Imposing Old-growth Patch Constraints in Forest Harvest Scheduling Models

Juan Pablo Vielma

University of Pittsburgh and IBM Watson Research Center

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Rodolfo Carvajal
Georgia Tech

Miguel Constantino
Lisbon University

Marcos Goycoolea
Adolfo Ibañes University

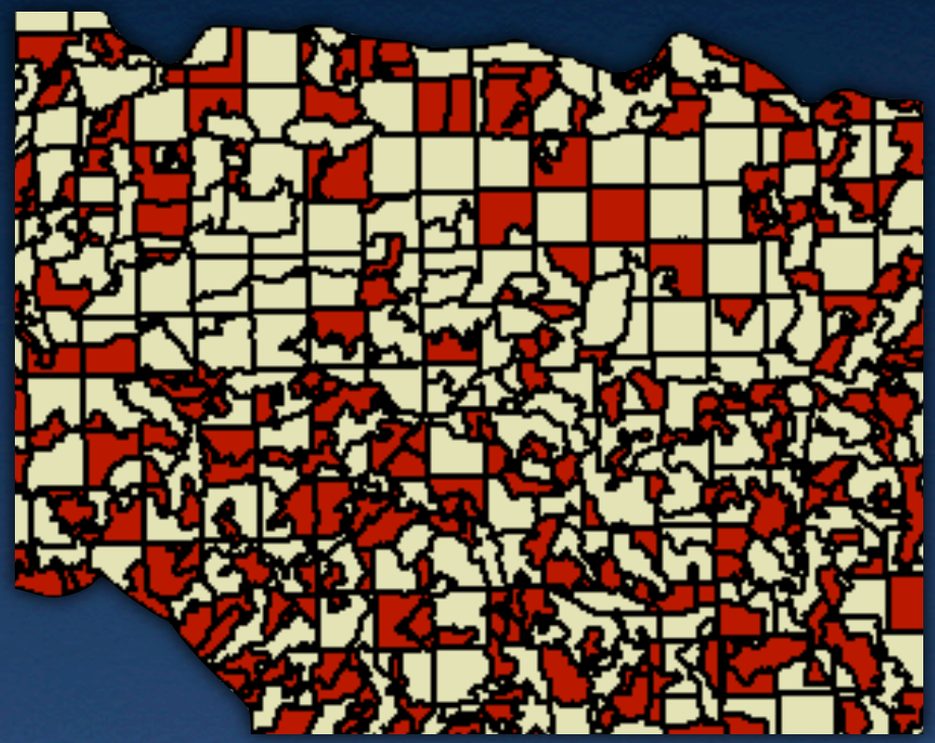
Andres Weintraub
University of Chile

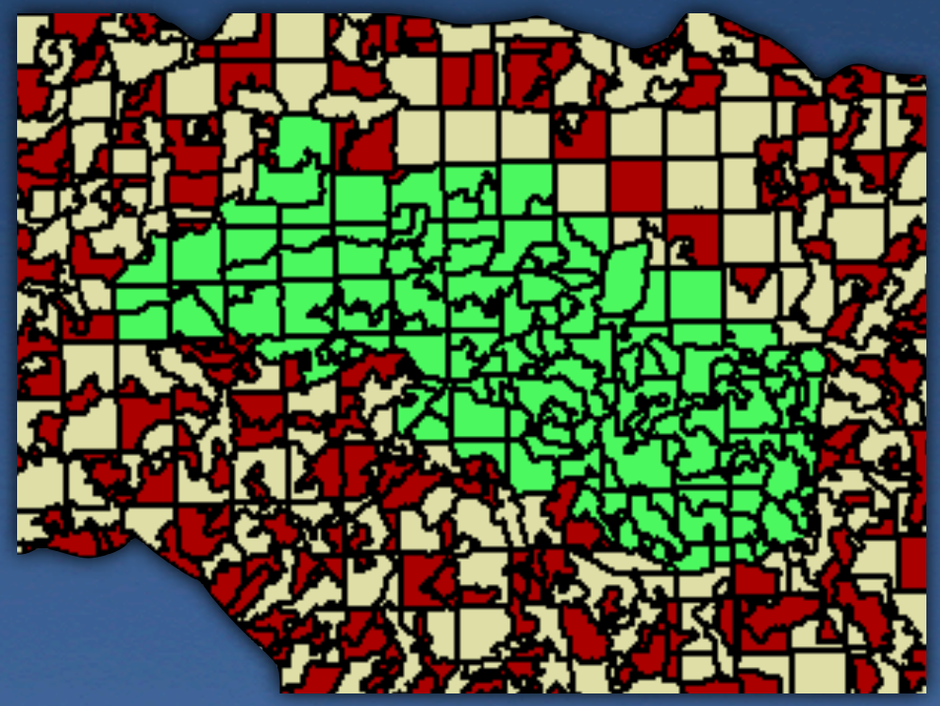
Outline

- Introduction
- Connectivity Constraints
- Computational Example
- Conclusions and Future Work

Beyond ARM, 1st Step: Connectivity

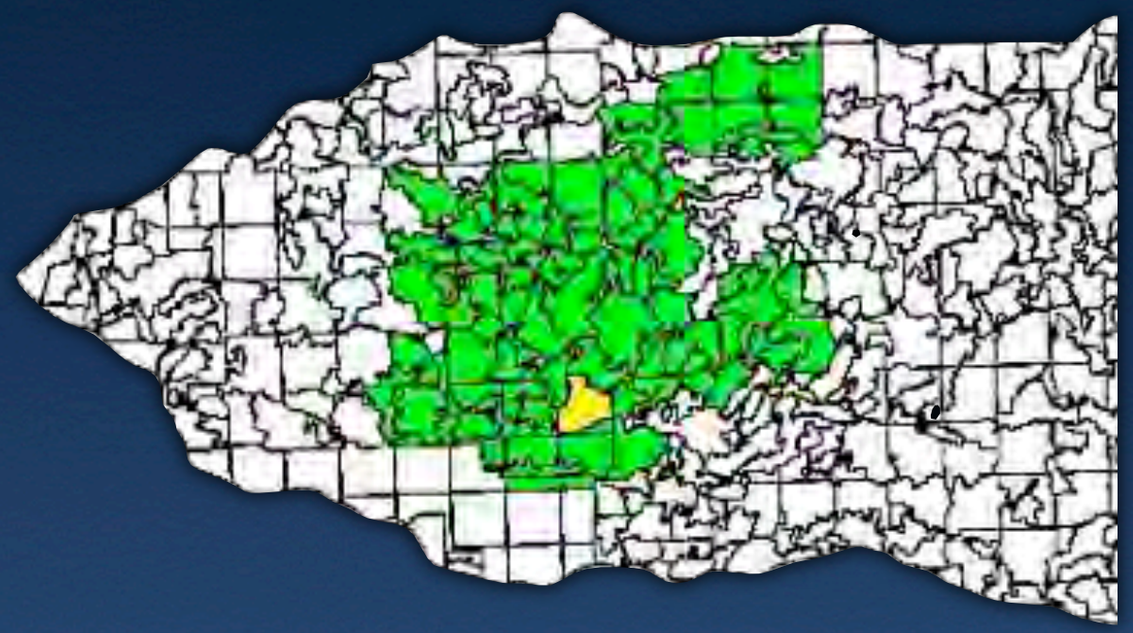
- Area Restriction Model
  - Forbid large clear-cut areas
  - ARM is not enough.
- 1+ connected regions:
  - ***minimum*** (average) area
  - is old-growth, contains animal population, contain water source, etc.



