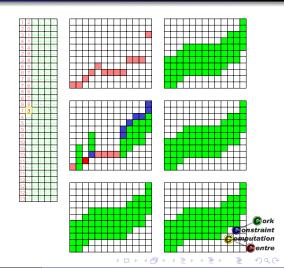


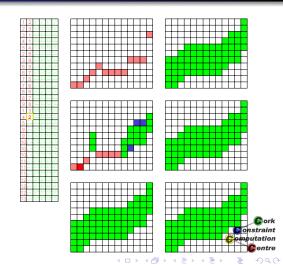


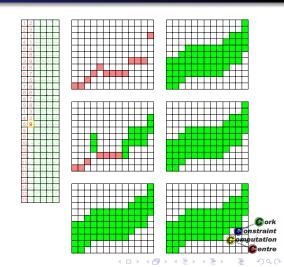


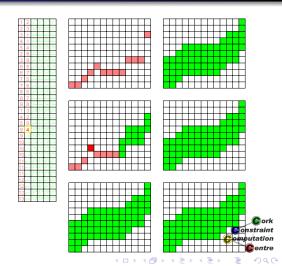


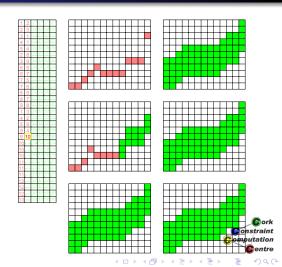


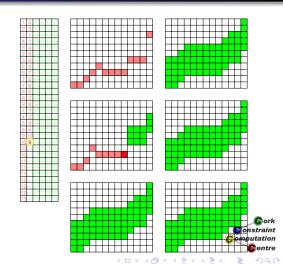


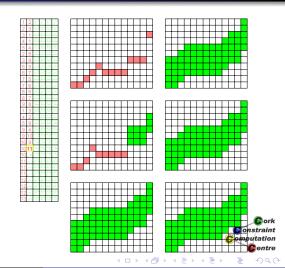




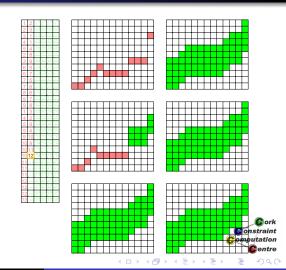




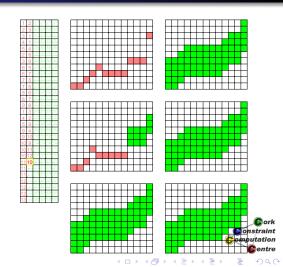


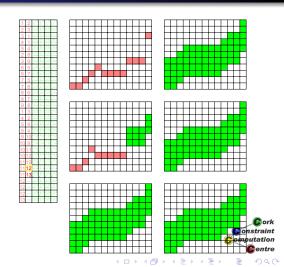


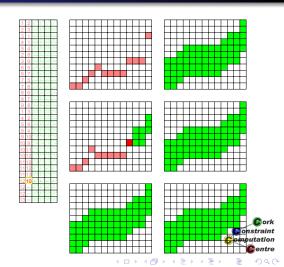
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First Fail Strategy
Layered Search
Layered with Credit Search
Randomized with Restart

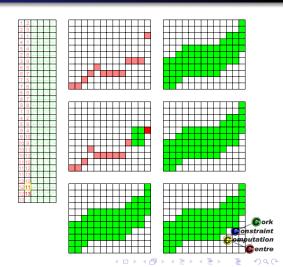


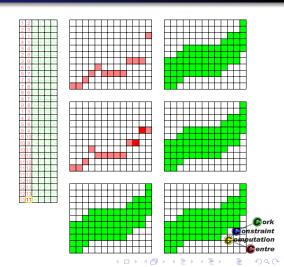
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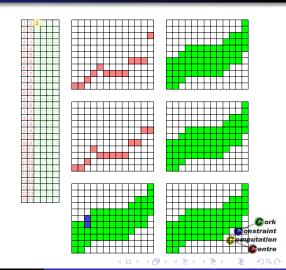


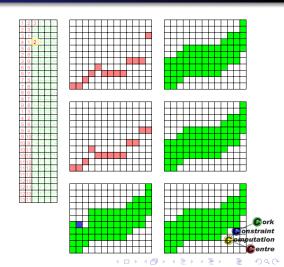


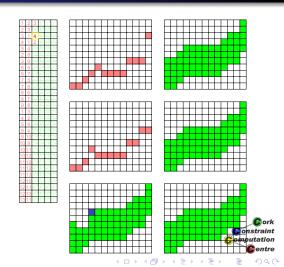


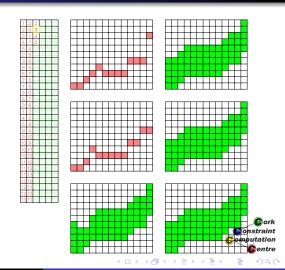


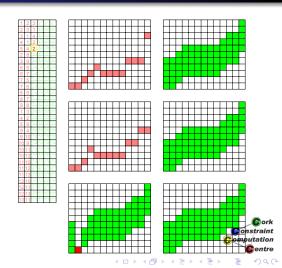
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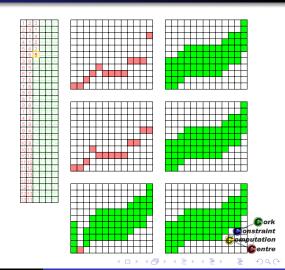


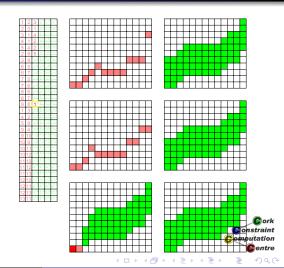


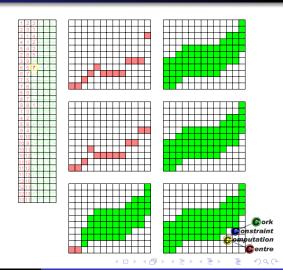


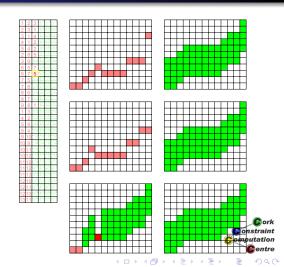


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Layered Search
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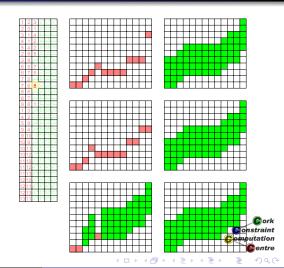


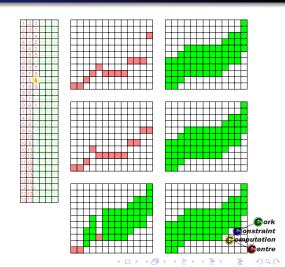


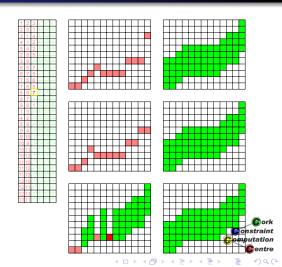


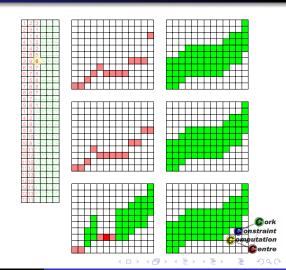


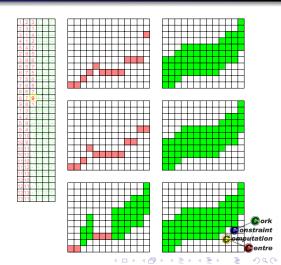
Naive Search
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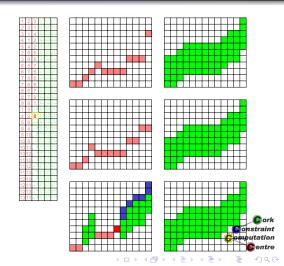


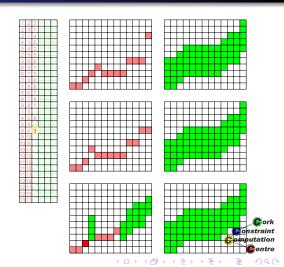


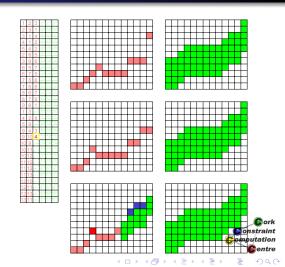


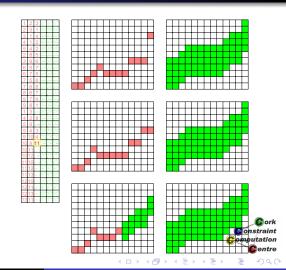


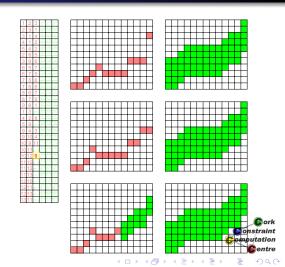
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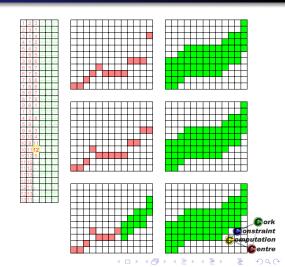


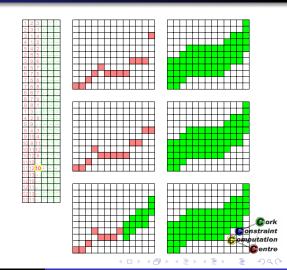


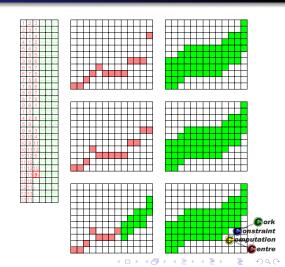


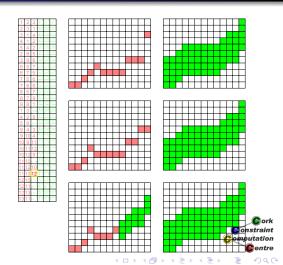


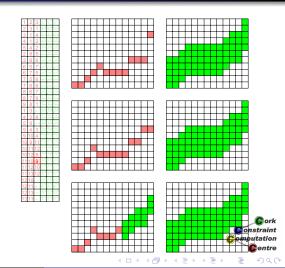




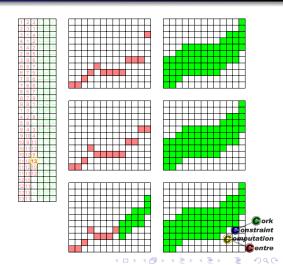


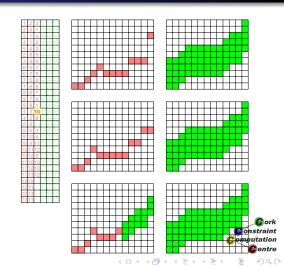


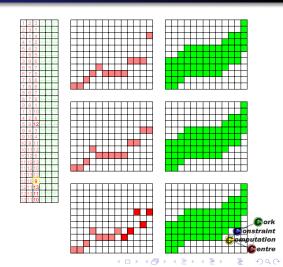


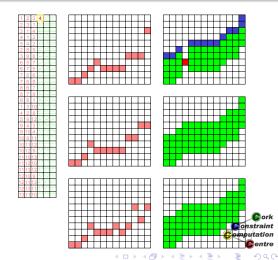


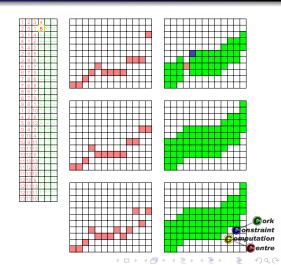
Naive Search
First Fail Strategy
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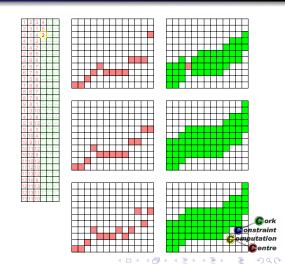




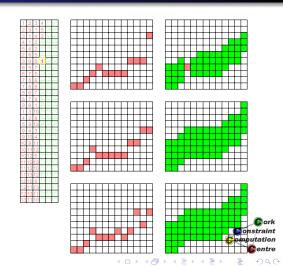


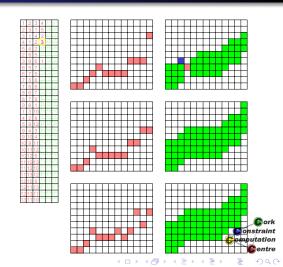


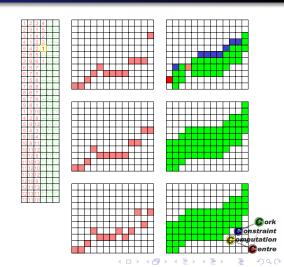




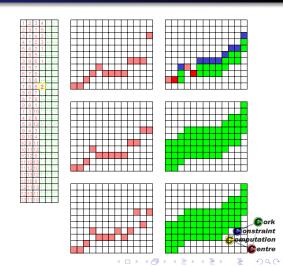
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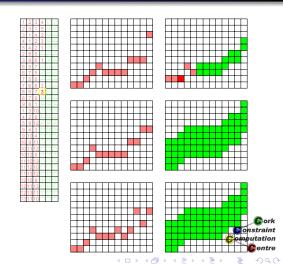


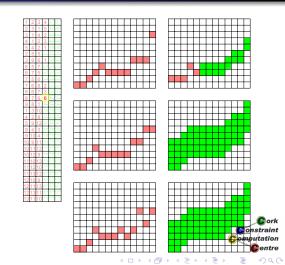


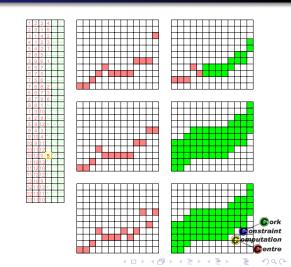


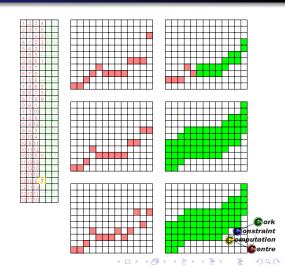
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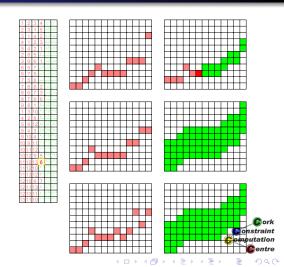


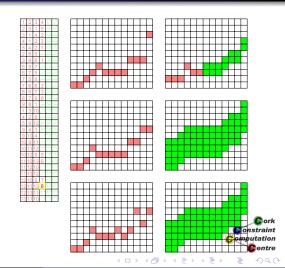


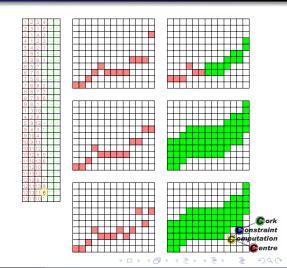


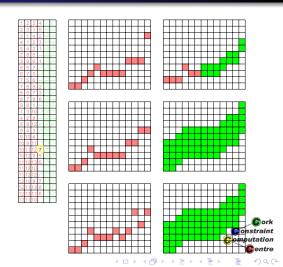


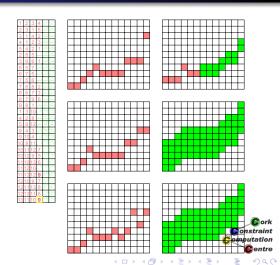


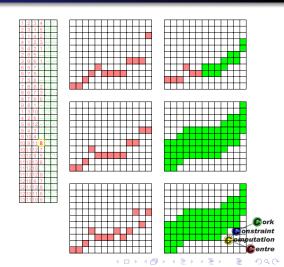


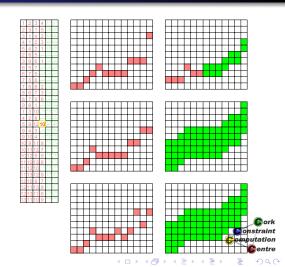


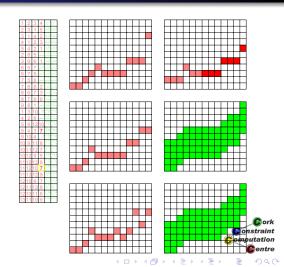


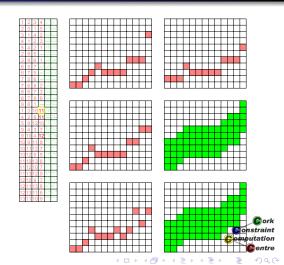


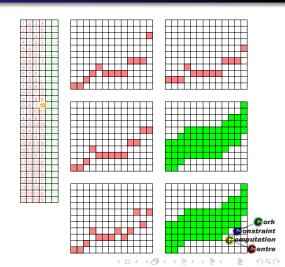


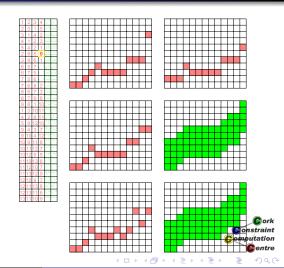


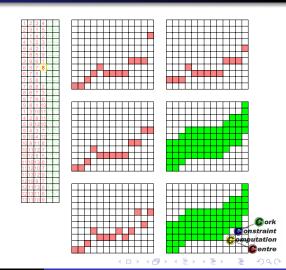


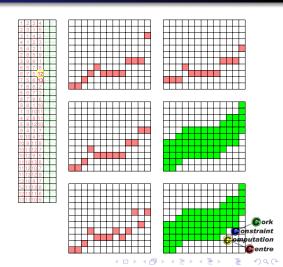


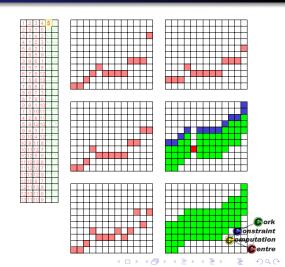


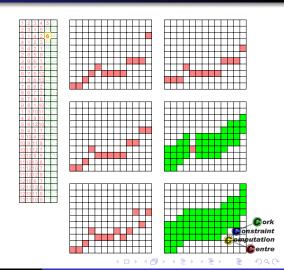


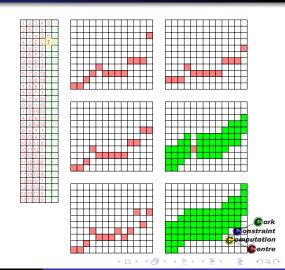


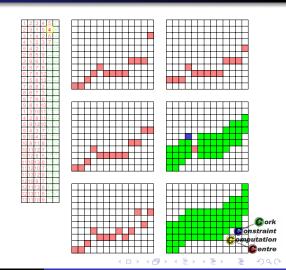




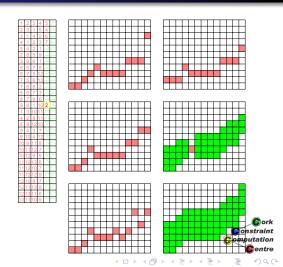




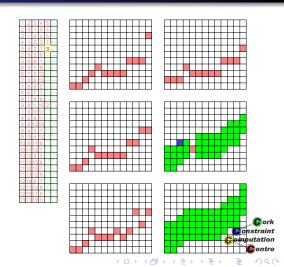


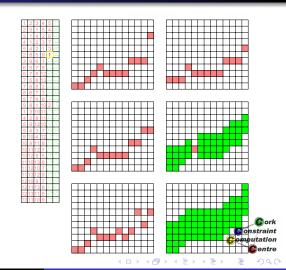


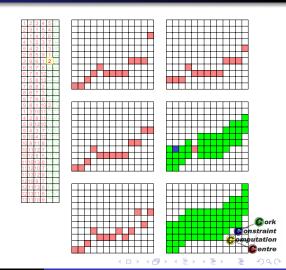
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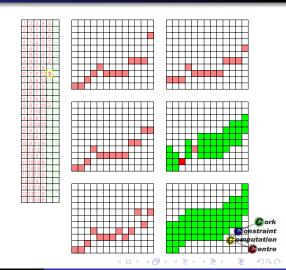


