離散最適化による最適保護区連結ネットワークの探求

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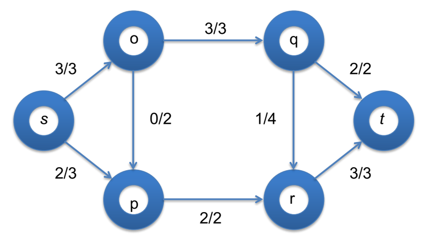
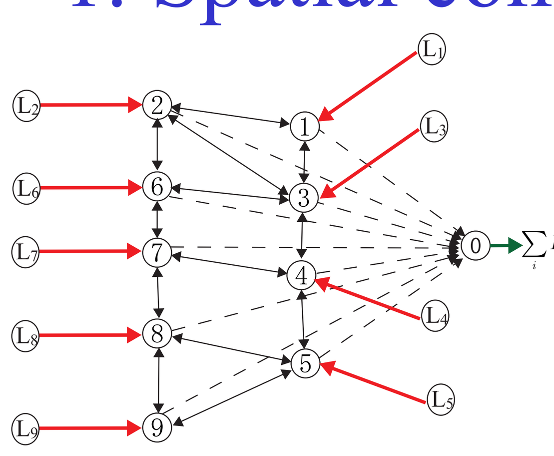
連結ネットワーク集約制約：
ある特定の林分に対し、その連結の集約に対する制約
ここでは、保護区連結ネットワーク形成に応用

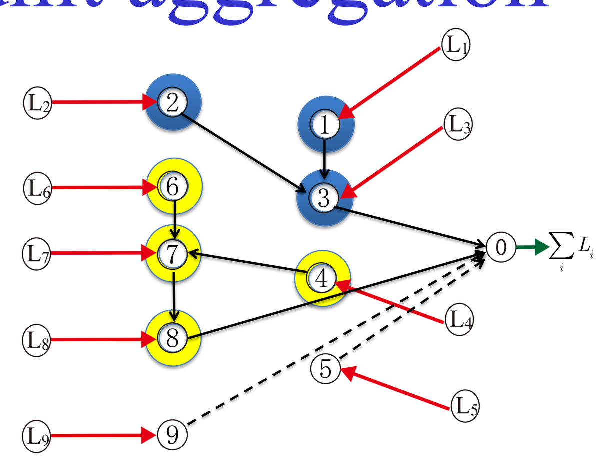
本研究の目的：
制約式により保護区連結ネットワークを形成し、最適保護区連結ネットワークを探求できる離散最適化モデルを構築

空間的制約：
ユニットの連結を伴う制約。特に隣接に関わる制約。集約化あるいは団地化。最大伐採面積の規制。



1. Spatial component for unit aggregation (MFC)

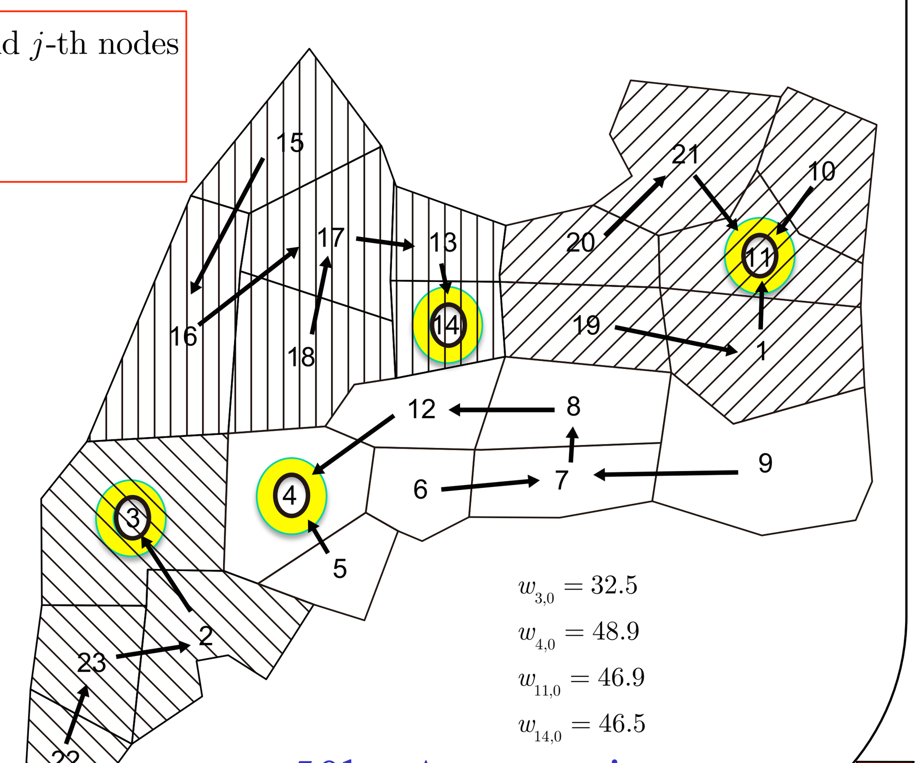




$$y_{ij}=\begin{cases}1 & \text{if an arc is connected between } i\text{-th and } j\text{-th nodes}\\ 0 & \text{otherwise}\end{cases}$$