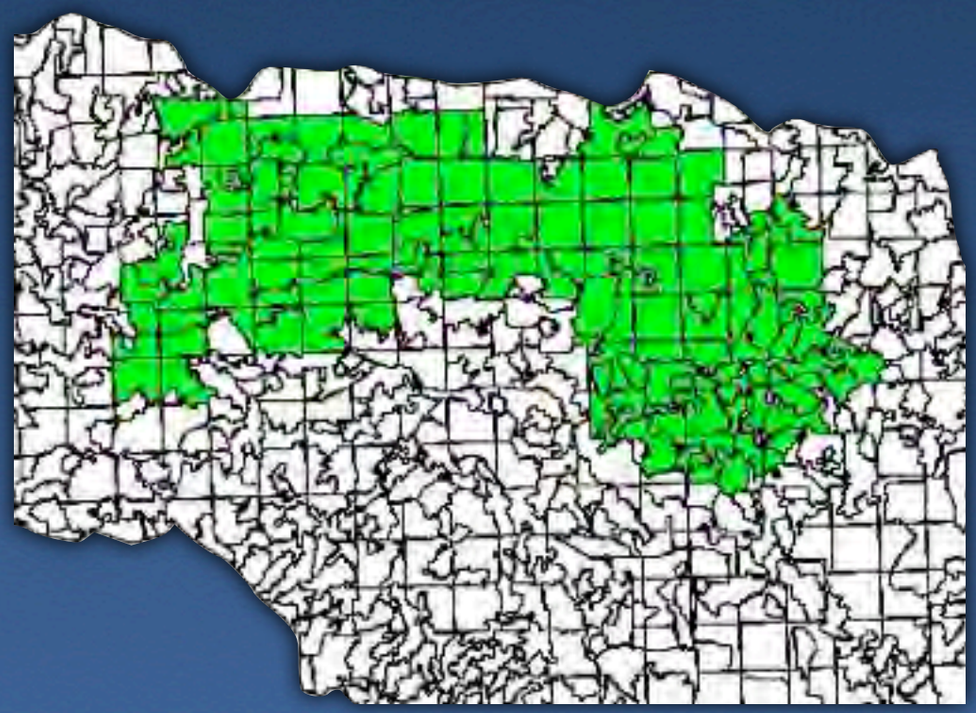


Connectivity: Single Patch

- Rooted



- Unrooted



Connectivity: Multiple Patches

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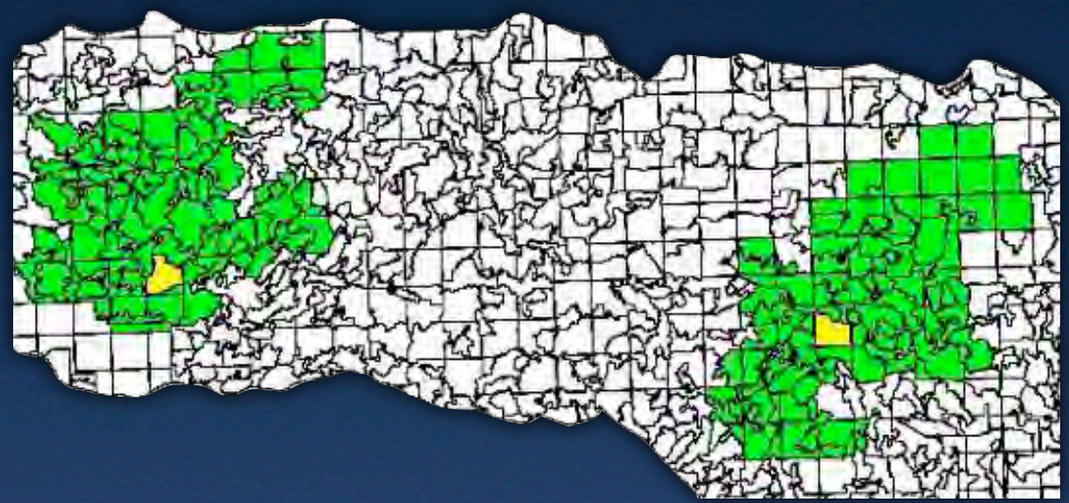
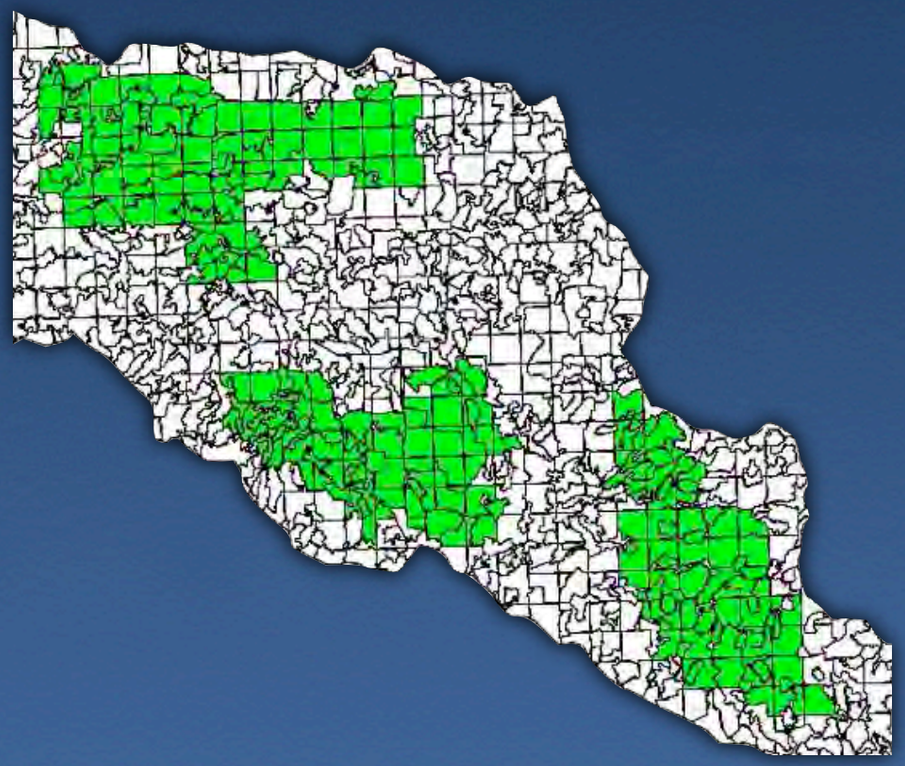
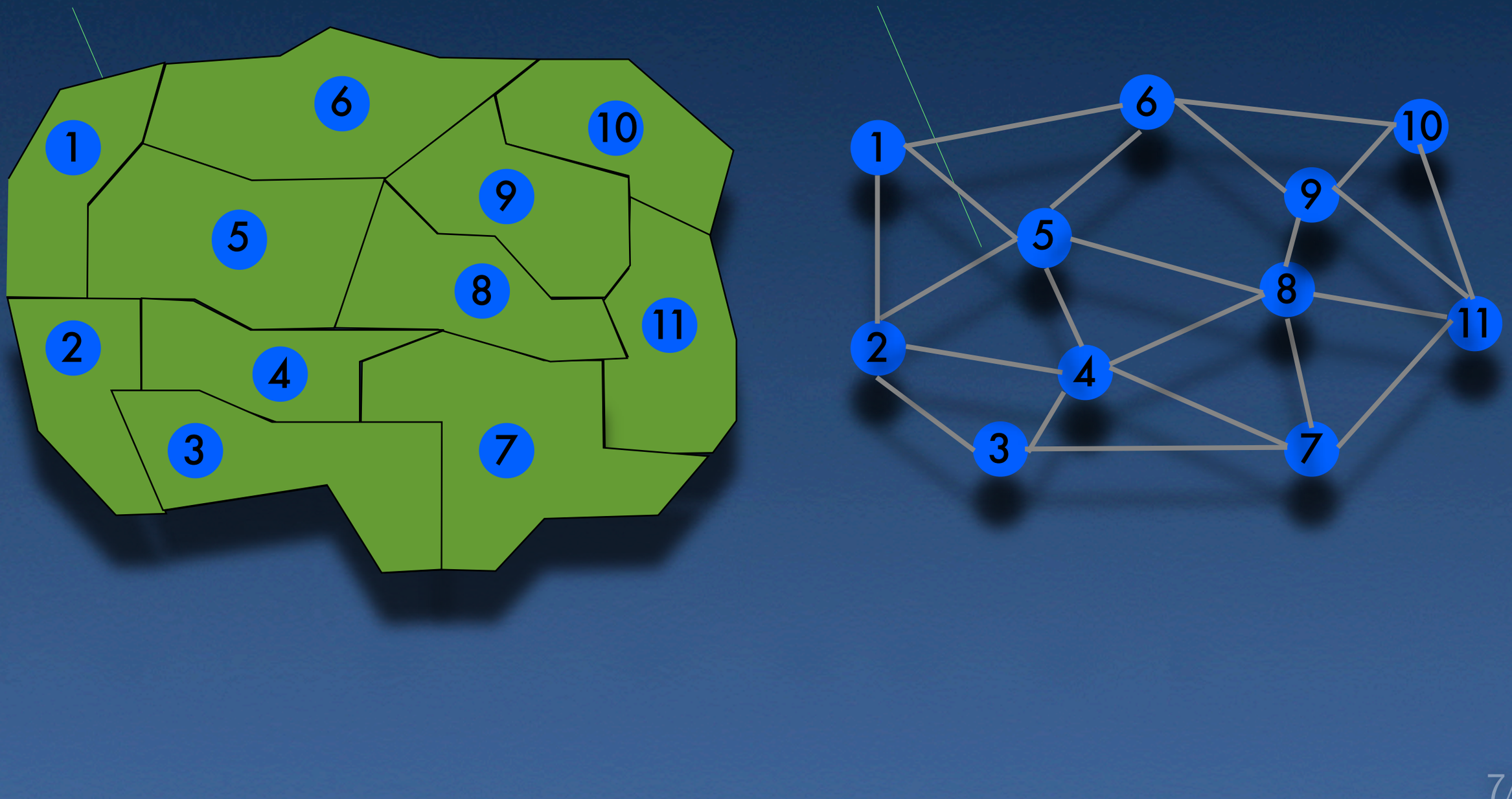