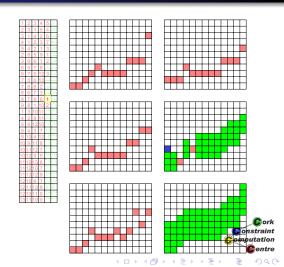
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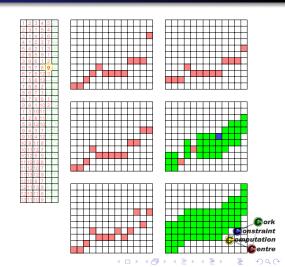


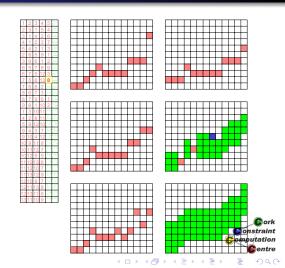


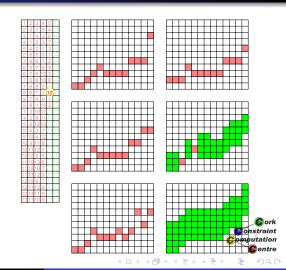


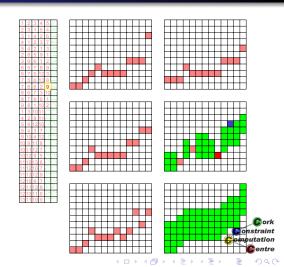


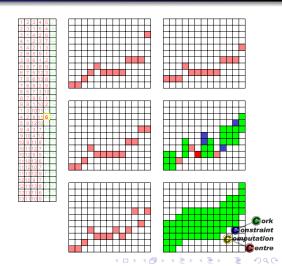


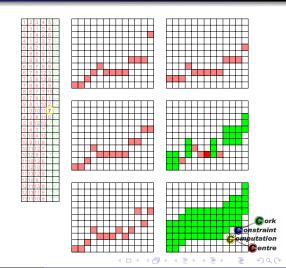


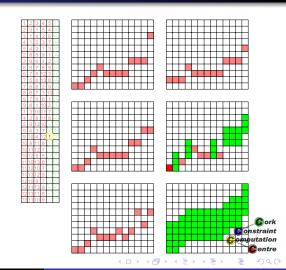


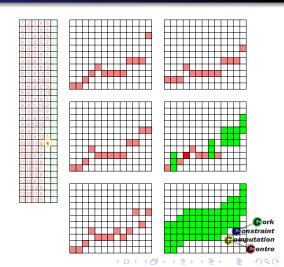


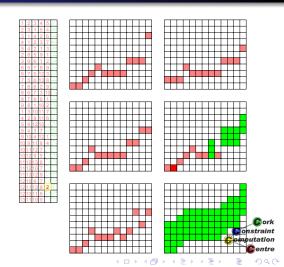


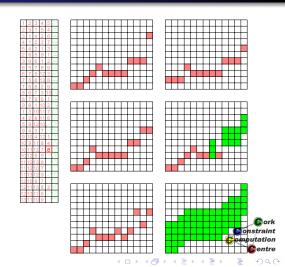


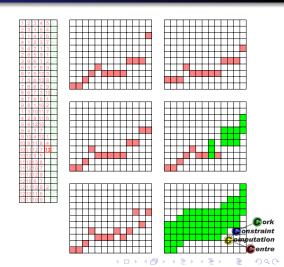


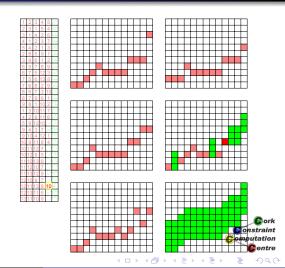


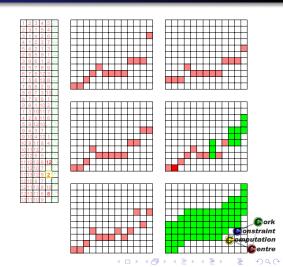


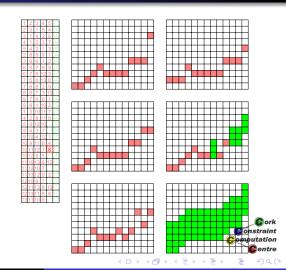


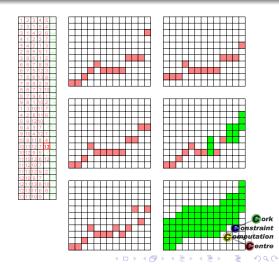


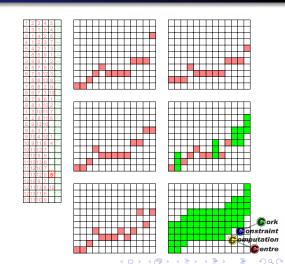


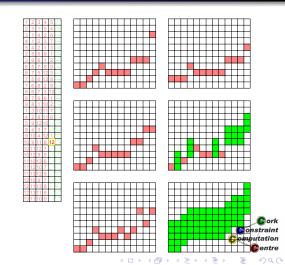


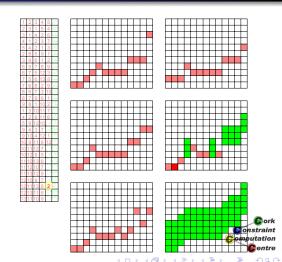


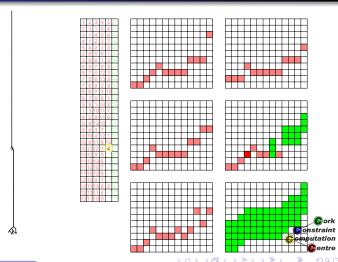


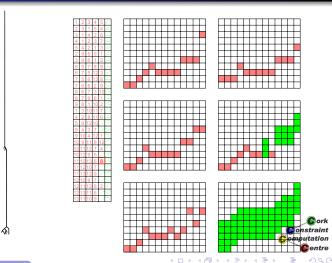


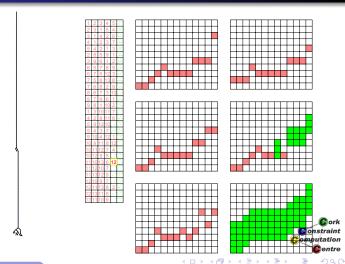


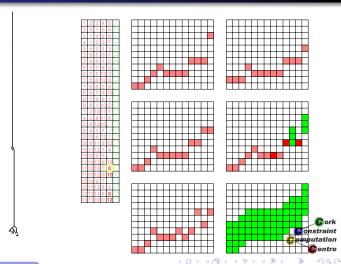


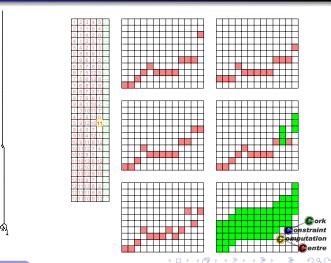


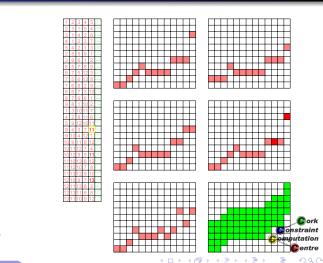


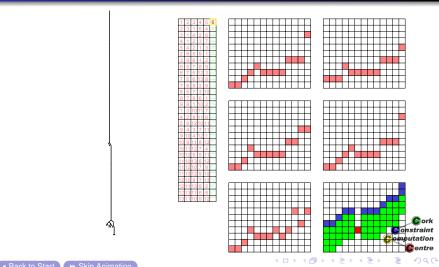


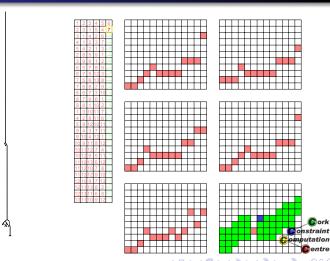


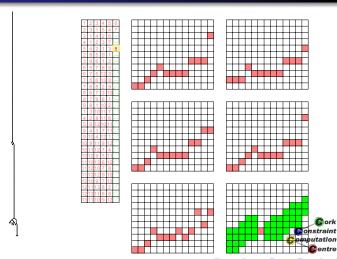


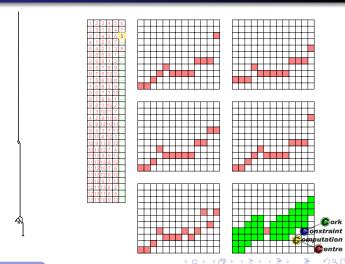


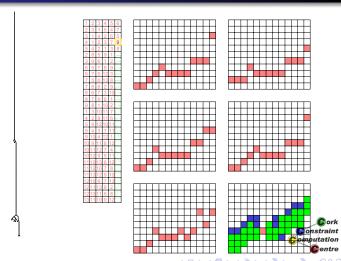


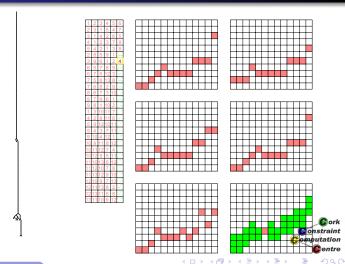


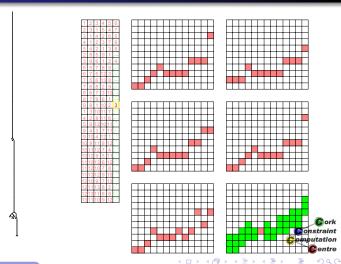


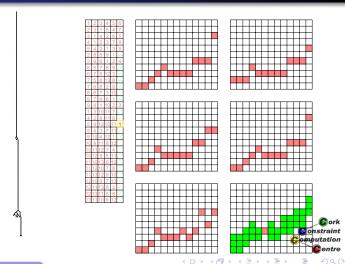


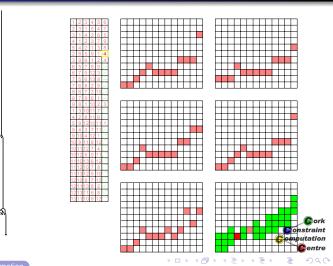


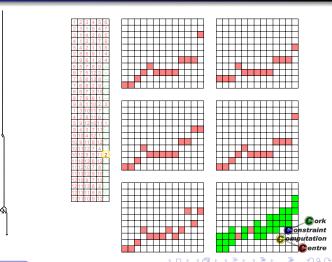


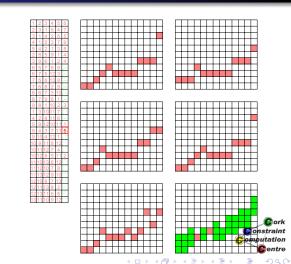


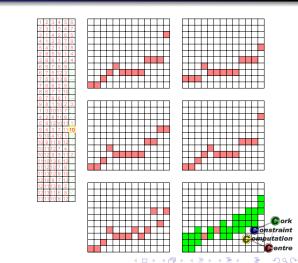


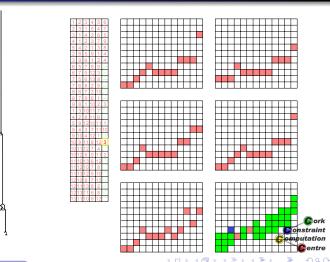


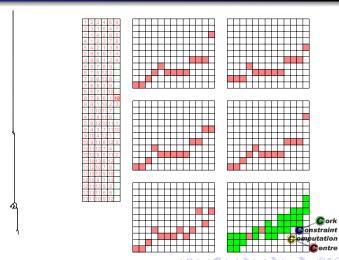


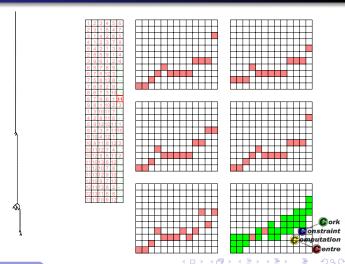


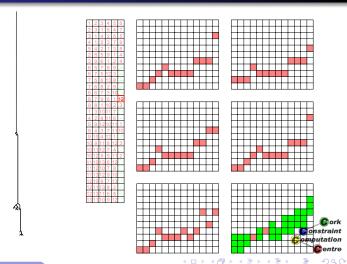


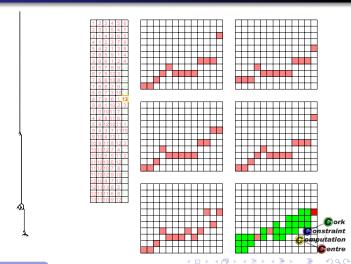


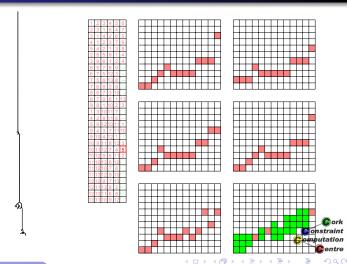


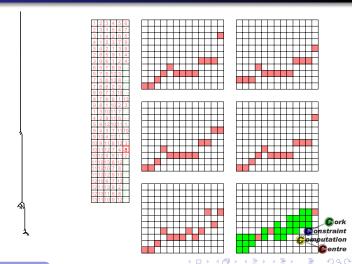


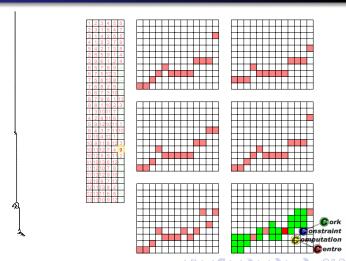


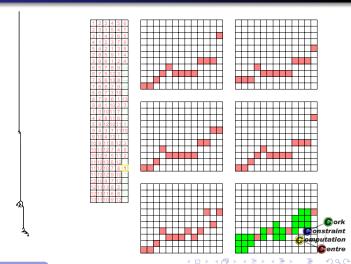


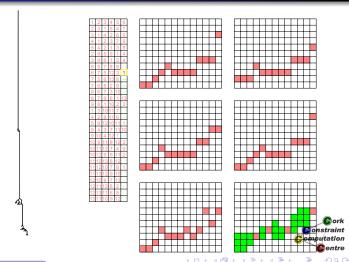


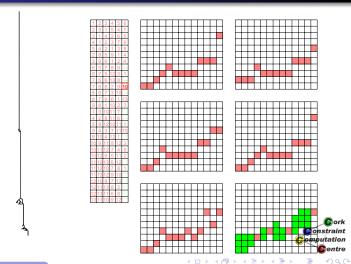


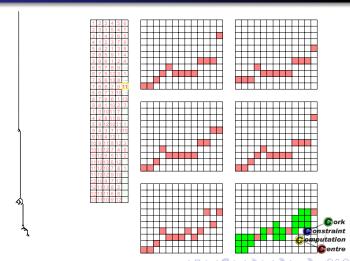


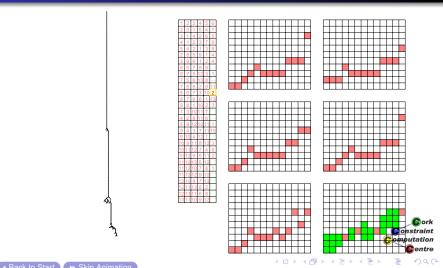


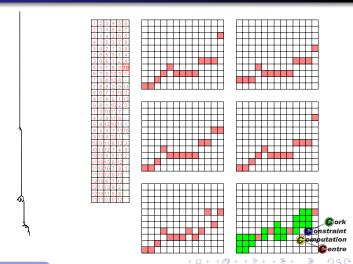


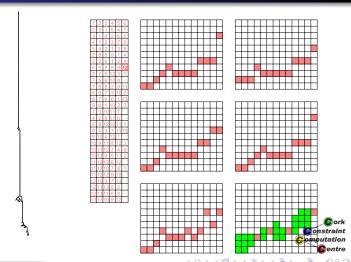


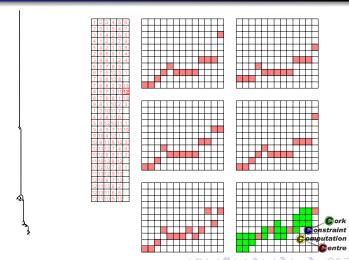


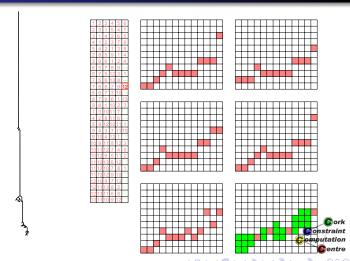


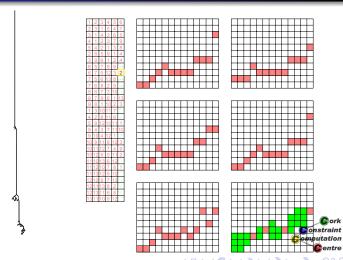


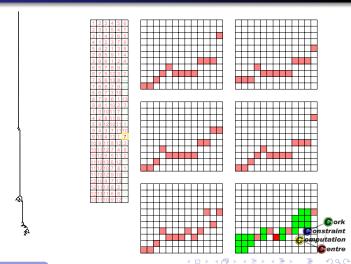


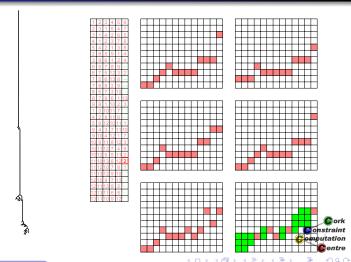


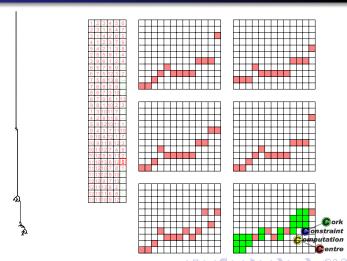


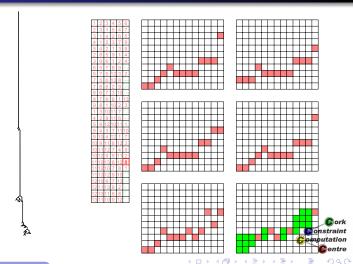


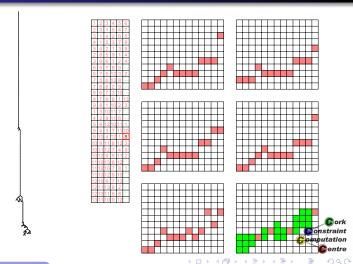


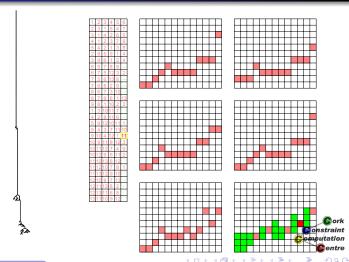


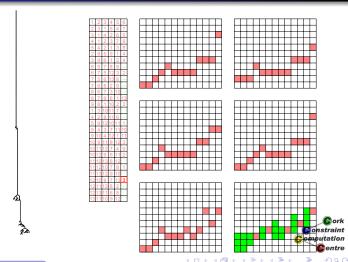


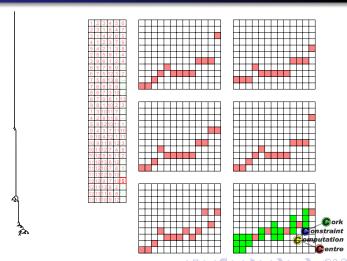


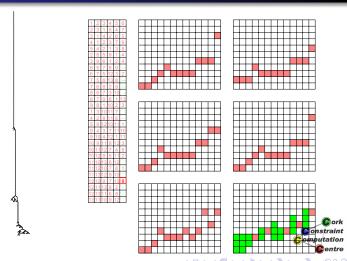


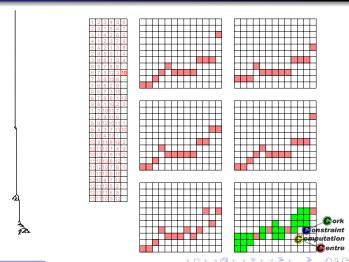


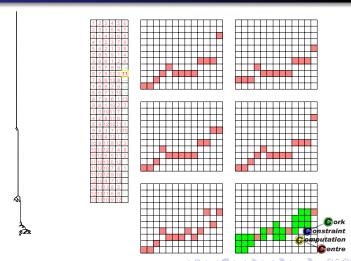


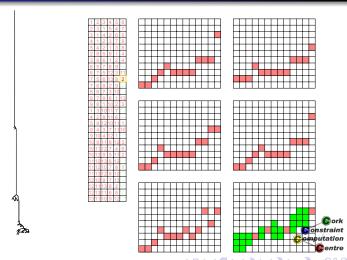


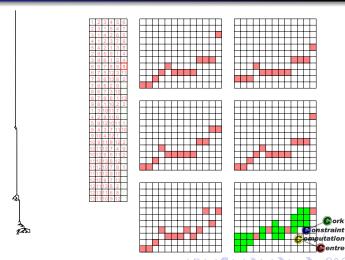


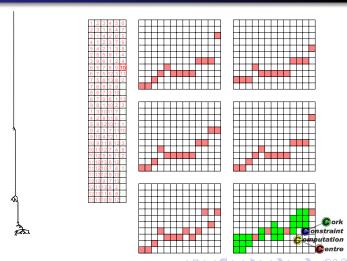


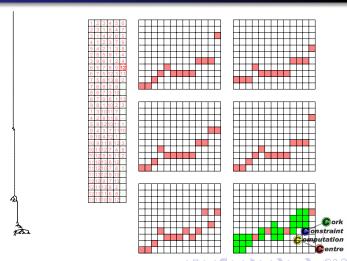


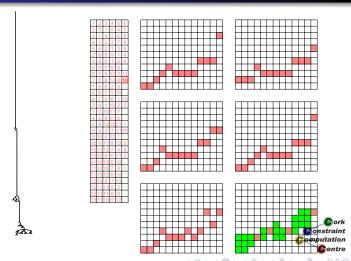


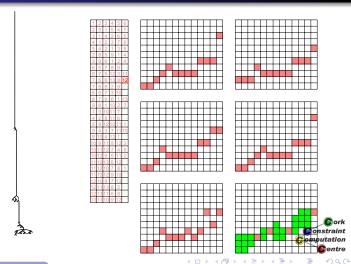


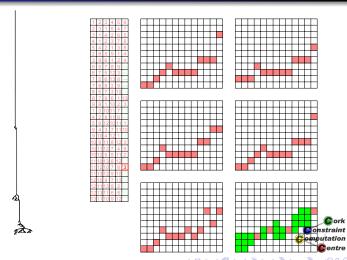


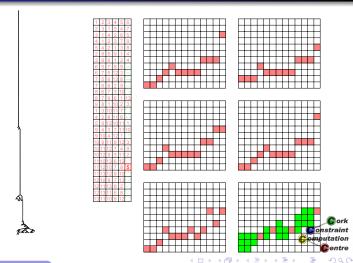


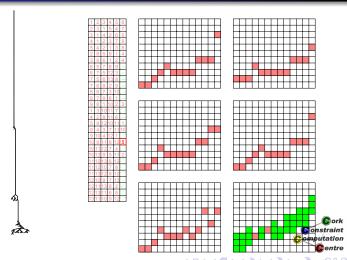


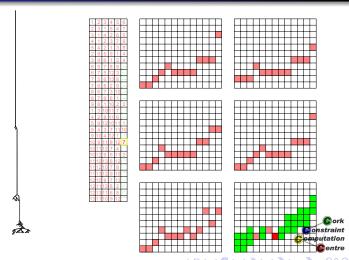


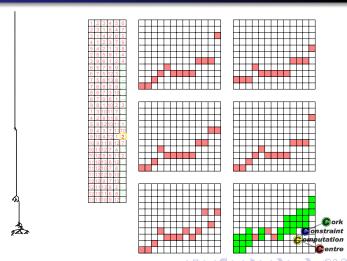


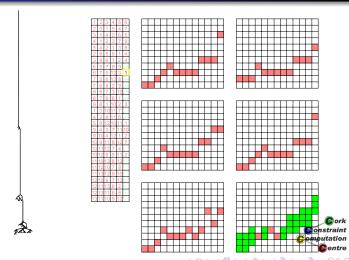




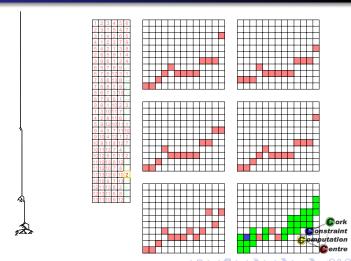




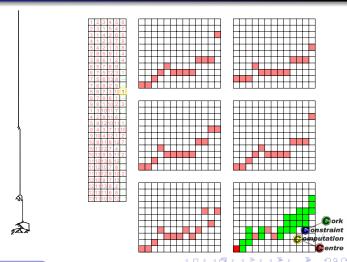


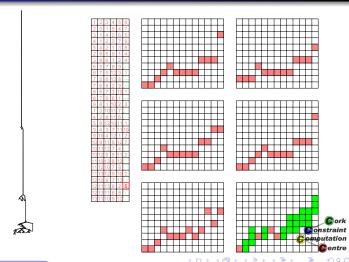


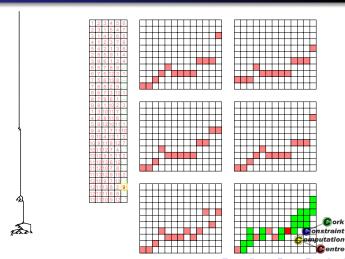
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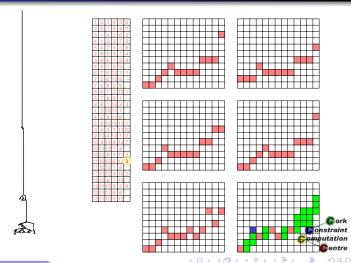


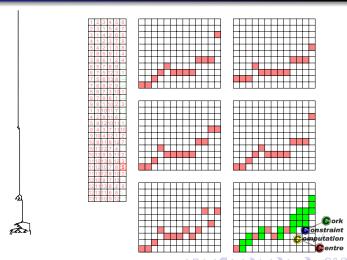
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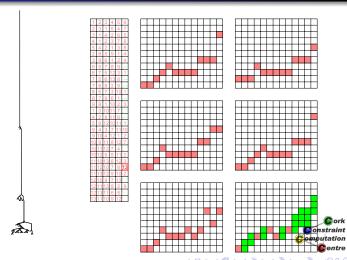