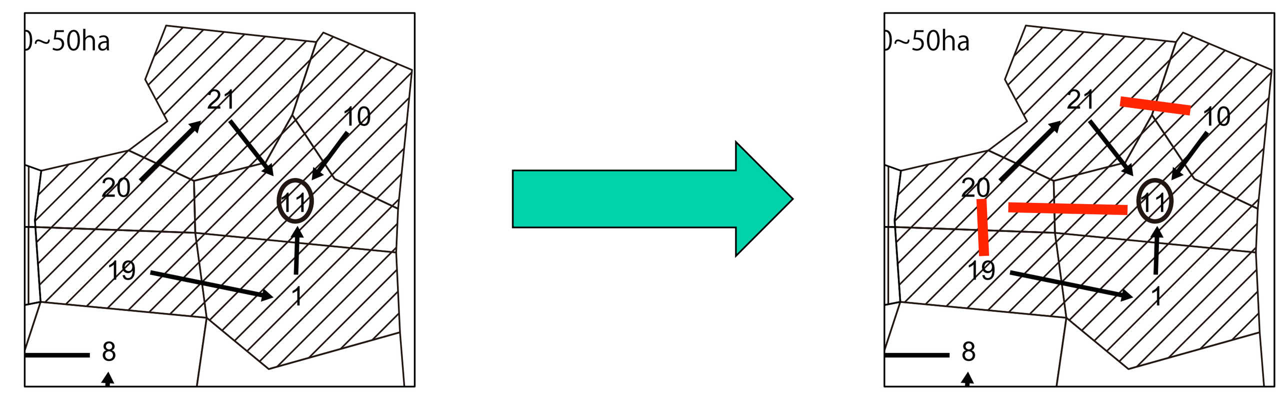
$w_{i,j}$: flow from i- to j-th node

$$y_{ij}+y_{ji}\le 1,\ {}^{\forall}i,j\in NB_i$$
$$y_{i0}+\sum_{j\in NB_i} y_{ij}=1,\ {}^{\forall}i$$
$$w_{ij}\le \bar{L}\cdot y_{ij},\ {}^{\forall}i,j\in NB_i$$
$$w_{i0}+\sum_{j\in NB_i} w_{ij}=\sum_{j\in NB_i} w_{ji}+L_i,\ {}^{\forall}i$$
$$\sum_{i=1}^{m} w_{i0}=\sum_{i=1}^{m} L_i$$
$$w_{i0}\le L_{up}\cdot y_{i0},\ {}^{\forall}i$$
$$\{y_{ij}\}\in\{0,1\},\{w_{ij}\}\ge 0,\ {}^{\forall}i,j\in(NB_i\cup\{0\})$$



50ha Aggregation

2. Sequential Triangle Connection (STC)



$$y_{ij}^{B(n)}=\begin{cases}1 & \text{if } n\text{-th process connects a boundary between } i\text{- and } j\text{-th nodes}\\ 0 & \text{otherwise}\end{cases}$$

$$u_{ijk}^{(n)}=\begin{cases}1 & \text{if the triangle by nodes } (i,j,k) \text{ is created at the } n\text{-th process}\\ 0 & \text{otherwise}\end{cases}$$

$$y_{ij}^{B(1)}=y_{ij}+y_{ji},\ {}^{\forall}i,j\in NB_i$$
$$2\cdot u_{ijk}^{(n)}+3\cdot\sum_{l=1}^{n-1}u_{ijk}^{(l)}\le\sum_{l=1}^{n}\{y_{ij}^{B(l)}+y_{ik}^{B(l)}+y_{jk}^{B(l)}\}\le 2\cdot u_{ijk}^{(n)}+3\cdot\sum_{l=1}^{n-1}u_{ijk}^{(l)}+1,\ {}^{\forall}i,j\in MB_i,k\in(MB_i\cap MB_j),n=1,\ldots,N$$
$$3\cdot u_{ijk}^{(n)}\le\sum_{l=1}^{n+1}\{y_{ij}^{B(l)}+y_{ik}^{B(l)}+y_{jk}^{B(l)}\},\ {}^{\forall}i,j\in MB_i,k\in(MB_i\cap MB_j),n=1,\ldots,N$$
$$y_{ij}^{B(n+1)}\le\sum_{k\in(MB_i\cap MB_j)}u_{ijk}^{(n)},\ {}^{\forall}i,j\in MB_i,n=1,\ldots,N$$
$$\sum_{n=1}^{N}y_{ij}^{B(n)}\le 1,\ {}^{\forall}i,j\in MB_i$$
$$\{y_{ij}^{B(n)}\},\{u_{ijk}^{(n)}\}\in\{0,1\}$$