- Unrooted



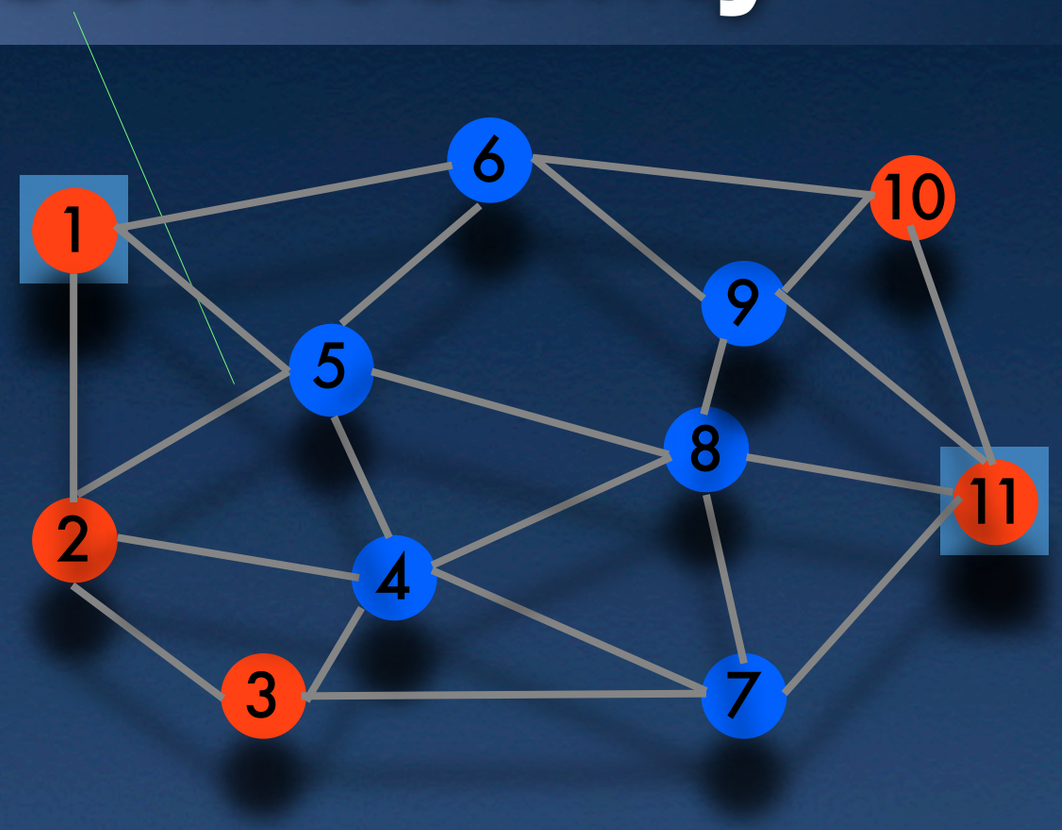
Graph Representation of Forest



Unrooted (Lack of) Connectivity

Selected Nodes

Disconnected Nodes



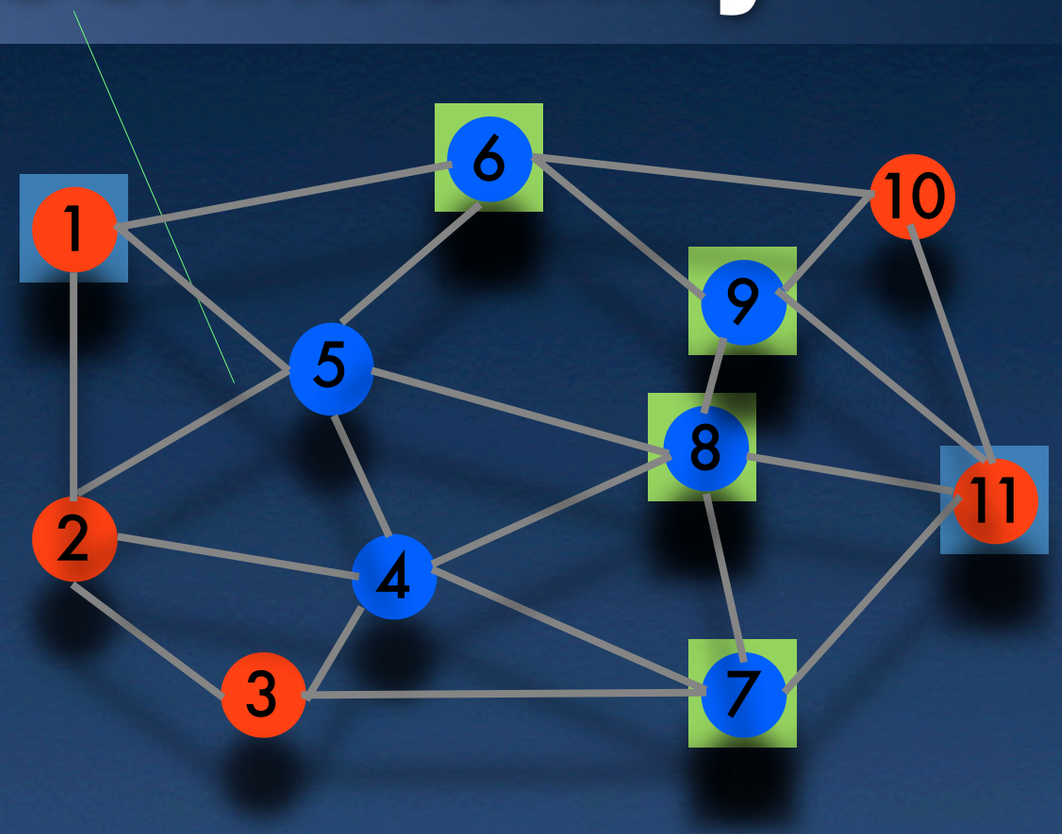
- Select red nodes for old-growth/reserve
- Red nodes are disconnected because:

Unrooted (Lack of) Connectivity

Selected Nodes

Disconnected Nodes

Cut Nodes



- Select red nodes for old-growth/reserve
- Red nodes are disconnected because:
  - There is a node-cut separating 1 and 11 with no selected nodes

Selected Set Is Connected if ...

- Set is connected $\Leftrightarrow$ pairs of nodes are connected