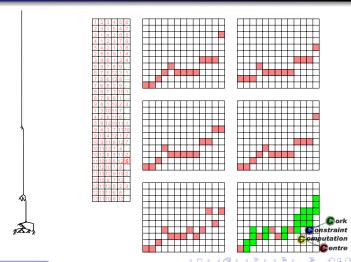


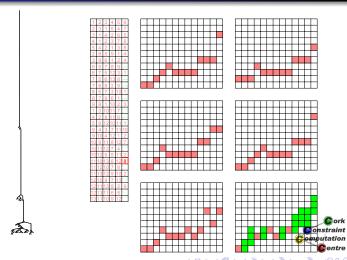


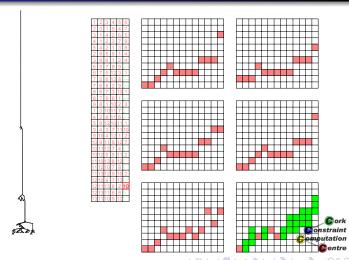


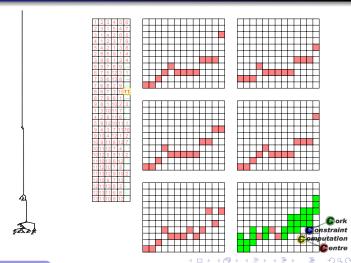


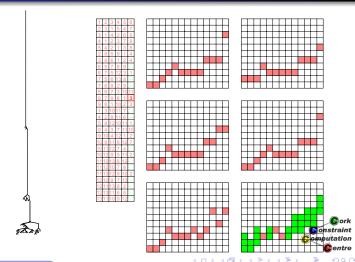


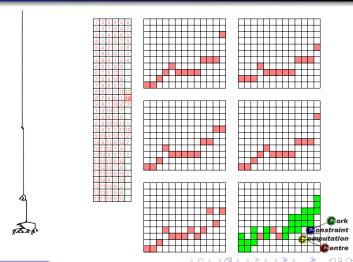


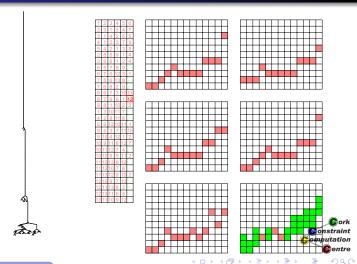


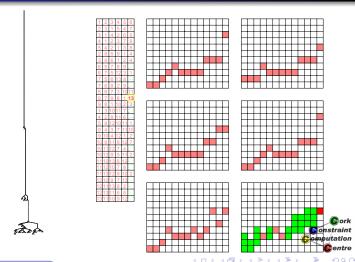


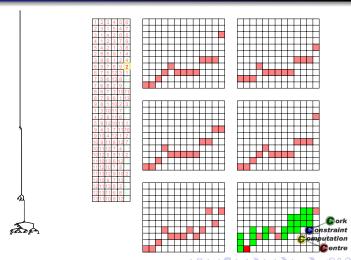


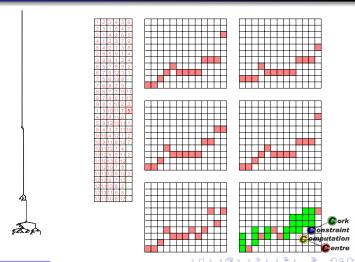


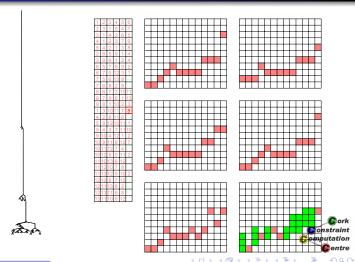


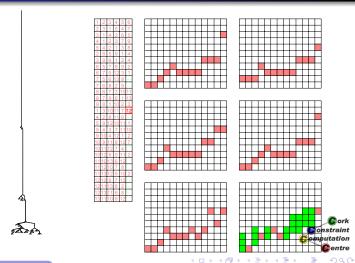


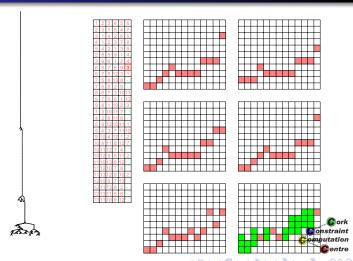


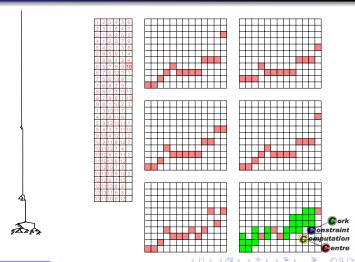


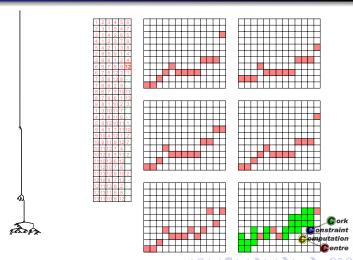


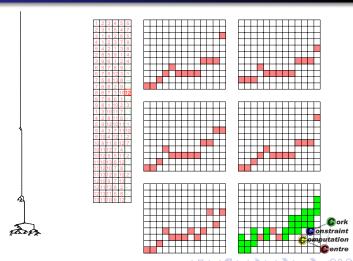


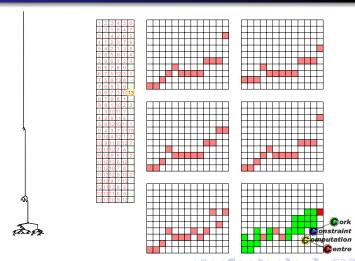


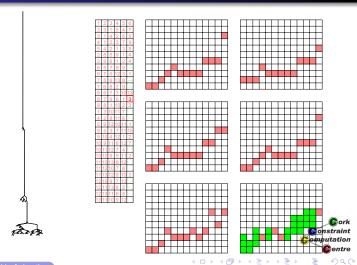


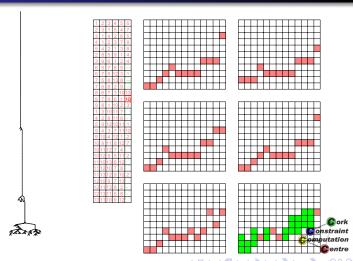


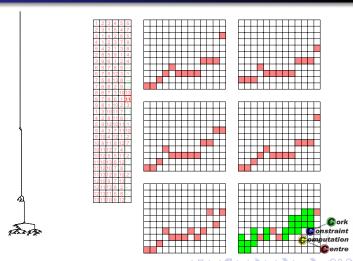


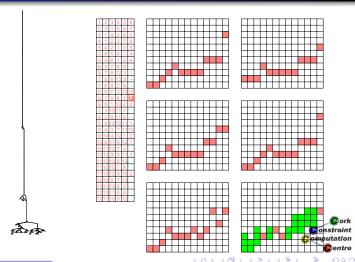


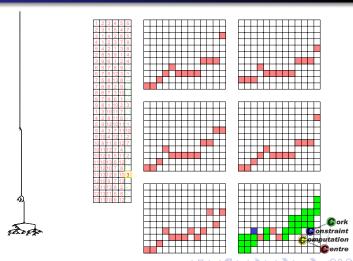


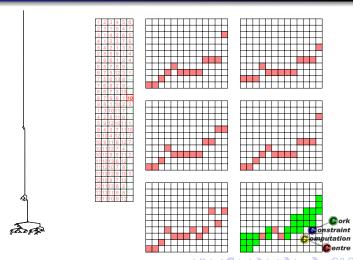


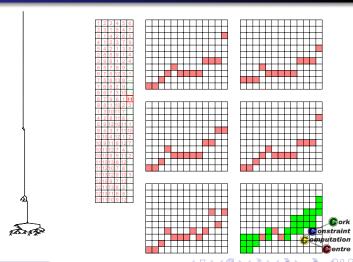


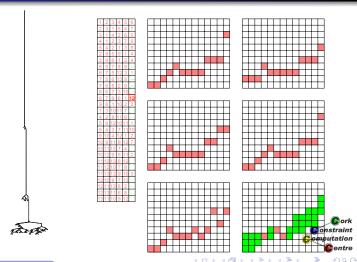


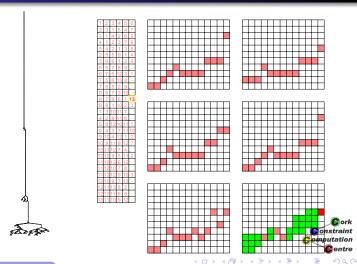


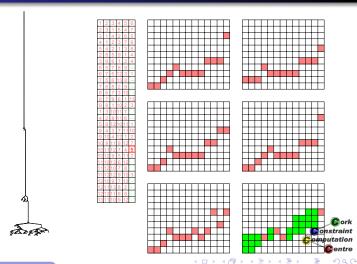


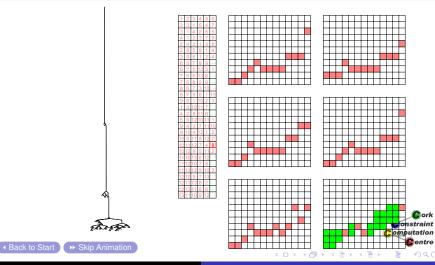


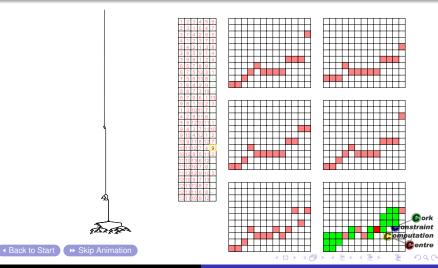


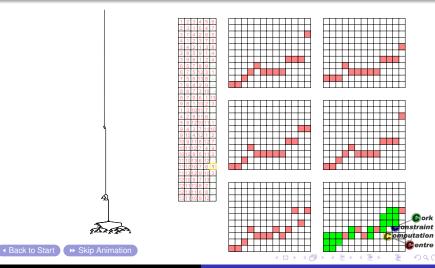


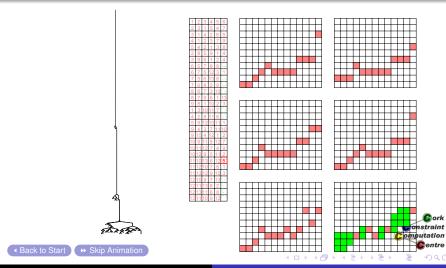


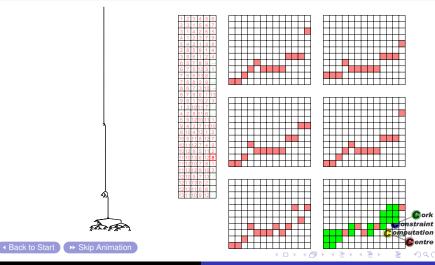


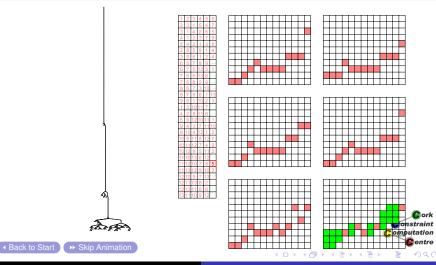


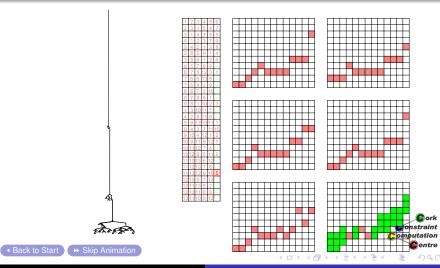


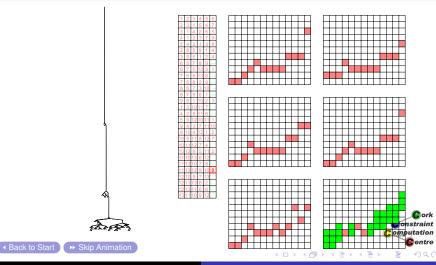


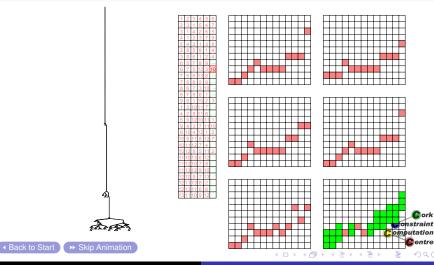


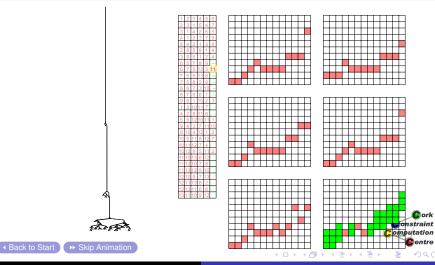


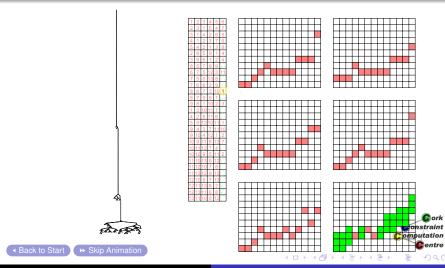


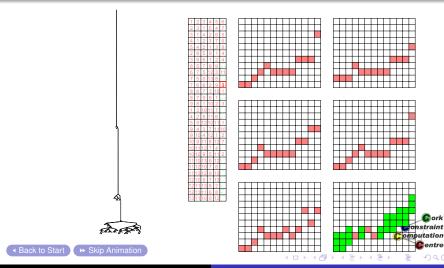


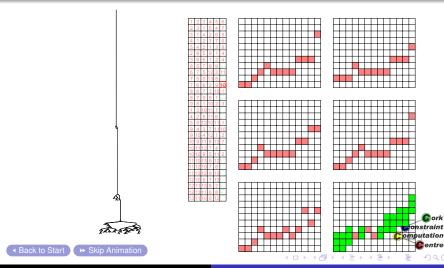


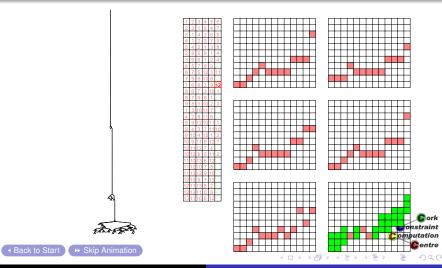


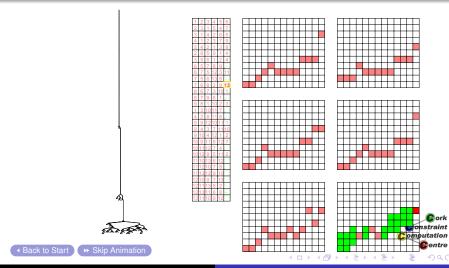


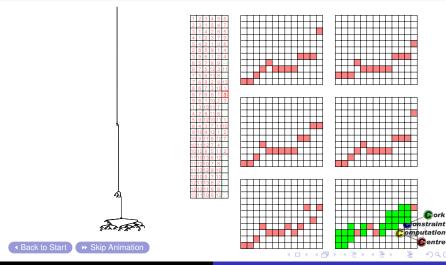


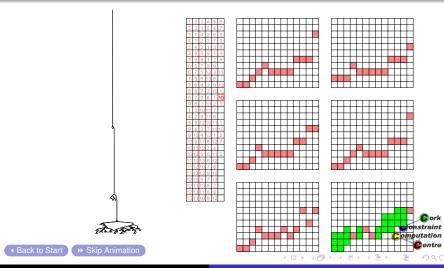


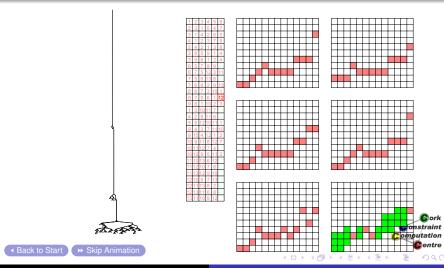


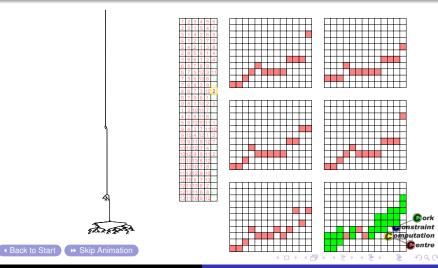