3. Temporal & Integrated component

Table 1: Example of treatments

	Treatment No.	Decision Variable	Coefficient	Period 1	2	3	4	5	6	7	8	9	10
Treatment	1	$x_{i,1}$	$c_{i,1}$	X	0	0	0	0	0	0	0	0	0
	2	$x_{i,2}$	$c_{i,2}$	X	0	0	0	0	0	X	0	0	0
	3	$x_{i,3}$	$c_{i,3}$	X	0	0	0	0	0	0	X	0	0
	4	$x_{i,4}$	$c_{i,4}$	X	0	0	0	0	0	0	0	X	0
	5	$x_{i,5}$	$c_{i,5}$	X	0	0	0	0	0	0	0	0	X
	6	$x_{i,6}$	$c_{i,6}$	0	X	0	0	0	0	0	0	0	0
	7	$x_{i,7}$	$c_{i,7}$	0	X	0	0	0	0	0	X	0	0
	8	$x_{i,8}$	$c_{i,8}$	0	X	0	0	0	0	0	0	X	0
	9	$x_{i,9}$	$c_{i,9}$	0	X	0	0	0	0	0	0	0	X
	10	$x_{i,10}$	$c_{i,10}$	0	0	X	0	0	0	0	0	0	0
	11	$x_{i,11}$	$c_{i,11}$	0	0	X	0	0	0	0	0	X	0
	12	$x_{i,12}$	$c_{i,12}$	0	0	X	0	0	0	0	0	0	X
	13	$x_{i,13}$	$c_{i,13}$	0	0	0	X	0	0	0	0	0	0
	14	$x_{i,14}$	$c_{i,14}$	0	0	0	X	0	0	0	0	0	X
	15	$x_{i,15}$	$c_{i,15}$	0	0	0	0	X	0	0	0	0	0
	16	$x_{i,16}$	$c_{i,16}$	0	0	0	0	0	X	0	0	0	0
	17	$x_{i,17}$	$c_{i,17}$	0	0	0	0	0	0	X	0	0	0
	18	$x_{i,18}$	$c_{i,18}$	0	0	0	0	0	0	0	X	0	0
	19	$x_{i,19}$	$c_{i,19}$	0	0	0	0	0	0	0	0	X	0
	20	$x_{i,20}$	$c_{i,20}$	0	0	0	0	0	0	0	0	0	X

Note: X denotes harvesting while 0 denotes no harvesting

Linking with Harvest Scheduling
Aggregation => Spatial
Harvesting => Temporal

$$\sum_{k=0}^{K}x_{ik}=1,\quad {}^{\forall}i$$
$$(1-\alpha)\cdot v_0\le\sum_{i=1}^{m}\sum_{k=1}^{K}v_{ik}^{t}\cdot x_{ik}\le(1+\alpha)\cdot v_0,\ {}^{\forall}t$$
$$a_{kl}^{v}\cdot x_{ik}+a_{lk}^{v}\cdot x_{jl}\le 1,\ {}^{\forall}i,j\in NB_i,k,l(\ne k)$$
$$\{x_{ij}\}\in\{0,1\}$$

$$2\cdot z_{ij}^{k}\le x_{ik}+x_{jk}\le 2\cdot z_{ij}^{k}+1,\ {}^{\forall}i,j\in NB_i,k$$
$$\sum_{n=1}^{N}y_{ij}^{B(n)}=\sum_{k=1}^{m}z_{ij}^{k},\ {}^{\forall}i,j\in NB_i$$
$$\{x_{ij}\},\{y_{ij}^{B(n)}\},\{z_{ij}^{k}\}\in\{0,1\}$$