- Pairs are connected $\Leftrightarrow$ every cut separating them intersects selected nodes

Selected Set Is Connected if ...

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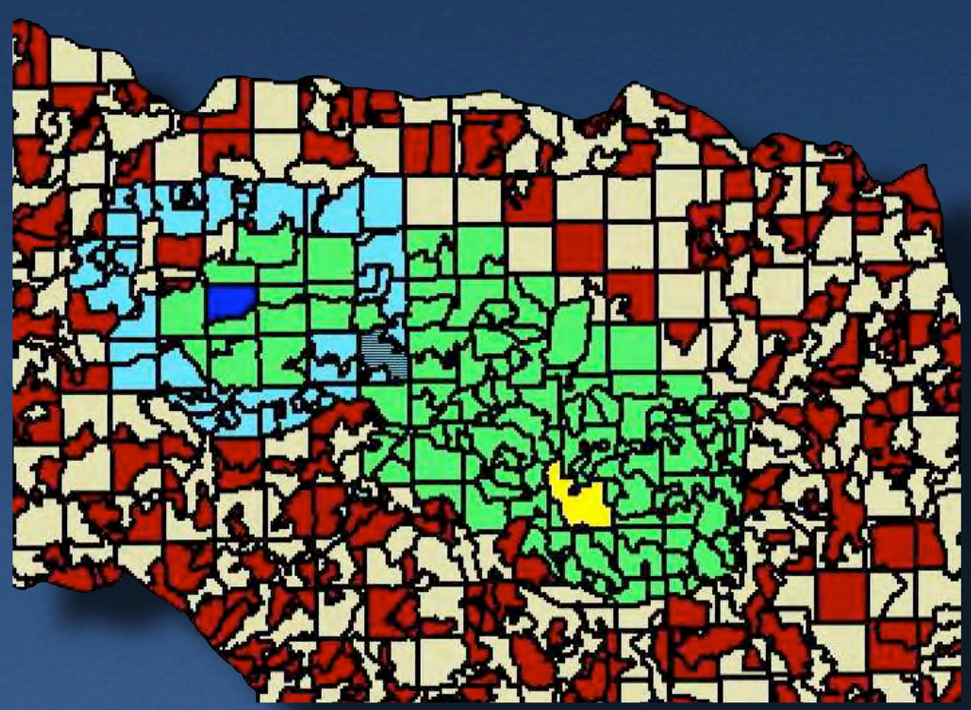

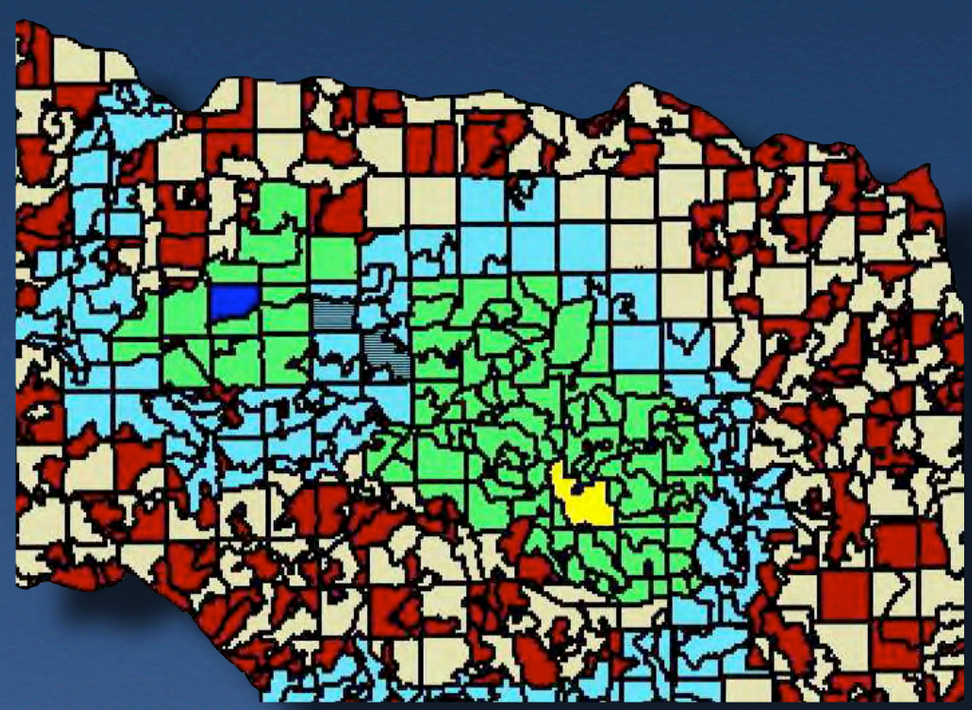

Selected pair of nodes

Other selected nodes

Separating cut

Separating cut intersects selected nodes

Force Connectivity Constraints

$$z_v = \begin{cases} 1 & \text{if stand } v \text{ is selected to be old-growth/reserve} \\ 0 & \text{otherwise} \end{cases}$$

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For every cut S separating u and v