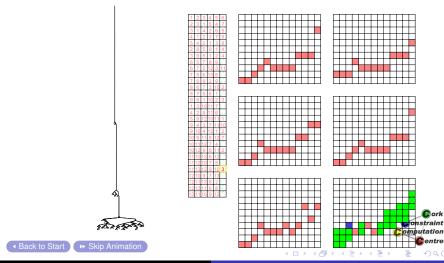


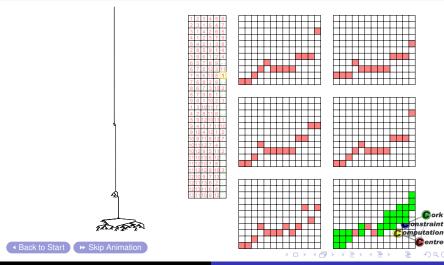


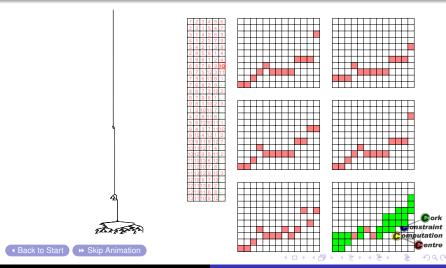


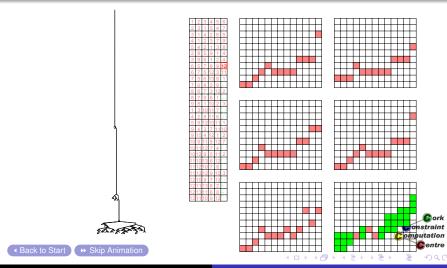


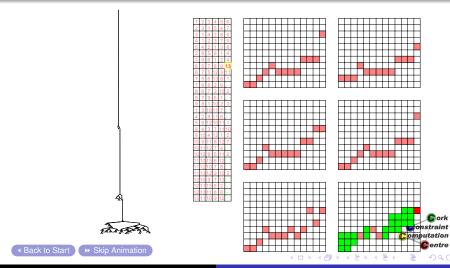


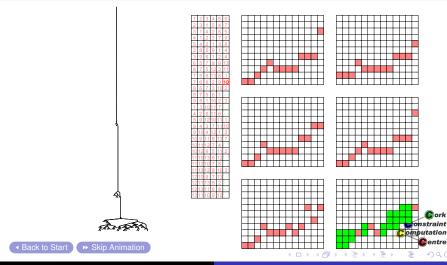


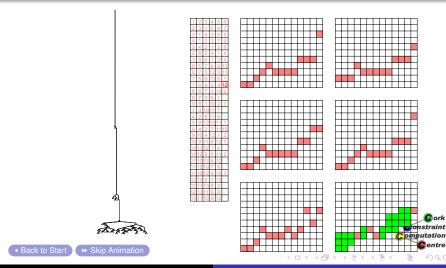


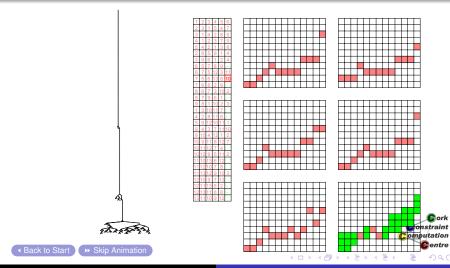


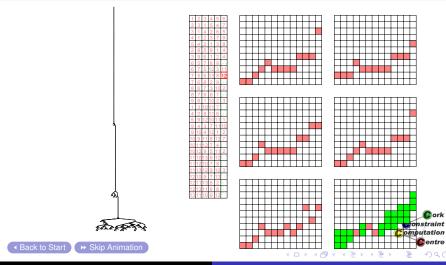


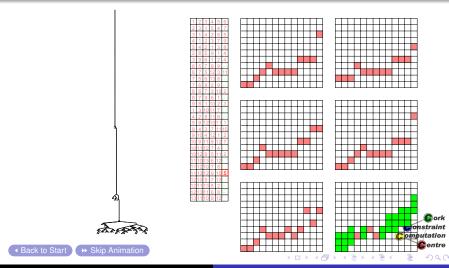


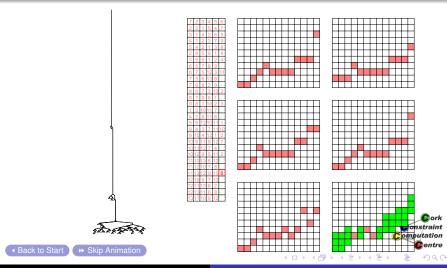


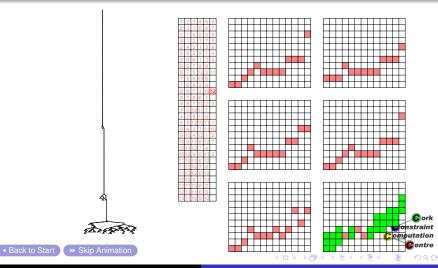


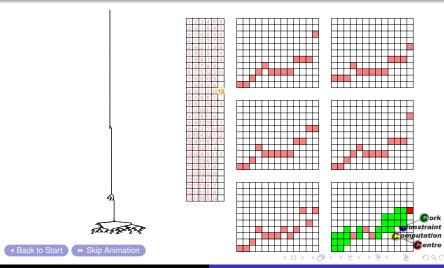


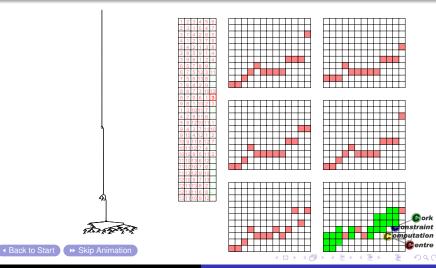


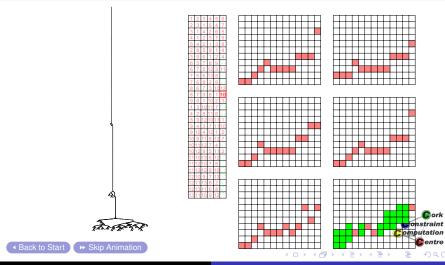


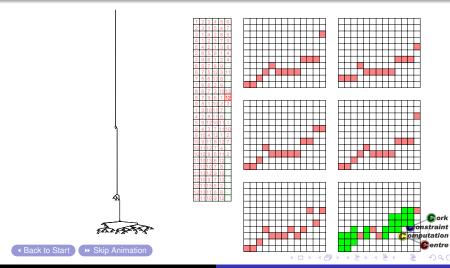


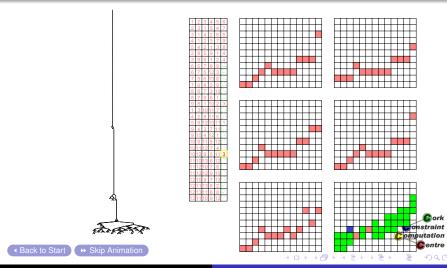


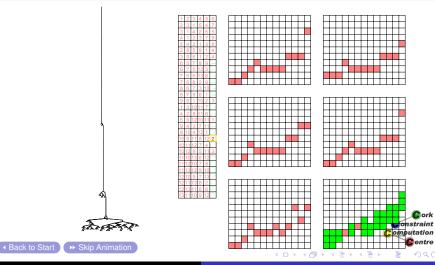


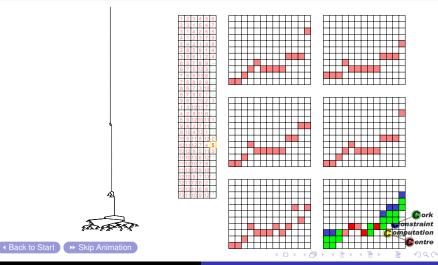


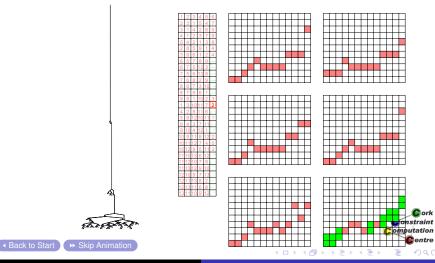


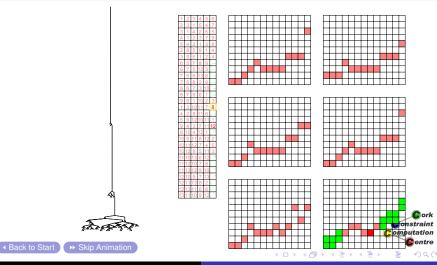


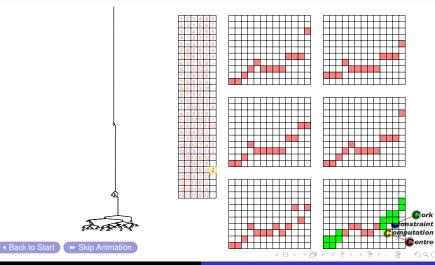


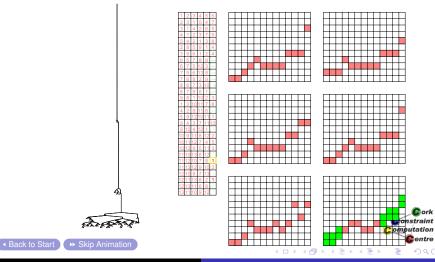


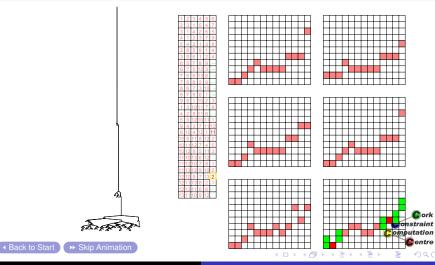


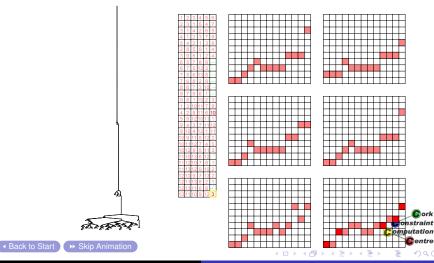


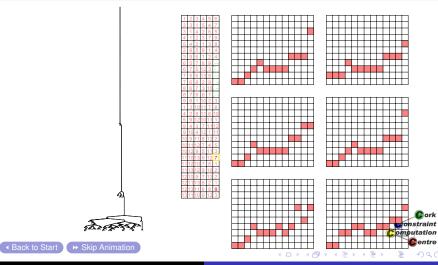


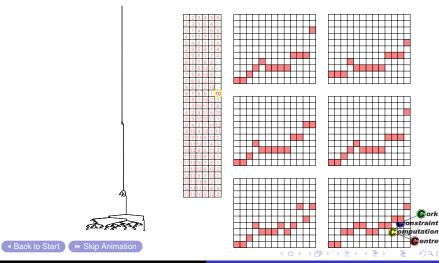


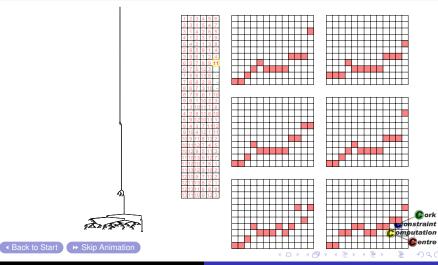


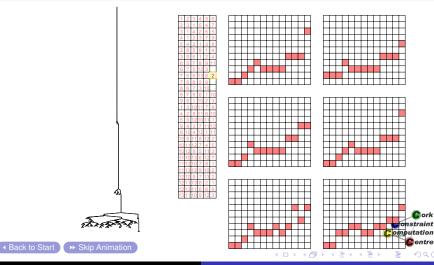


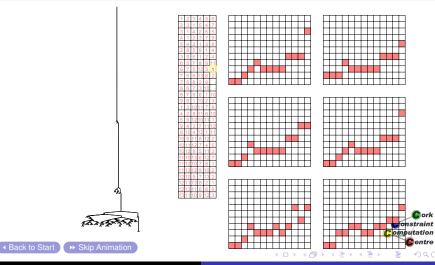


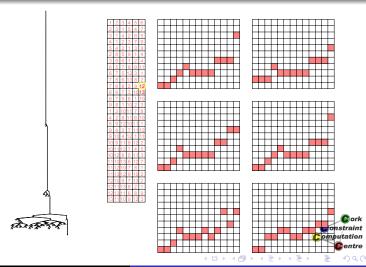












Observations

- Improved search
- Need more sample problems to really understand impact





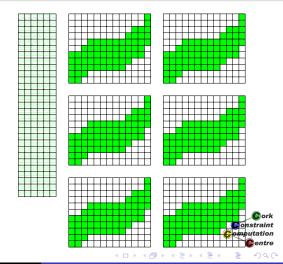
Idea

- Randomize value selction
- Remove bias picking bins in same order
- Allows to add restart
- When spending too much time without finding solution
- Restart search from beginning
- Randomization will explore other initial assignments
- Do not get caught in "dead" part of search tree

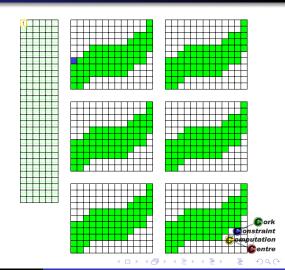


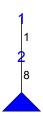
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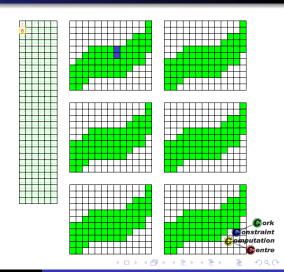