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- Rooted: All selected stands connected to root r

$$\sum_{w \in S} z_w \geq z_v \qquad \forall\, v$$

For every cut S separating r and v

Advantages and Disadvantages

- ☑ Can easily add extra requirements
  - e.g. minimum area

$$\sum_v a_v z_v \geq A_{\text{Min}}$$

$$a_v = \text{ area of stand } v$$

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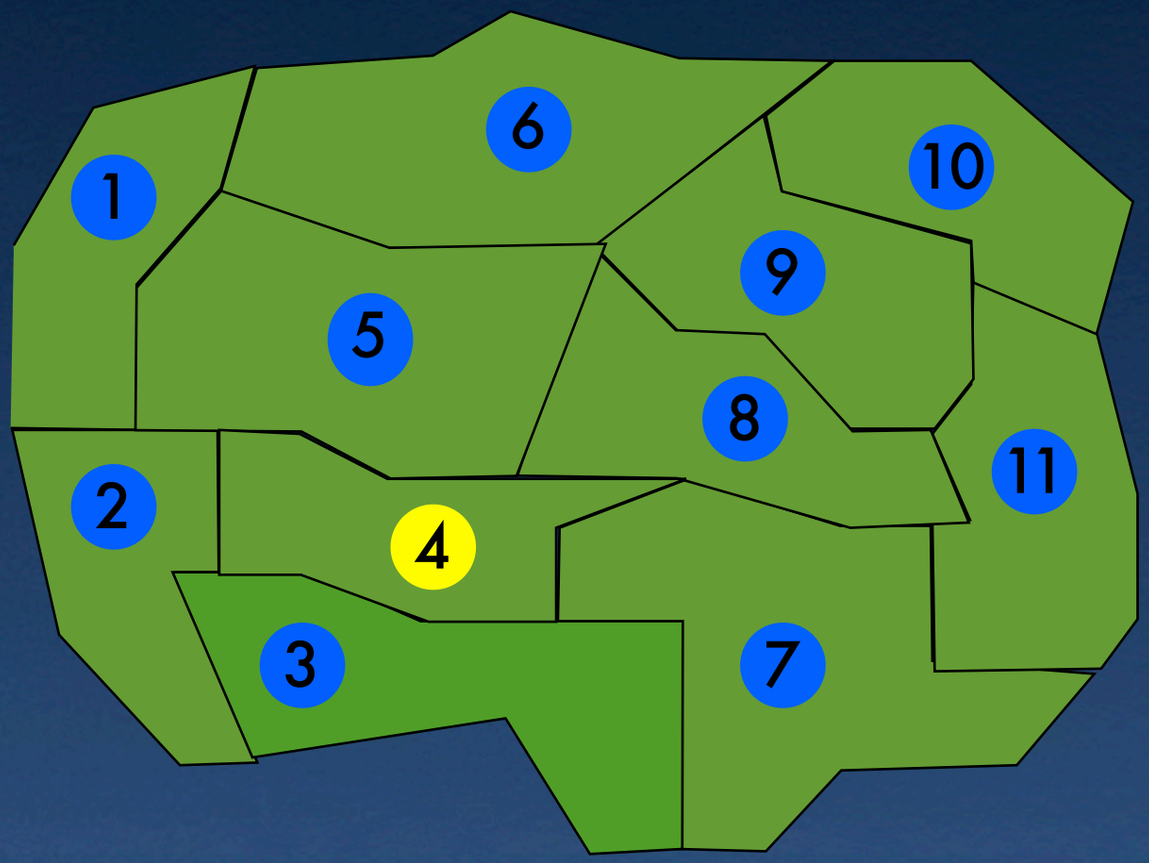
- ☐ Too many separating-cut constraints
  - ☑ Separating the constraints is easy: use Max Flow = Min Cut.
- ☐ Not for model unrooted multi-patch...

Ring Cuts for Min Area Connectivity



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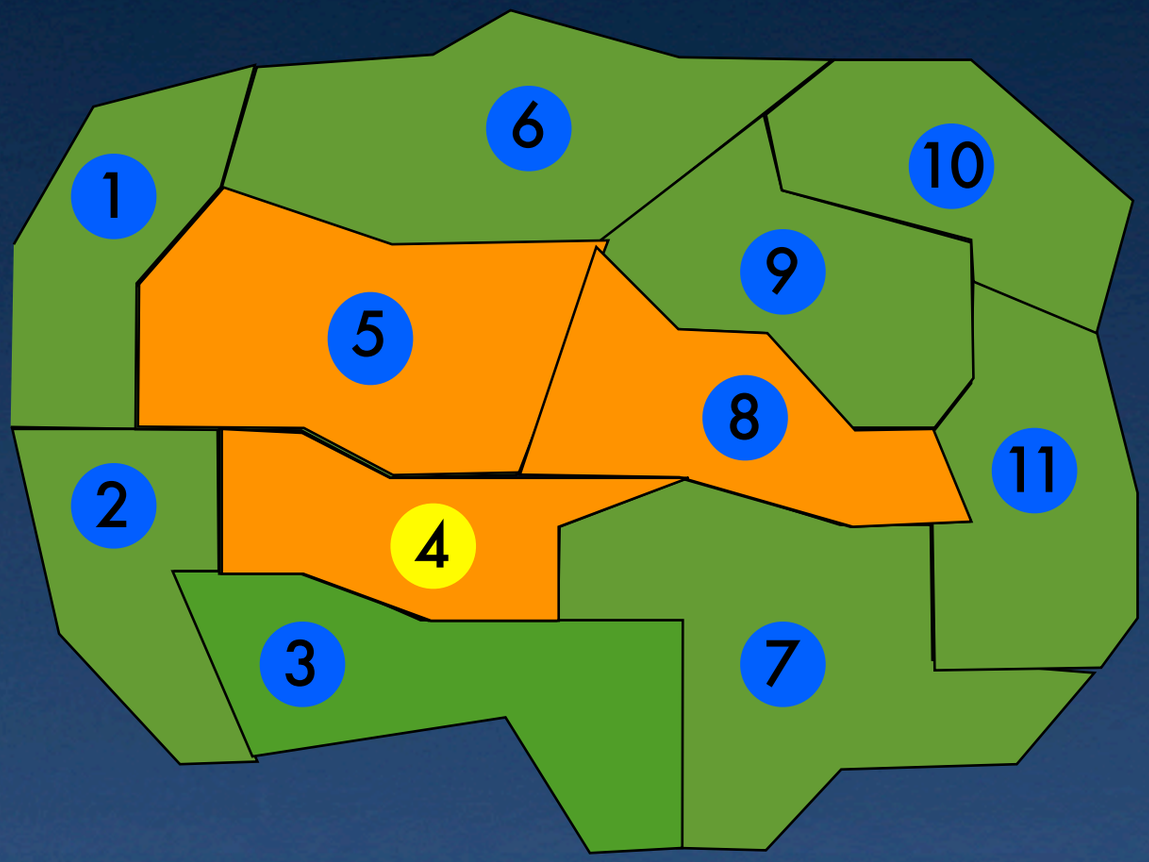

$$C = \{4, 5, 8\}$$

$$\sum_{w \in C} a_w < A_{\min}$$

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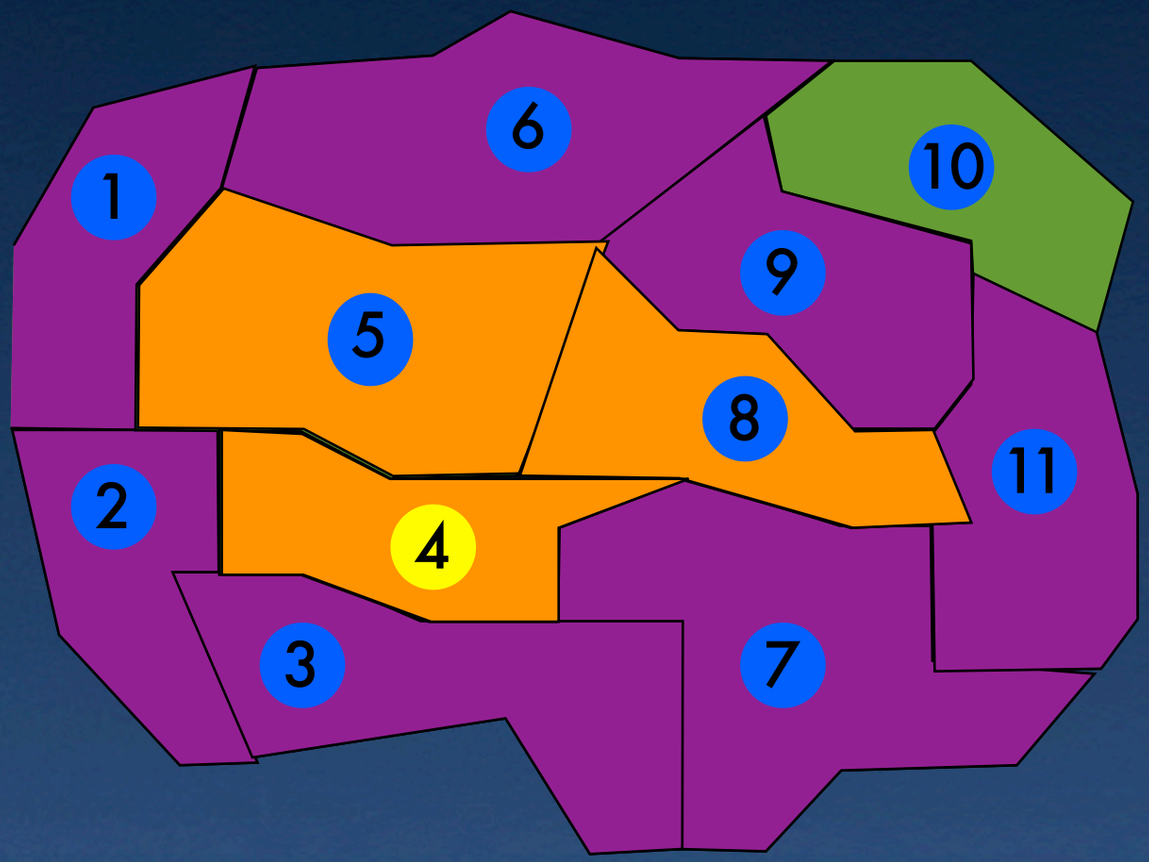

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$$\partial C = \{1, 2, 3, 7, 11, 9, 6\}$$

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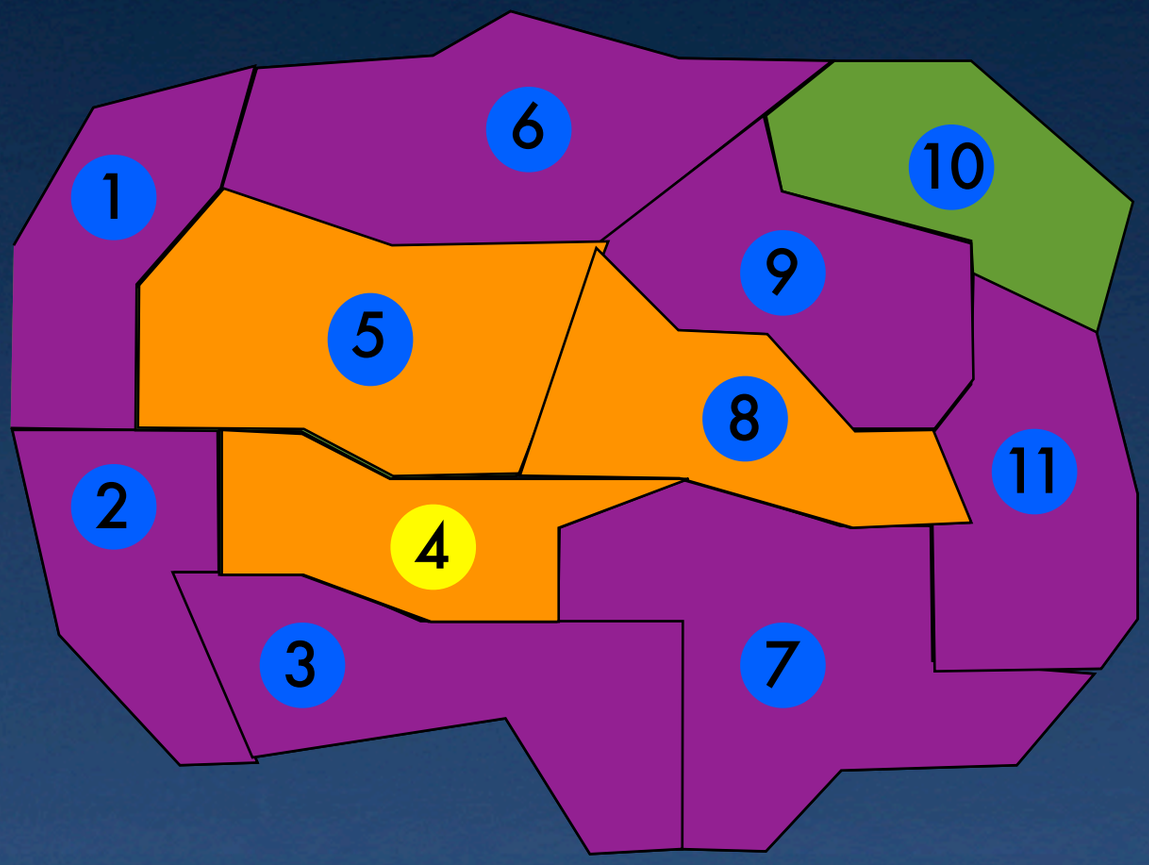