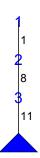


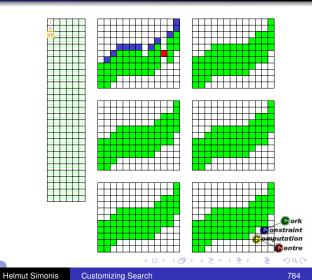


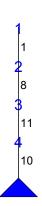


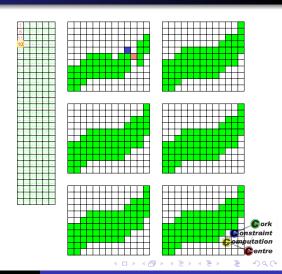


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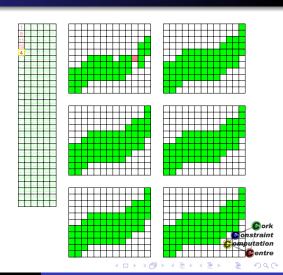




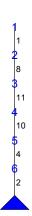


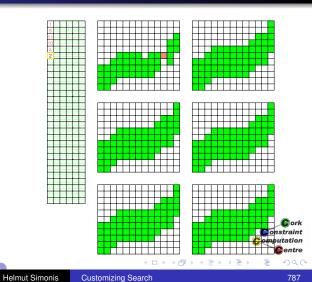




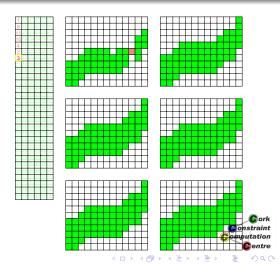


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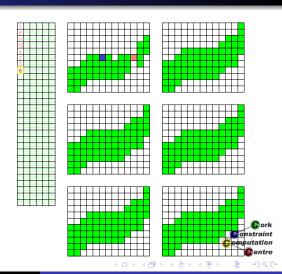








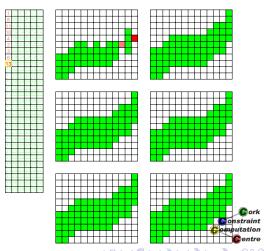




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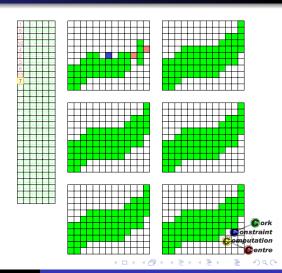
Randomized Search





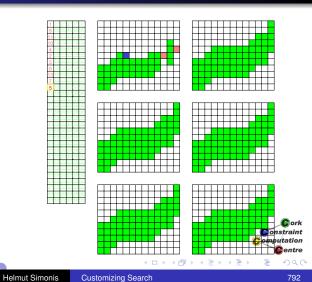
Customizing Search



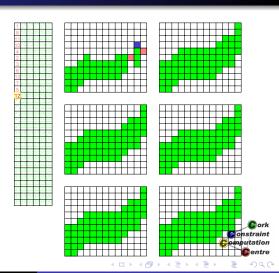


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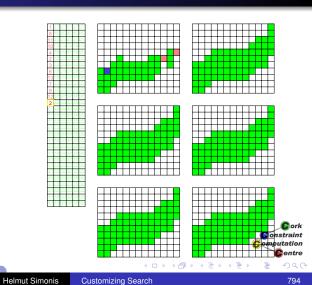


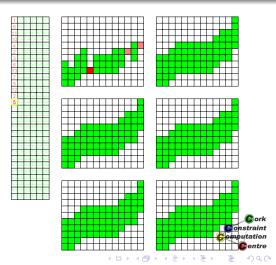




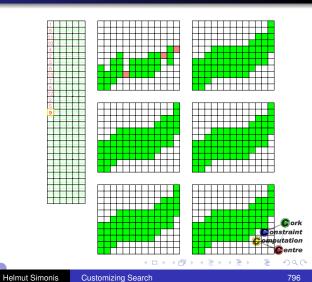






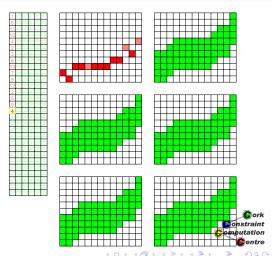






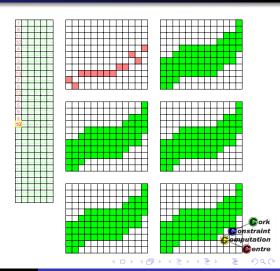
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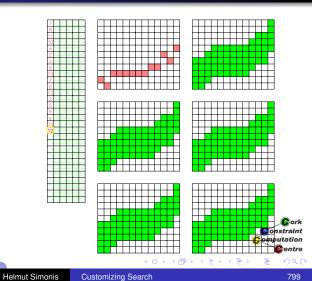




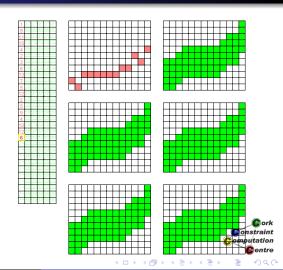
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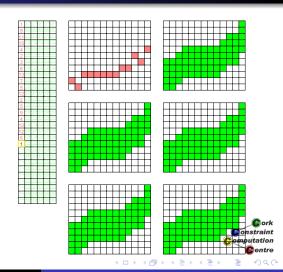




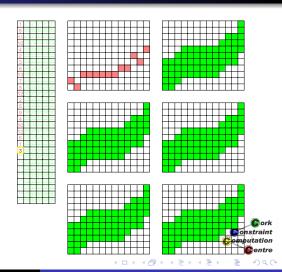


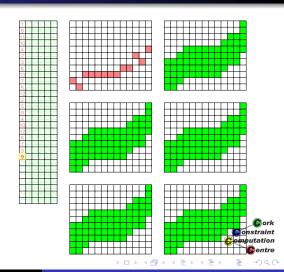




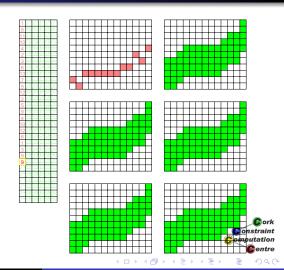


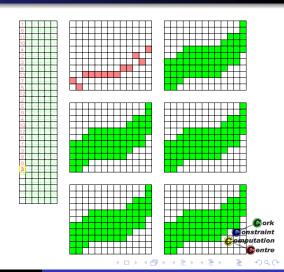




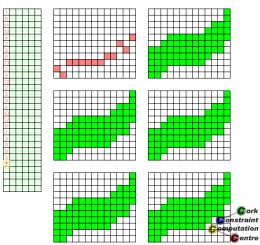


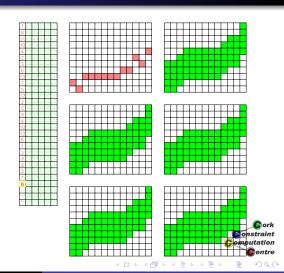


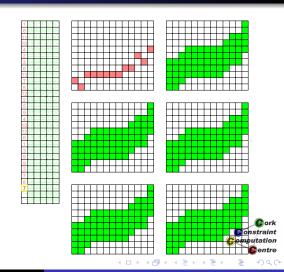




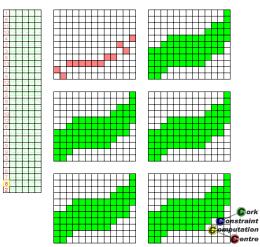


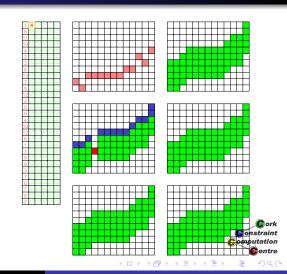


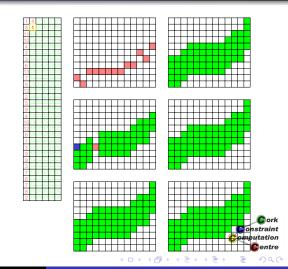


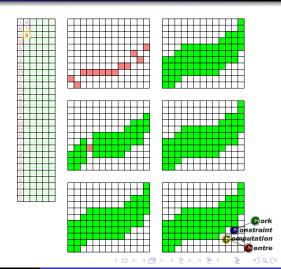


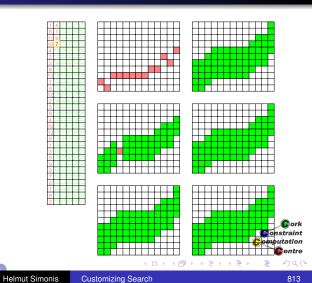


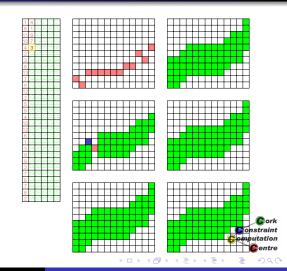


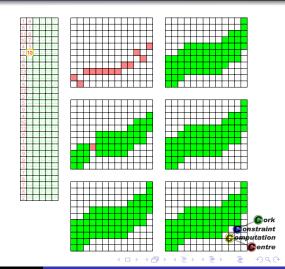


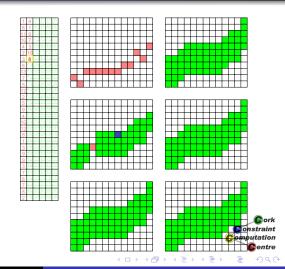


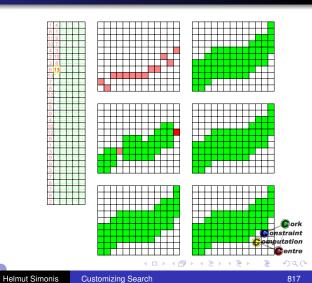


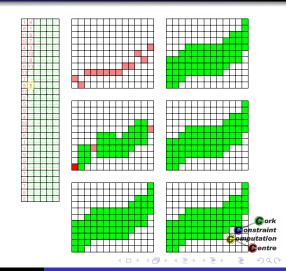


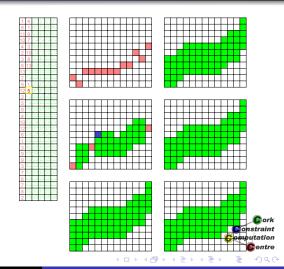


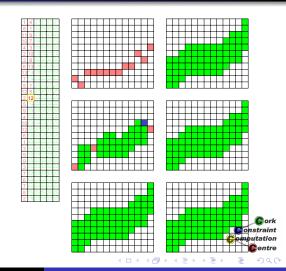


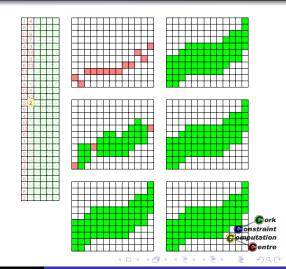


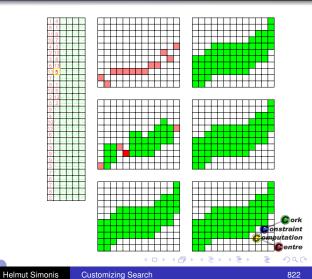


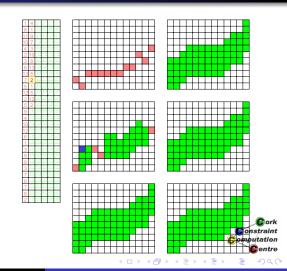


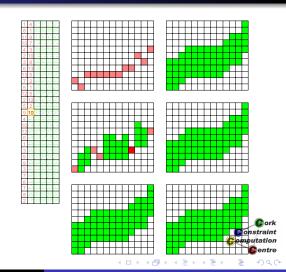


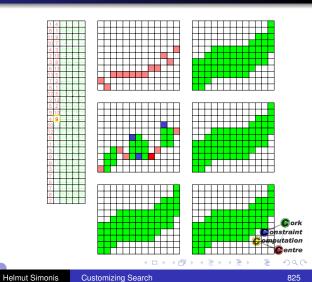


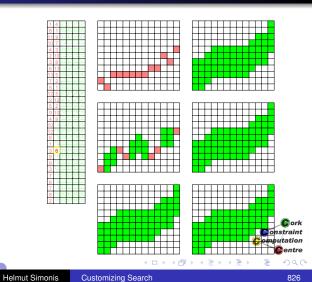


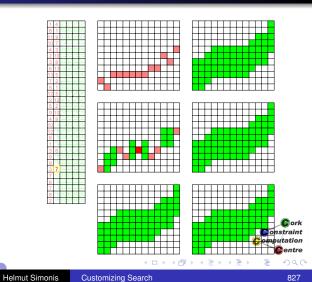


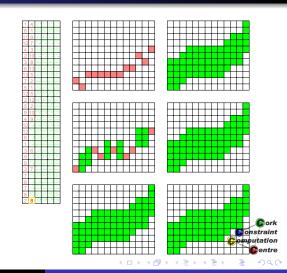


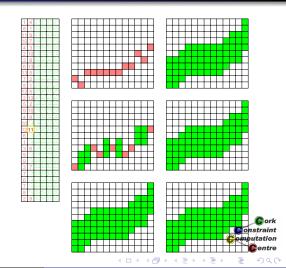


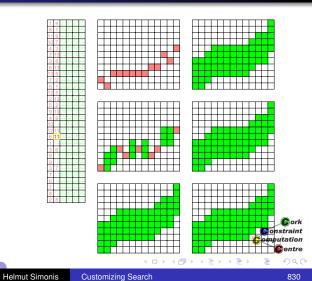


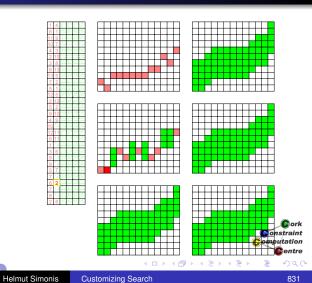


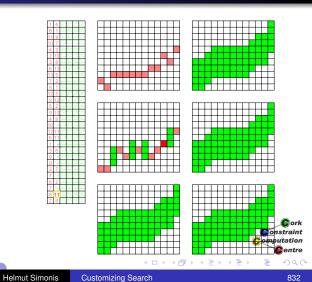


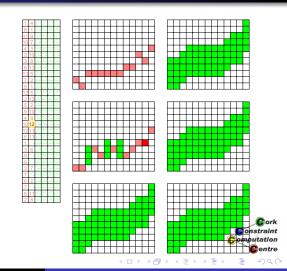


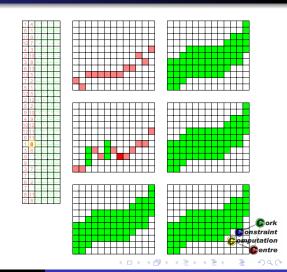


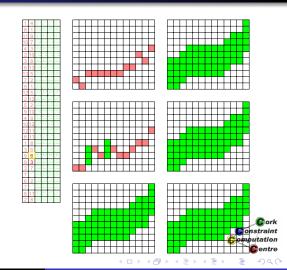


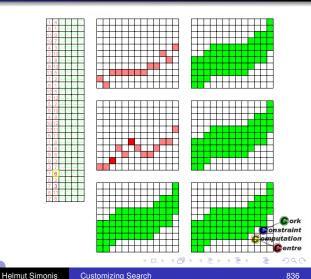


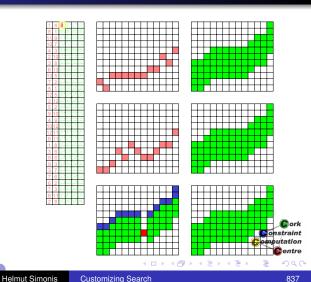


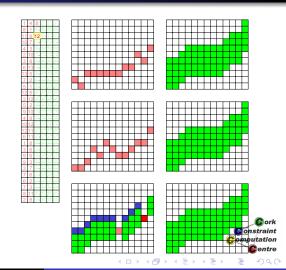






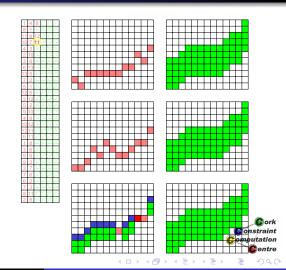


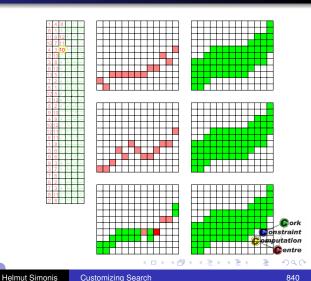


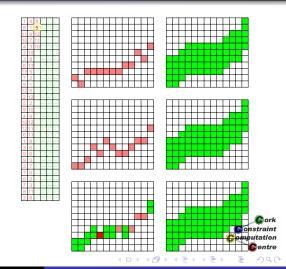


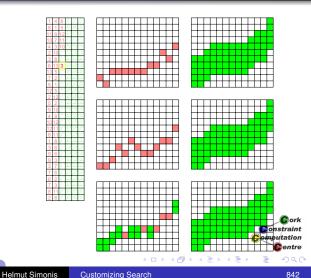
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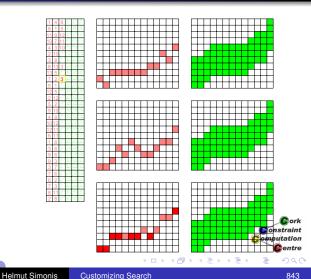
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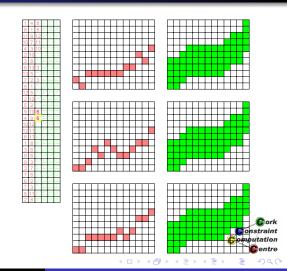




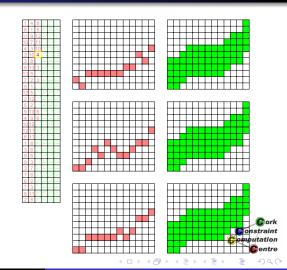


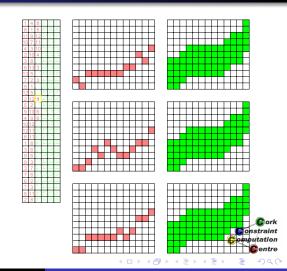


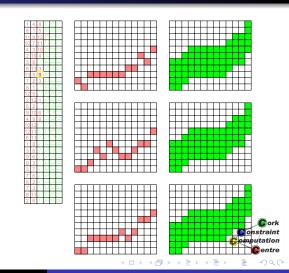
Randomized Search

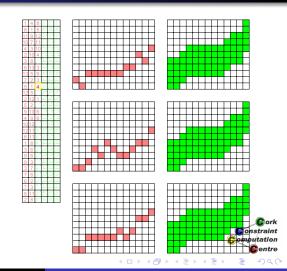


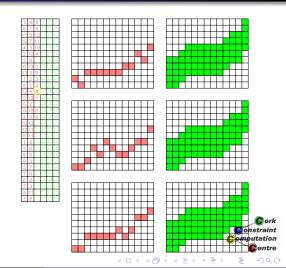
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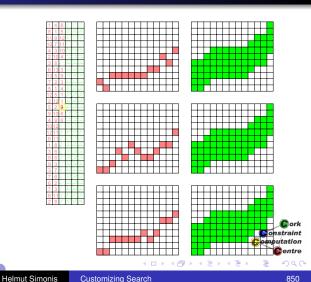