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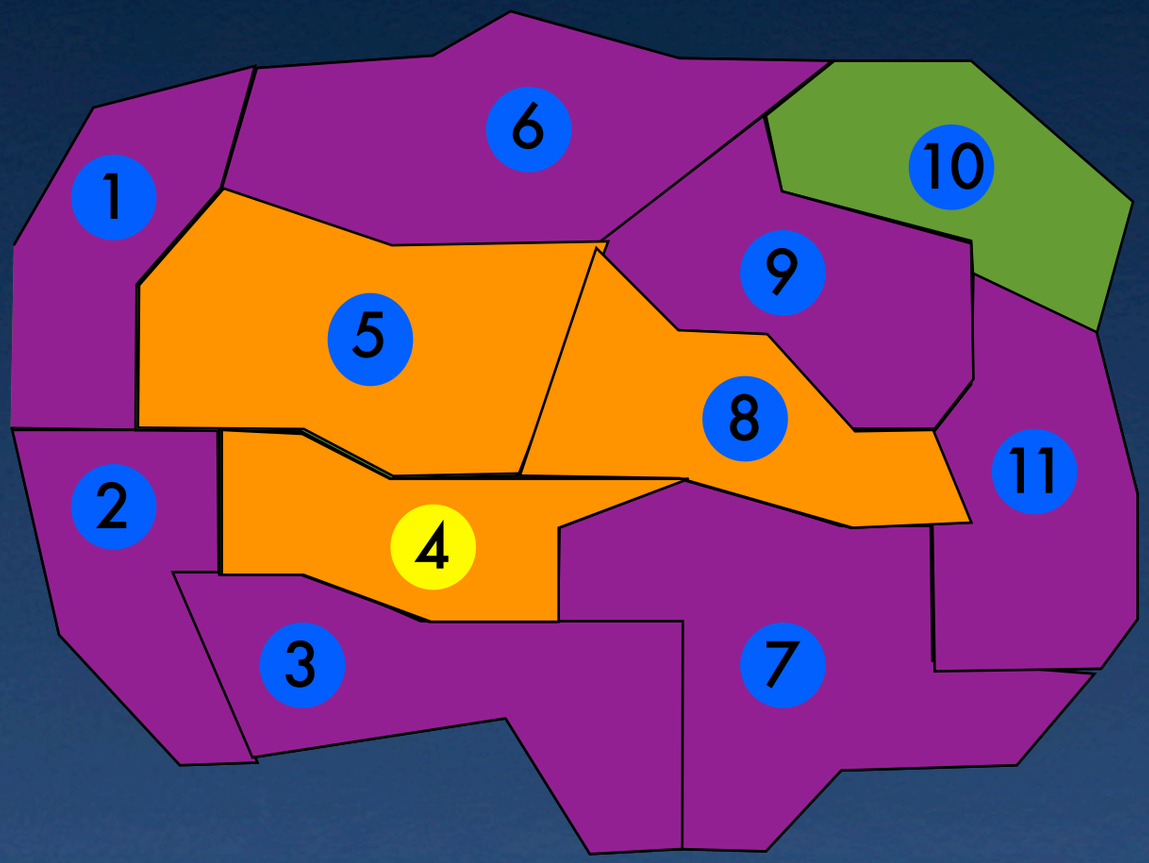


$$C = \{4, 5, 8\}$$

$$\sum_{w \in C} a_w < A_{\min}$$

$$\partial C = \{1, 2, 3, 7, 11, 9, 6\}$$

- Together they force that every patch has area greater than $A_{\min}$.

$$\sum_{w \in \partial C} z_w \geq z_v$$

Problem Specification

1. Maximize NPV of harvest schedule s.t.:
   - ARM Constraints: maximum clear-cut
   - Volume flow constraints
   - Bound on average ending age of forest
2. Additionally:
   - Reserve 10% of forest area as a contiguous old-growth path (unrooted model)

Can solve ARM + Old Growth

- 5-period instances from FMOS repository:

Instance	Stands	Total area	Max CC Area
El Dorado	1363	52,255.5	120
Shulkell	1039	11,116.65	40
NBCL5A	5581	149,235	80
FLG9A	850	24,708.1	80

- CPLEX 11 on a Quad-core Xeon with 32Gb RAM

Results: Time limit of 4 hours

1.ARM:

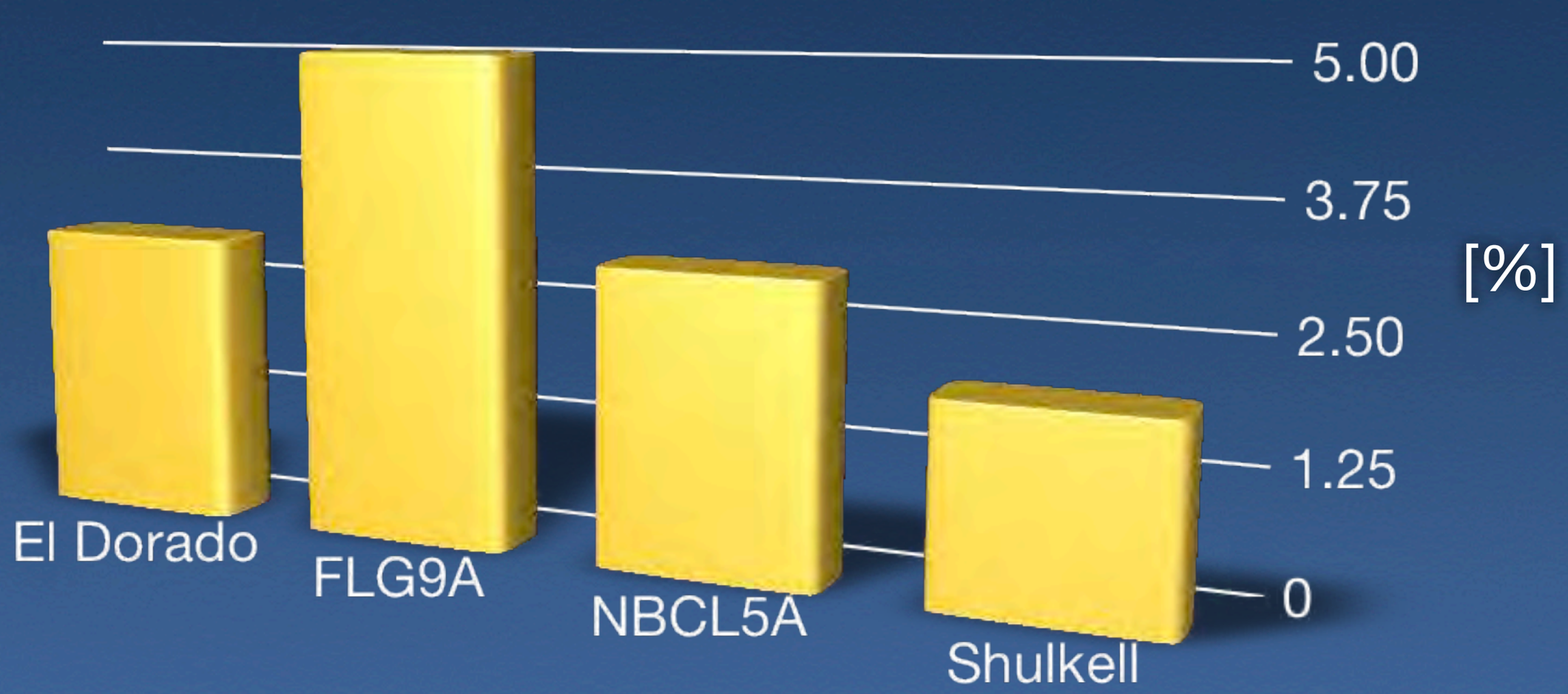
- Directly solved by CPLEX
- 3 optimal in <400s, 1 reaches 0.03% GAP