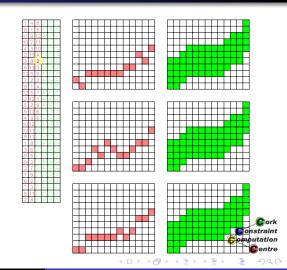


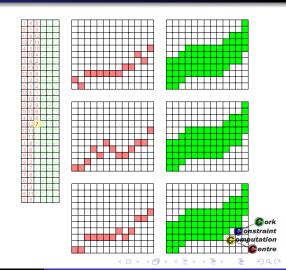


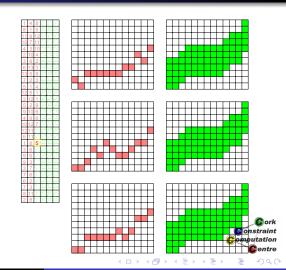


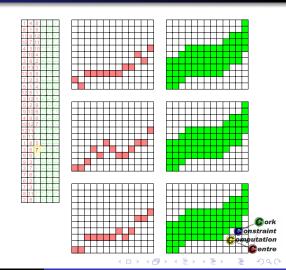


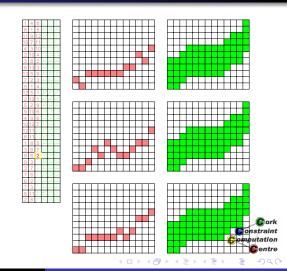


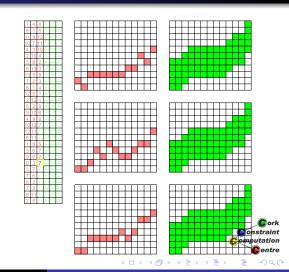


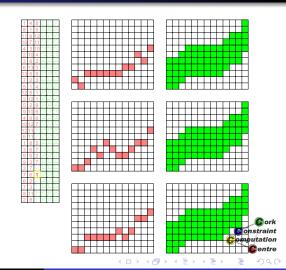


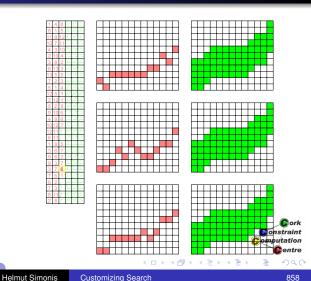


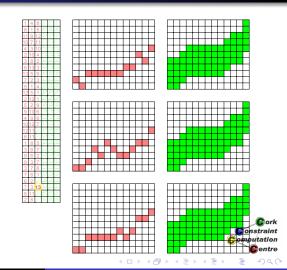


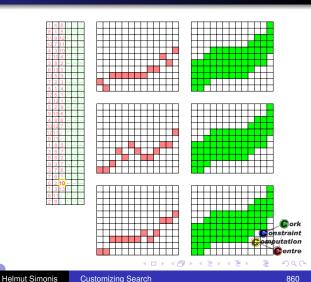


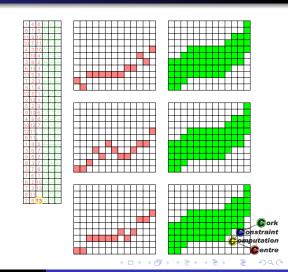


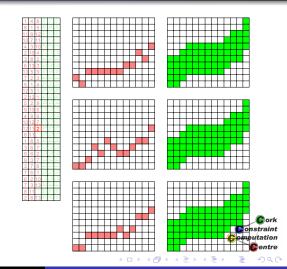


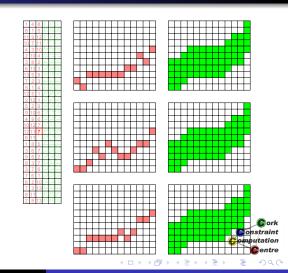


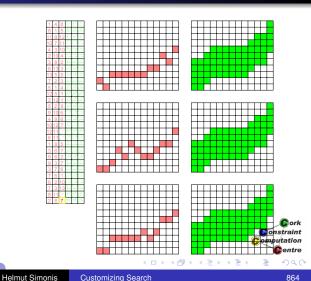


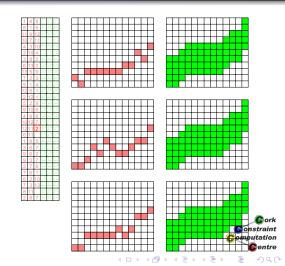


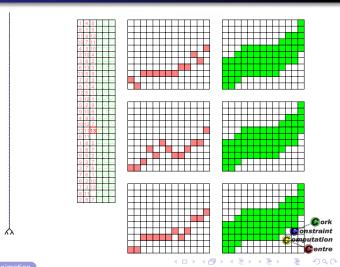




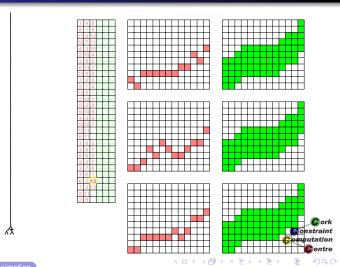




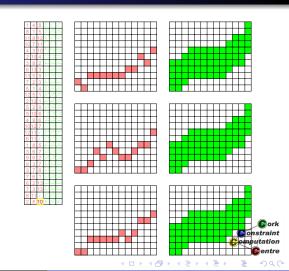


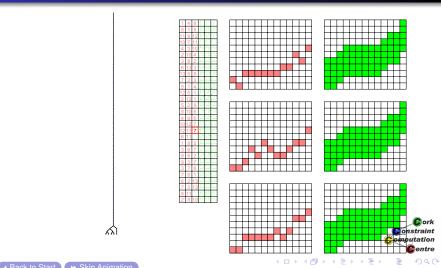


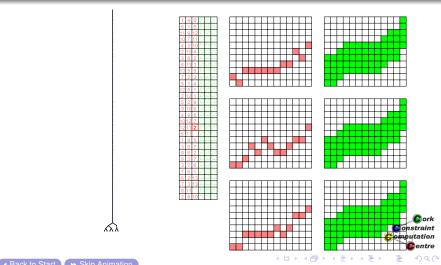
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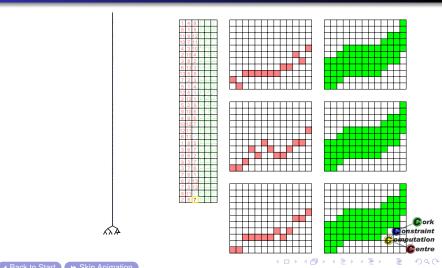


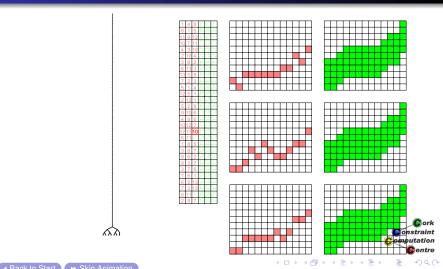
Helmut Simonis

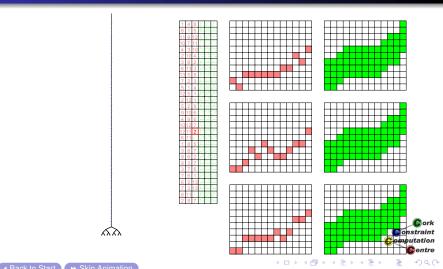


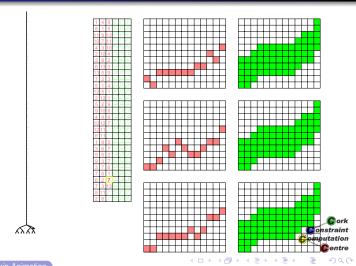


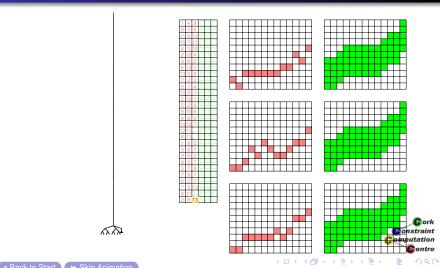


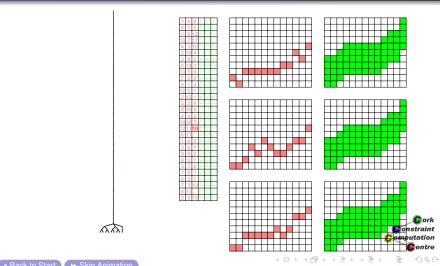


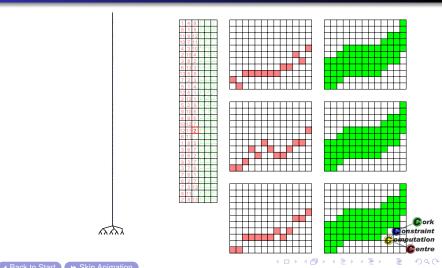


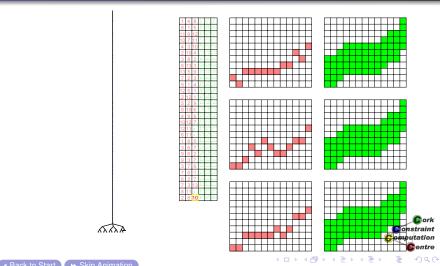


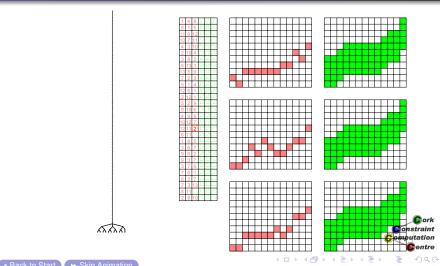


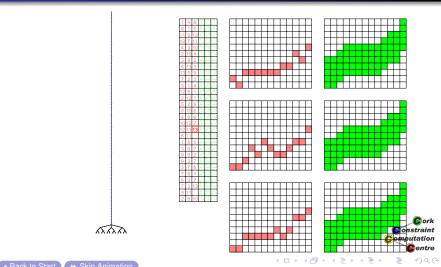


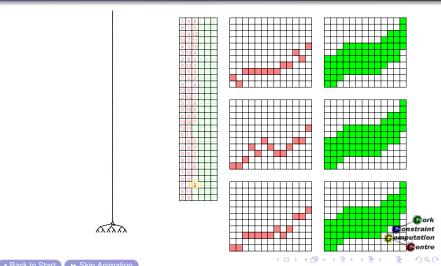


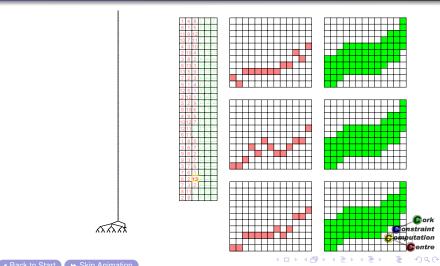


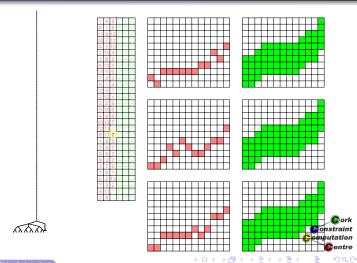


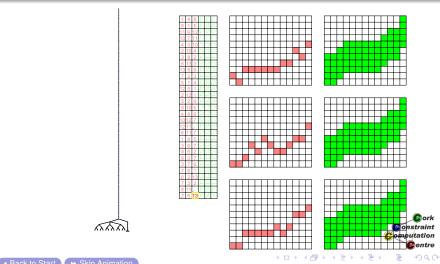




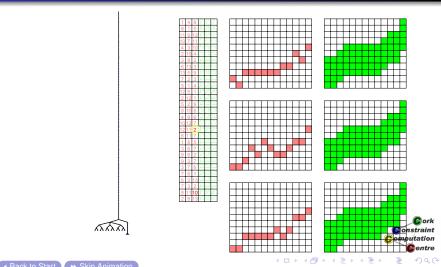




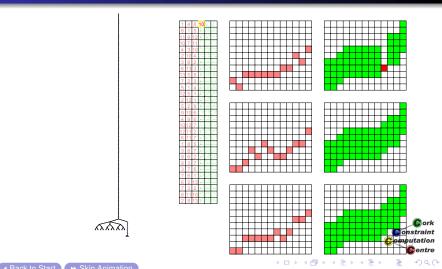


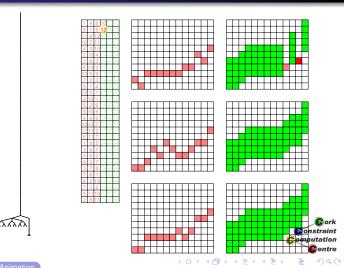


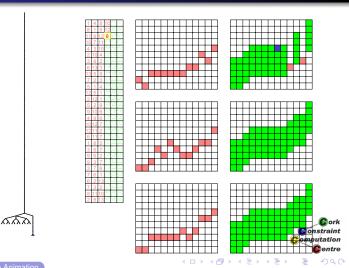
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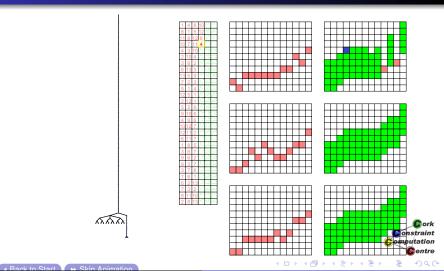


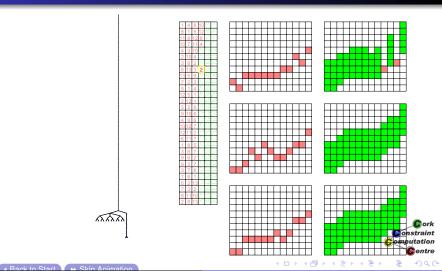
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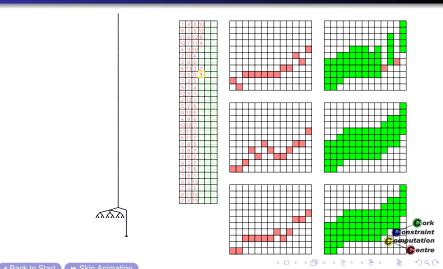


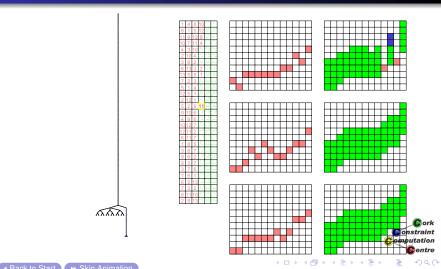


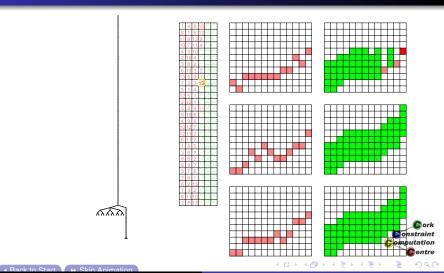


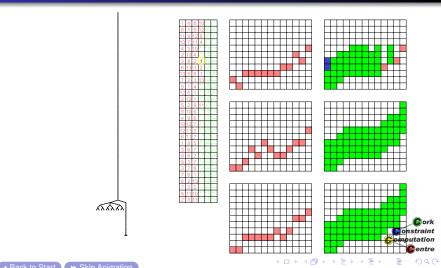


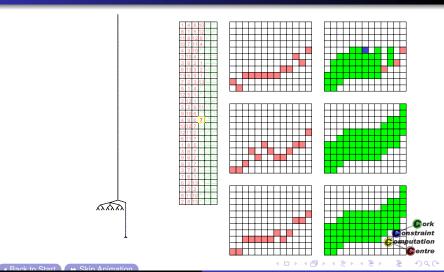


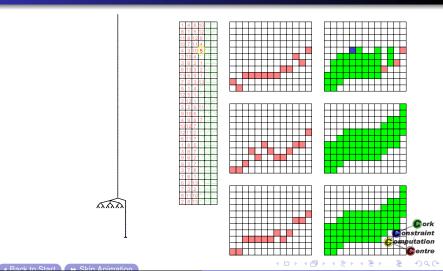


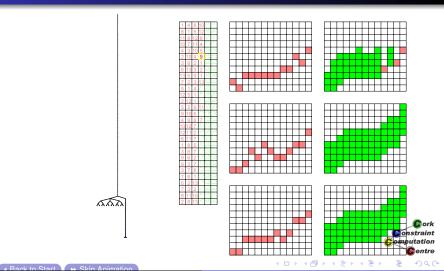


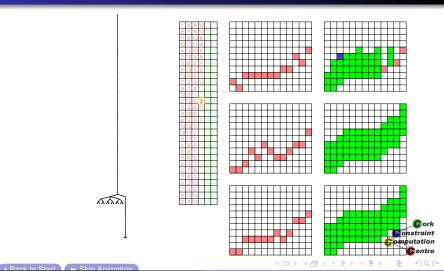


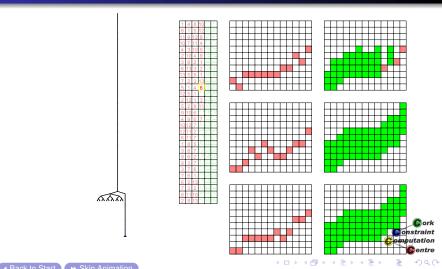


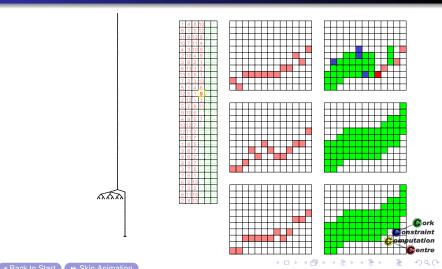


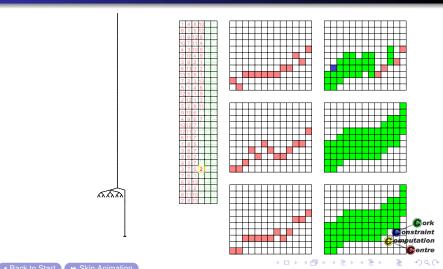


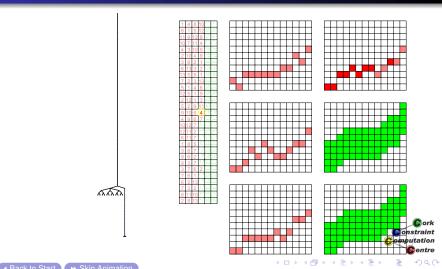


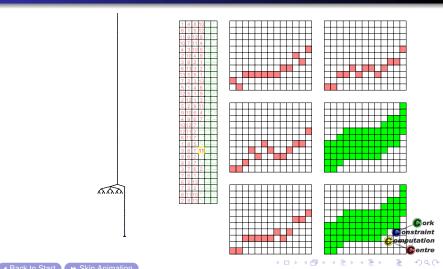




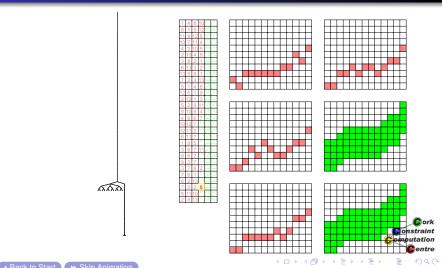




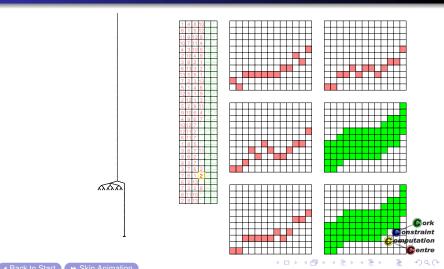


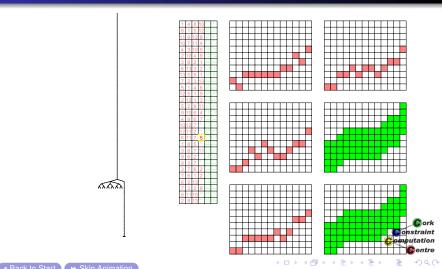


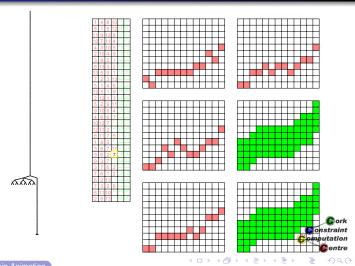
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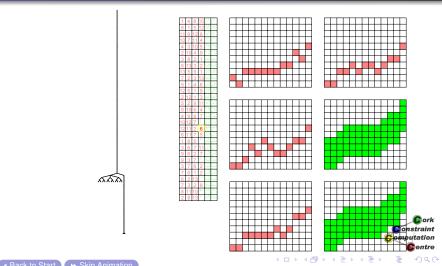


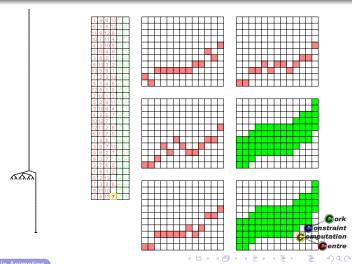
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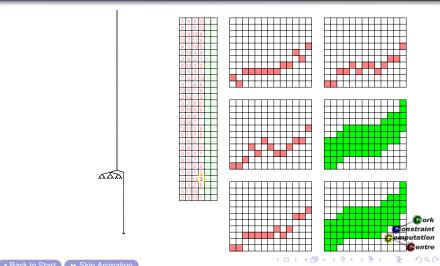


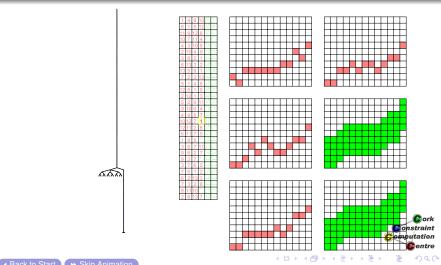




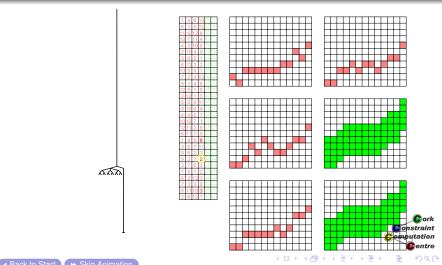




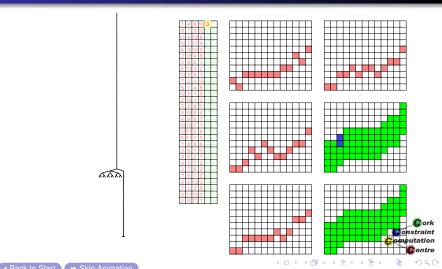


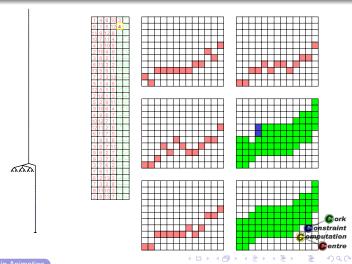


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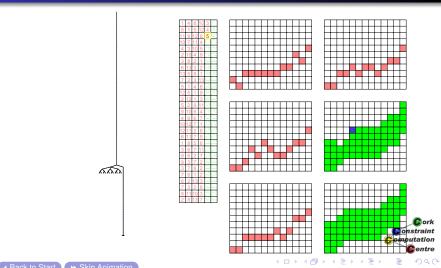


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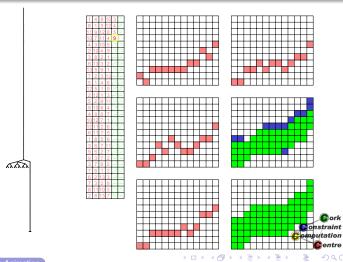


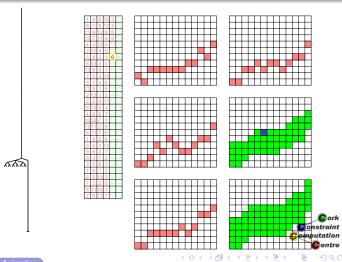


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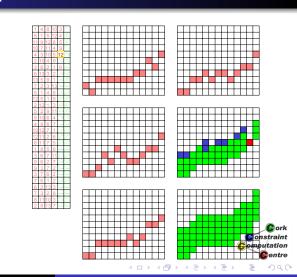


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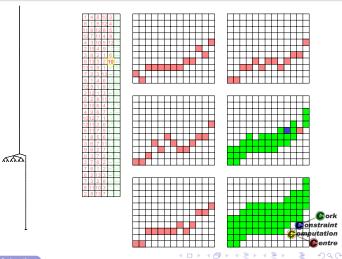




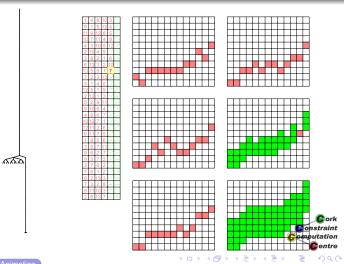
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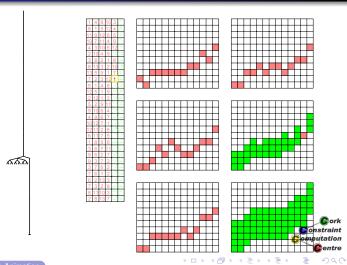
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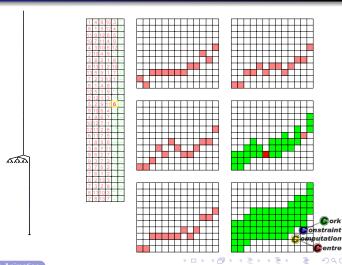


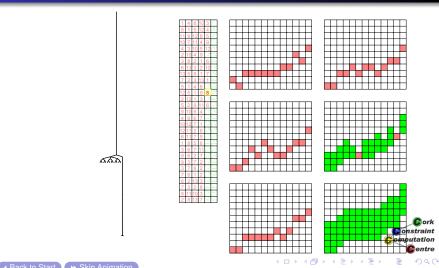
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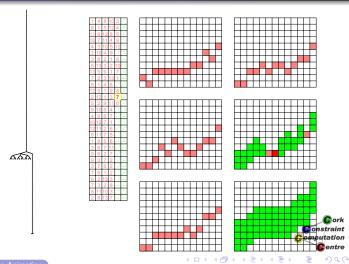


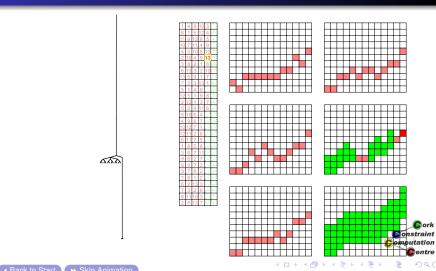
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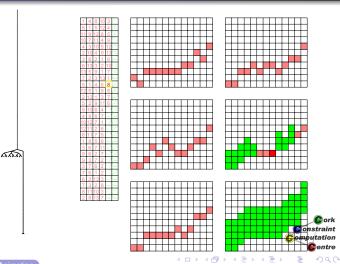




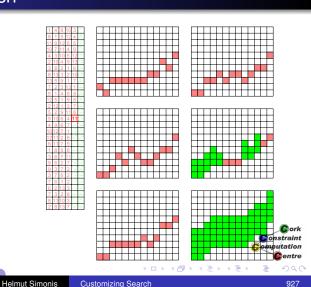




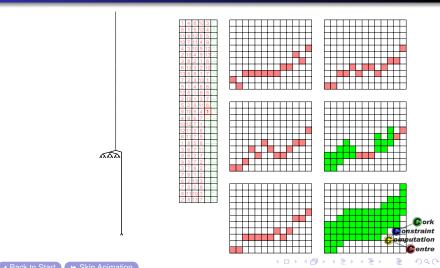


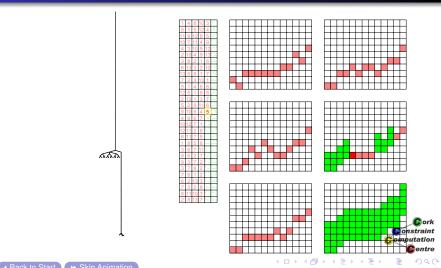


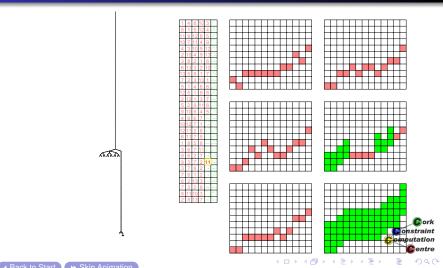
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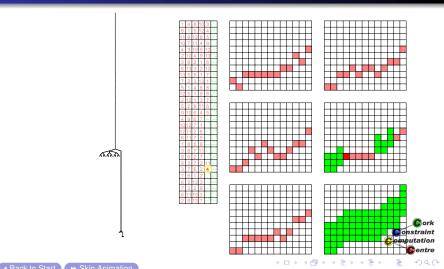


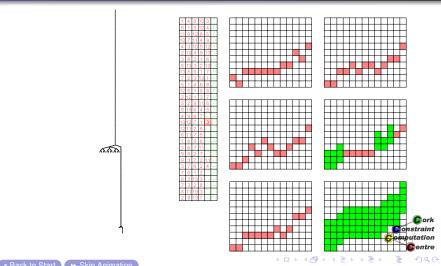
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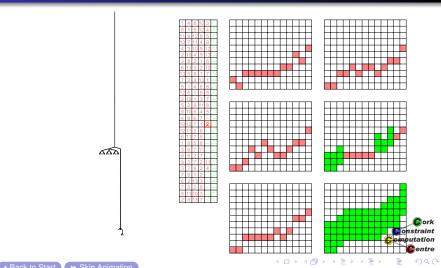


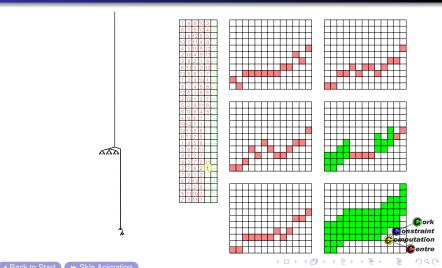


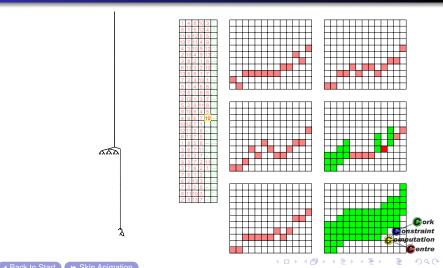


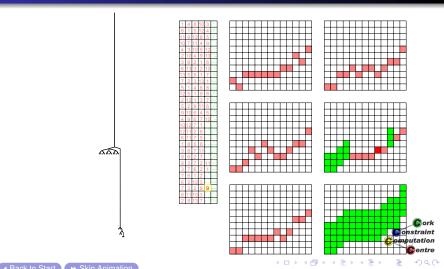




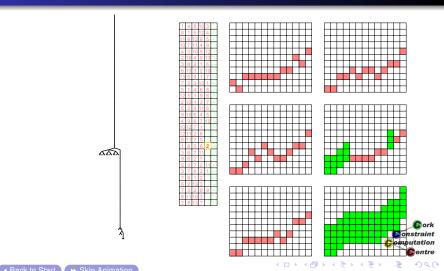


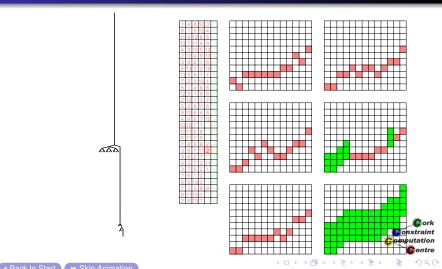


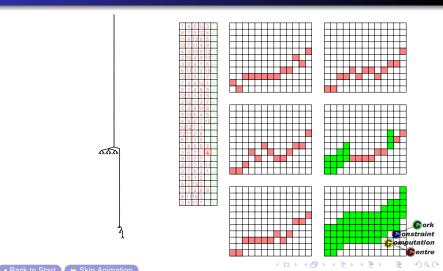


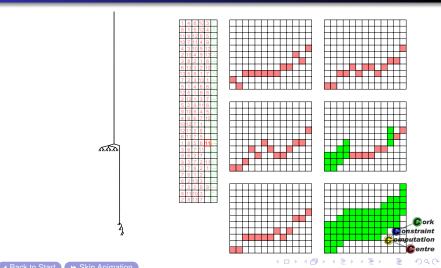


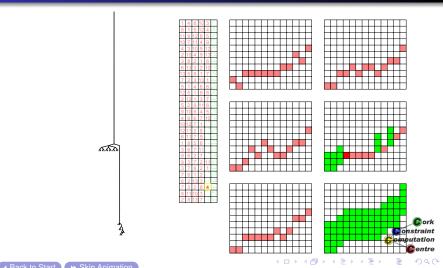
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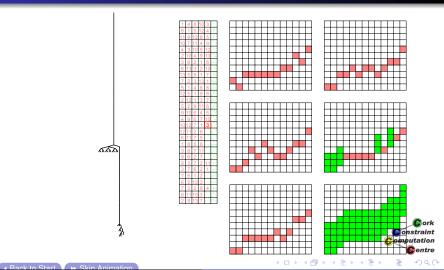




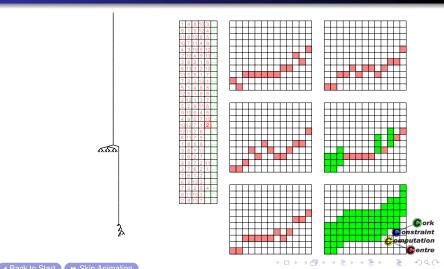




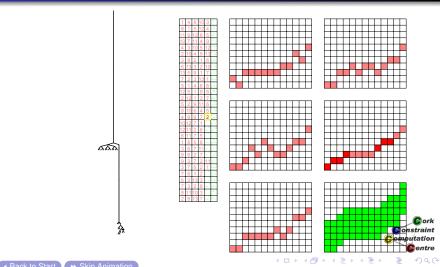
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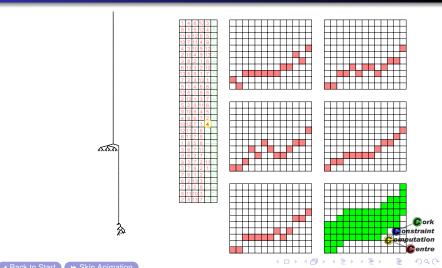


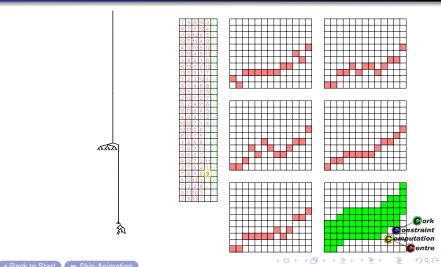
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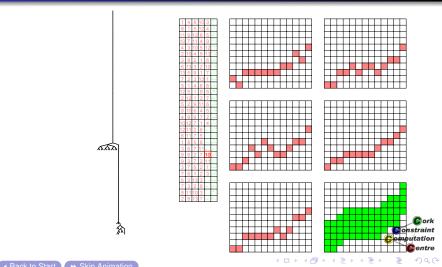


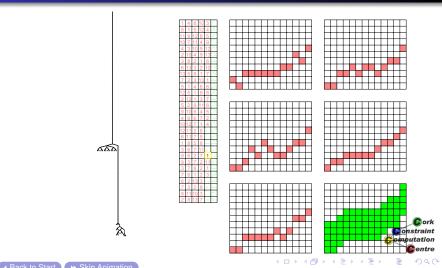
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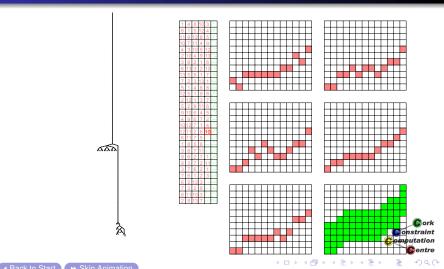


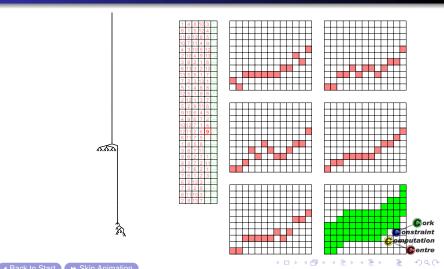


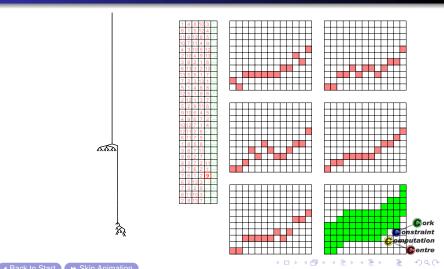




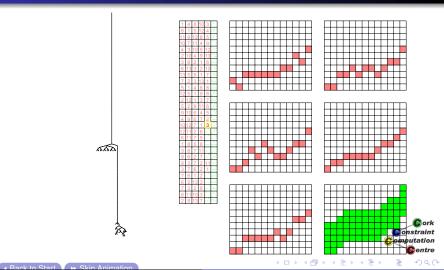




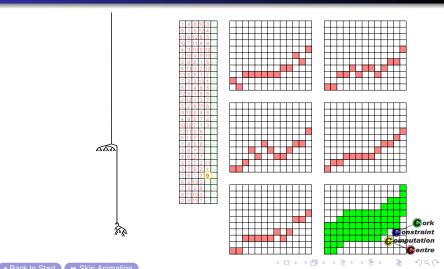


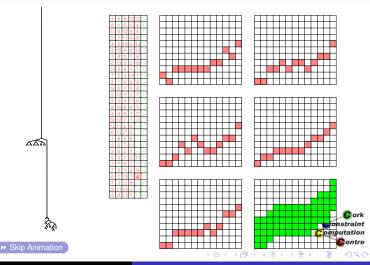


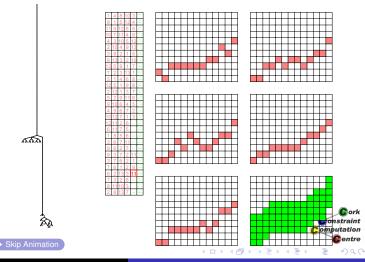
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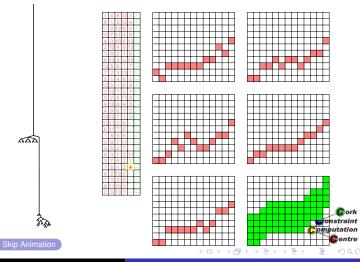