2.ARM+old-growth

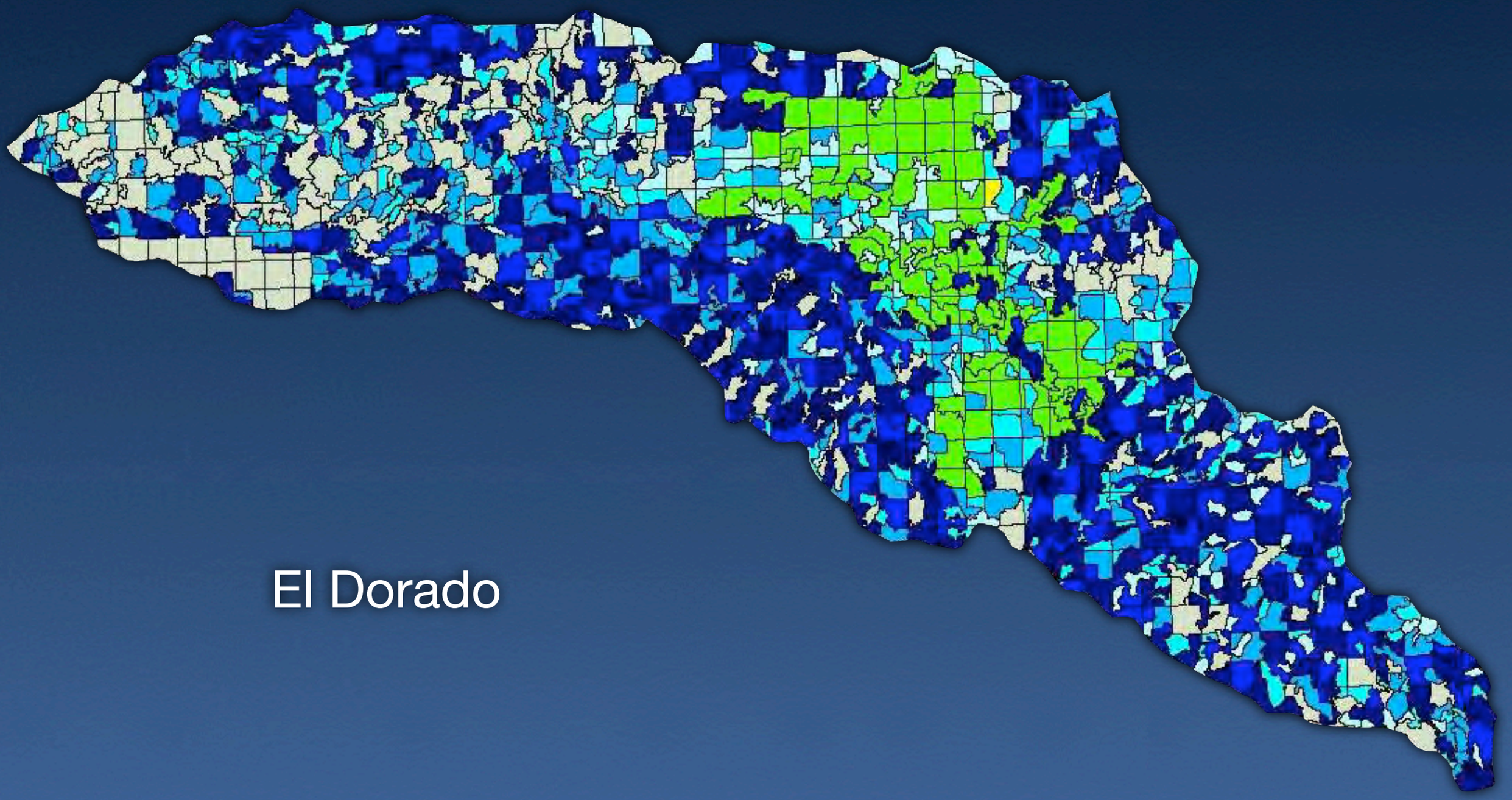
- CPLEX based branch-and-cut: need heuristics, use of rooted formulations, “ring” cuts, etc.
- 3 with <1% GAP, 1 with 2.2% GAP

Economic Effect

- ARM: 2-5% loss in NPV
- ARM+old-growth: additional loss of:



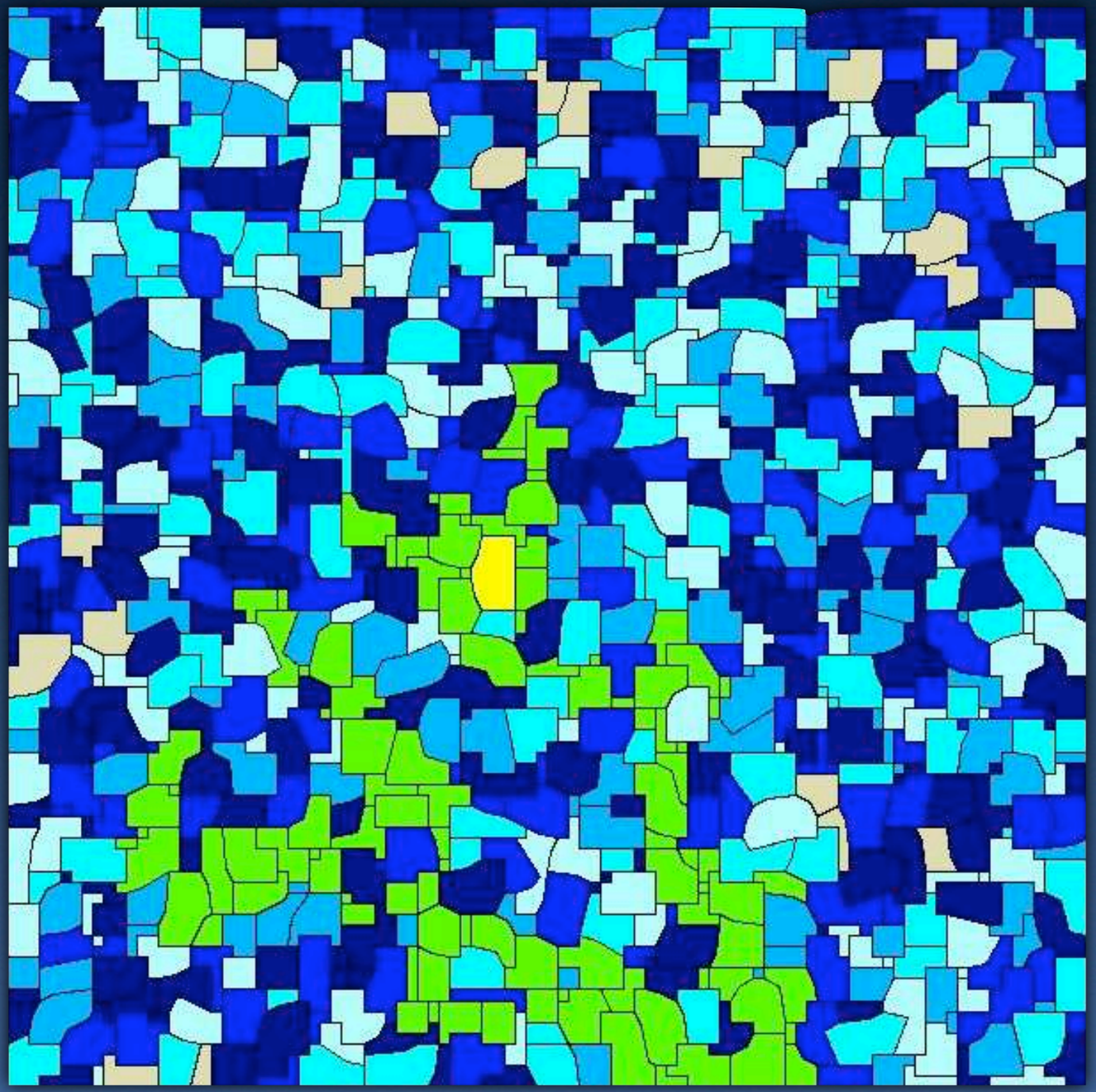
Solutions Sometime Look Good



El Dorado

Solutions Sometime Don’t Look Good

FLG9A



Conclusions and Future Work

- Done:
  - Can obtain good solutions for old-growth
  - Optimization: Cost is moderate
- To do:
  - Optimization too “clever”: snake like patches
    - Shape Constraints, core area, etc.