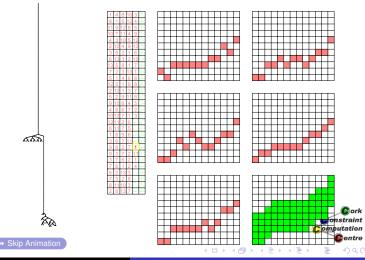
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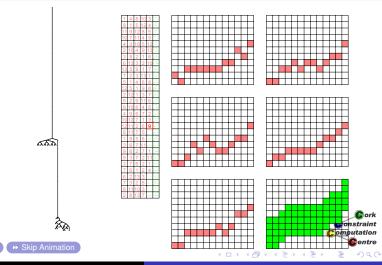


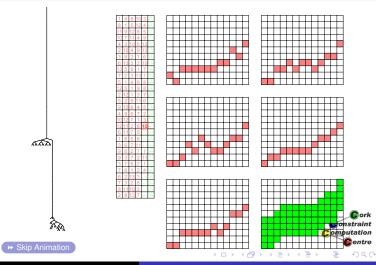


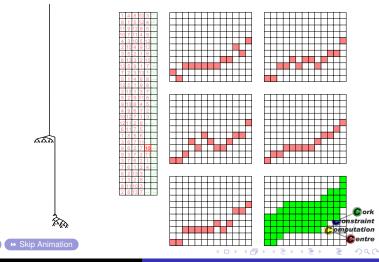


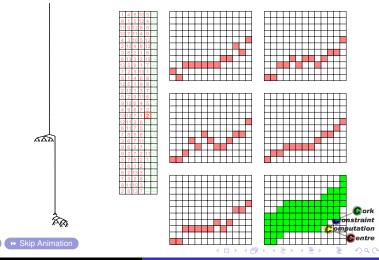


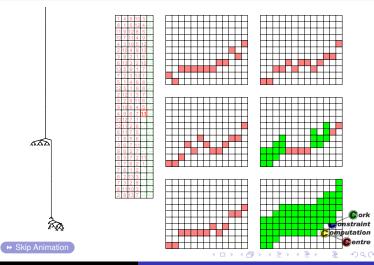


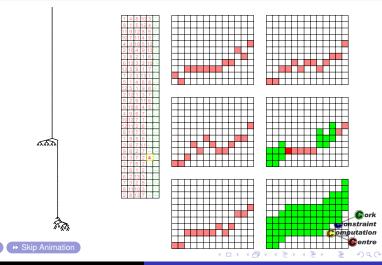


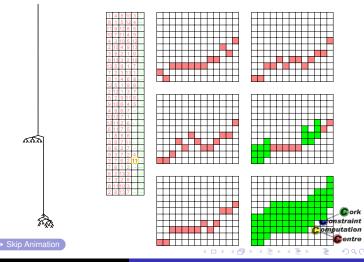






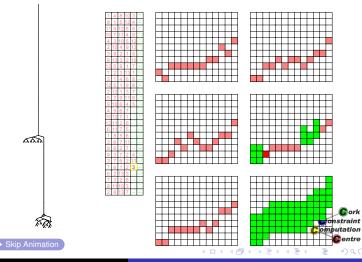


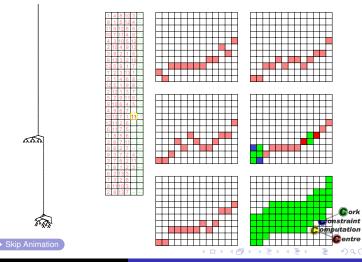


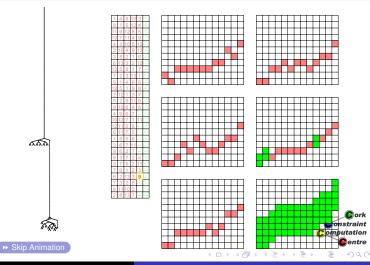


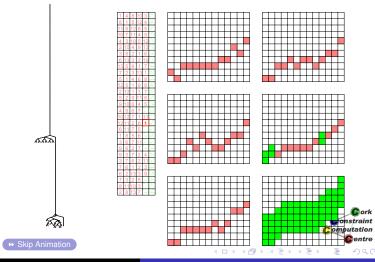
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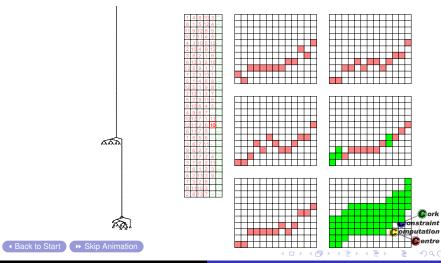
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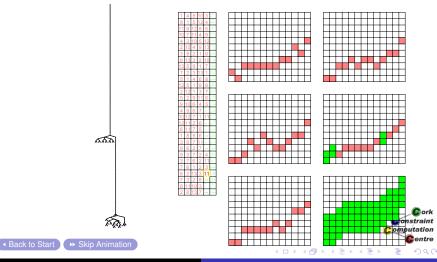


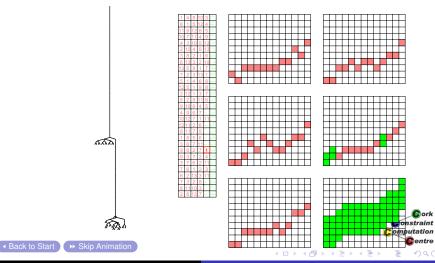


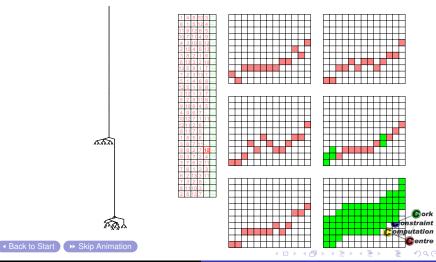


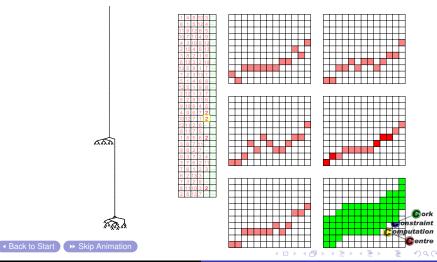


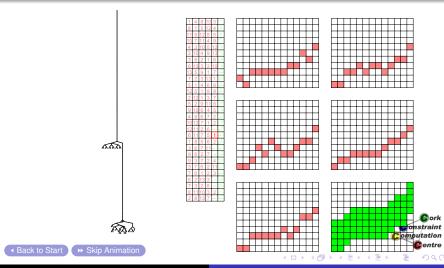


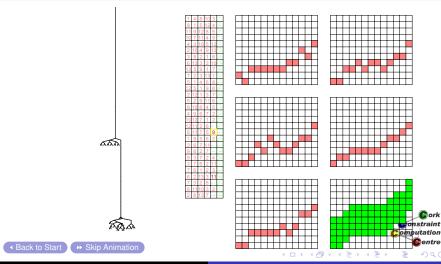


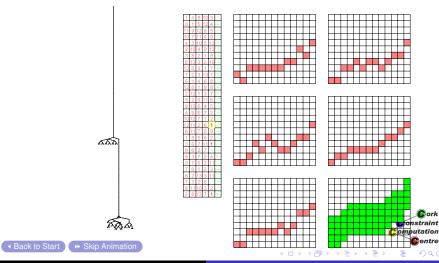


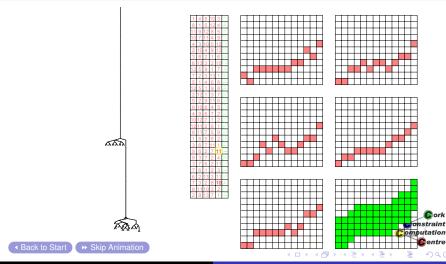


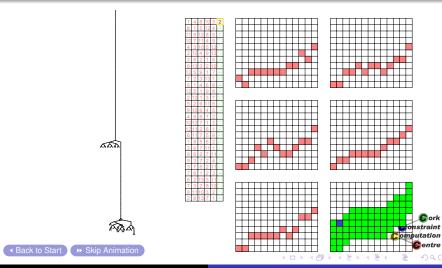


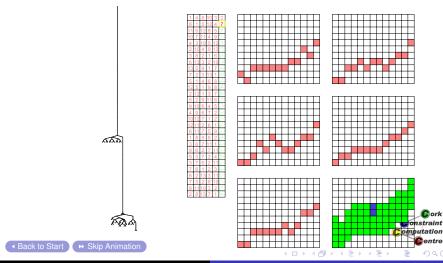


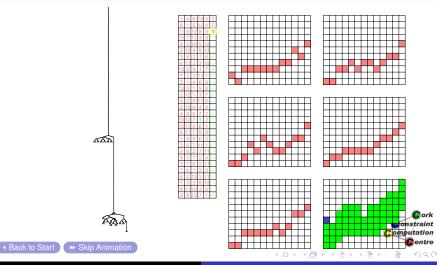


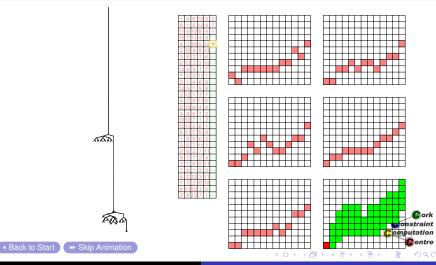




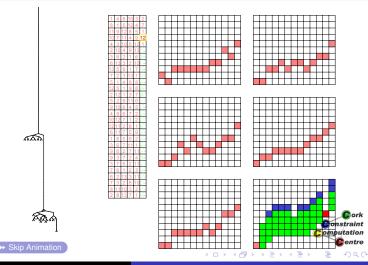


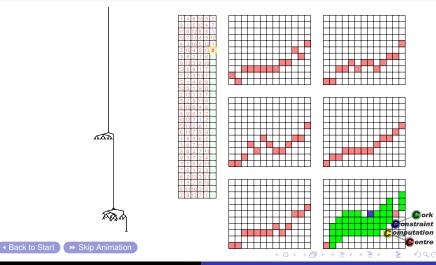


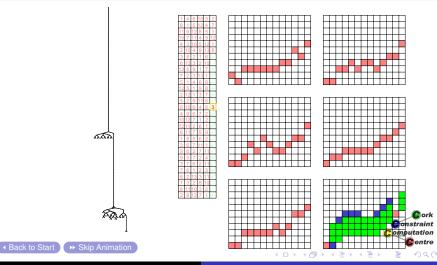




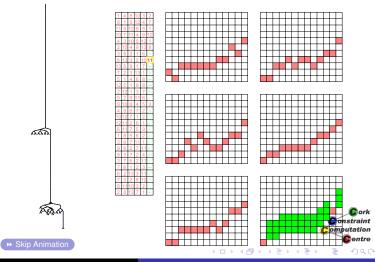
Randomized Search

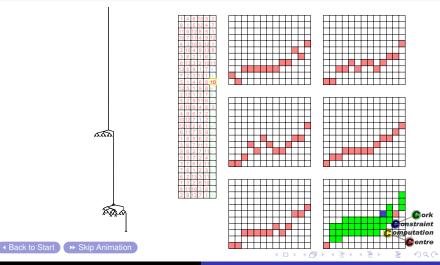


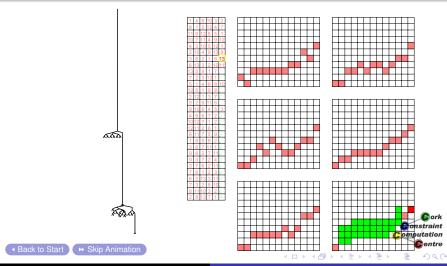


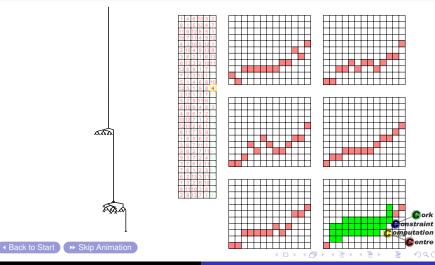


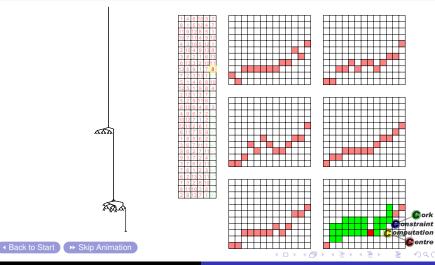
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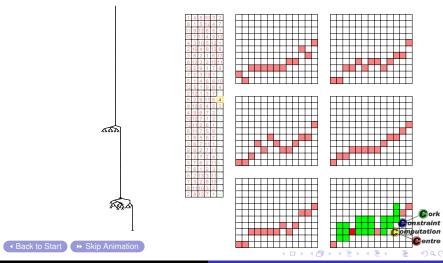


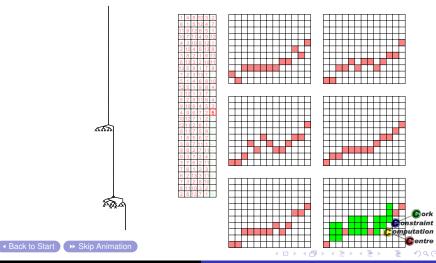


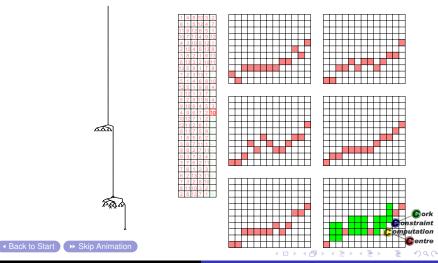


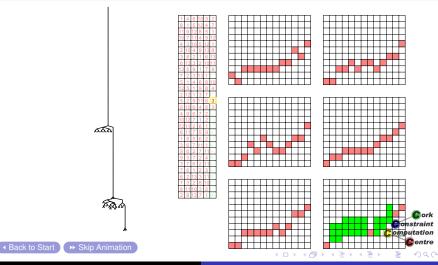


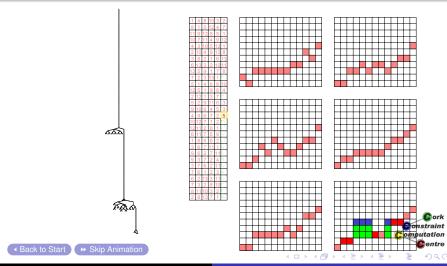


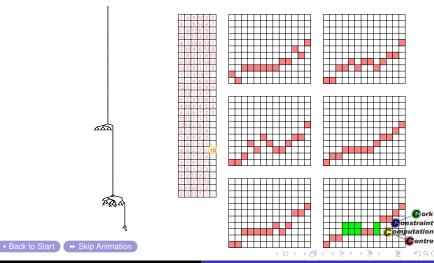


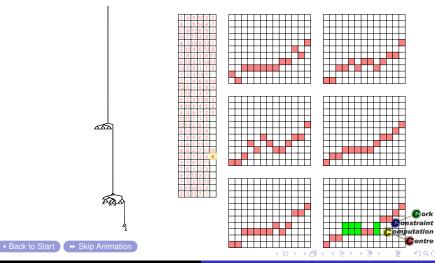


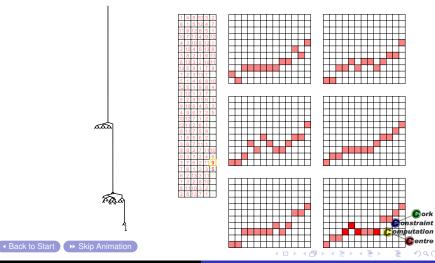




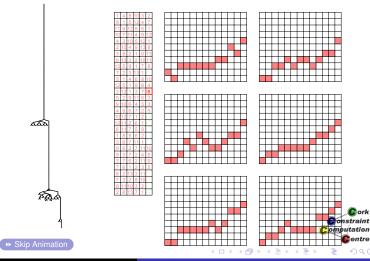




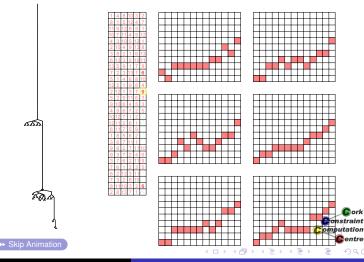




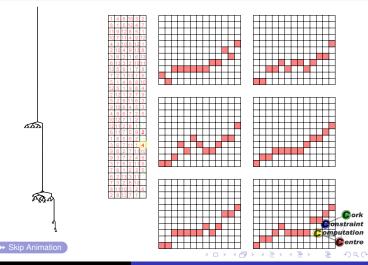
Randomized Search

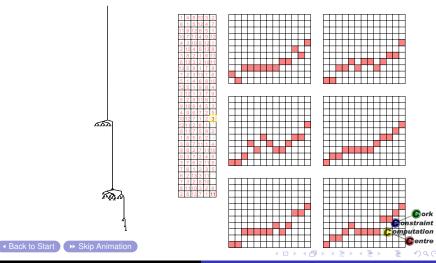


Randomized Search

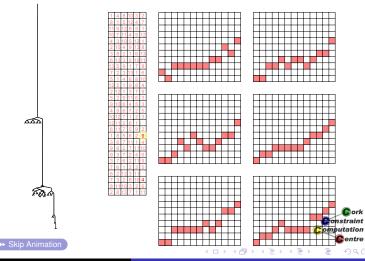


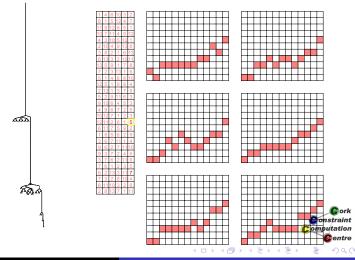
Randomized Search





Randomized Search





Observations

- Avoids deep backtracking in last time periods
- Perhaps by mixing values more evenly
- Impose fewer disequality constraints for last periods
- Easier to find solution
- Should allow to find solutions with more time periods



Changing time periods

Problem	Size	Naive	FF	Layered	Credit	Random
10	5	0.812	1.453	1.515	0.828	1.922
10	6	14.813	2.047	2.093	1.219	2.469
10	7	79.109	3.688	50.250	3.234	3.672
10	8	-	-	141.609	55.156	6.328
10	9	-	-	-	-	10.281



Observations

- Randomized method is strongest for this problem
- Not always fastest for smaller problem sizes
- Restart required for size 9 problems
- Same model, very different results due to search
- Very similar results for other problem instances