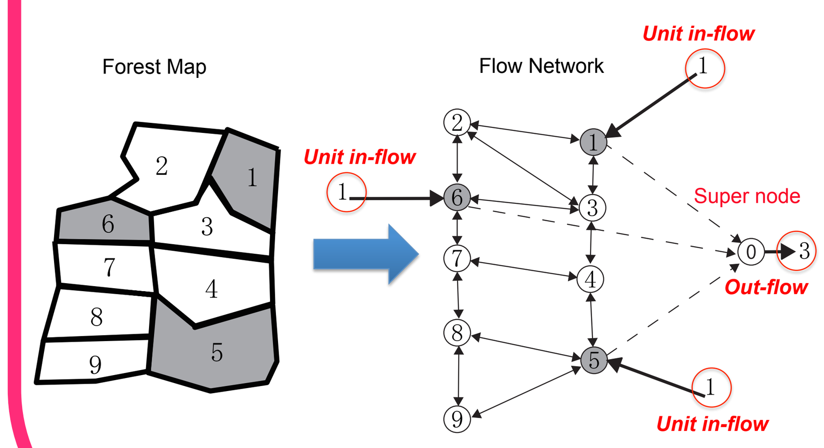
$$a_{kl}^{v}=\begin{cases}1 & \text{if } k\text{-th and } l\text{-th treatments have any concurrent harvest}\\ 0 & \text{otherwise}\end{cases}$$

4. Habitat connection

Arc connection

$$y_{ij}+y_{ji}\le 1,\ {}^{\forall}i,j\in NB_i$$
$$y_{i0}+\sum_{j\in NB_i}y_{ij}=1,\ {}^{\forall}i$$

Maximum flow network



Corridor flow constraints

No connection, no flow
$$w_{ij}^{c}\le N^{c}\cdot y_{ij},\ {}^{\forall}i,j\in NB_i$$
$$w_{i0}^{c}\le N^{c}\cdot y_{i0},\ {}^{\forall}i\in S^{c}$$
N^{c}: the number of habitats

Flow balance, no leakage
$$w_{i0}^{c}+\sum_{j\in NB_i}w_{ij}^{c}=\sum_{j\in NB_i}w_{ji}^{c}+1,\ {}^{\forall}i\in S^{c}$$
$$\sum_{j\in NB_i}w_{ij}^{c}=\sum_{j\in NB_i}w_{ji}^{c},\ {}^{\forall}i\notin S^{c}$$

One connection to super node
$$\sum_{i\in S^{c}}w_{i0}^{c}=N^{c}$$
$$\sum_{i\in S^{c}}y_{i0}=1$$

結果

Model I

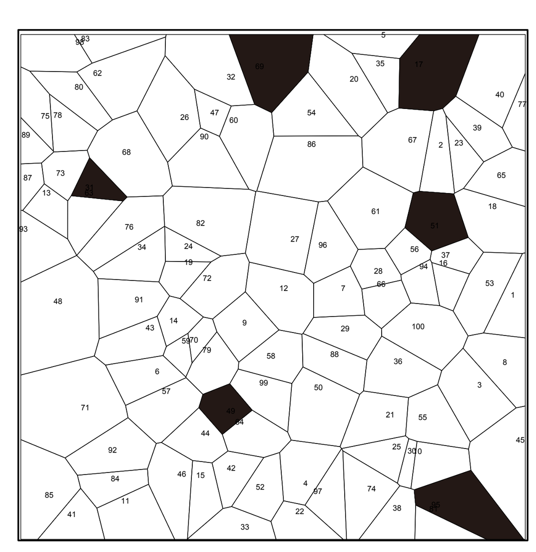
Max NPV

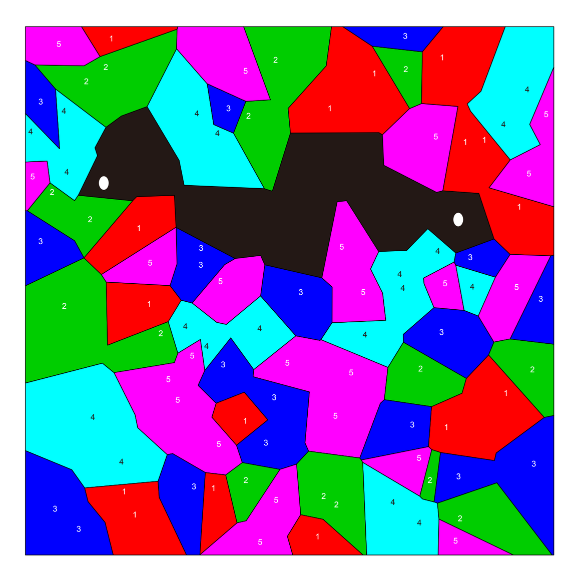
$$Z=\max_{\{x_{ij}\}}\sum_{i=1}^{m}\sum_{j=1}^{K}c_{ij}\cdot x_{ij}$$
$st.$
$$\sum_{k=0}^{K}x_{ik}=1,\quad {}^{\forall}i_m \quad \text{Land Account Constraints}$$
$$(1-\alpha)v_0\le\sum_{i=1}^{m}\sum_{j=1}^{K}v_{ij}^{p}\cdot x_{ij}\le(1+\alpha)v_0,\quad p=1,\cdots,T$$
Harvest Flow Constraints

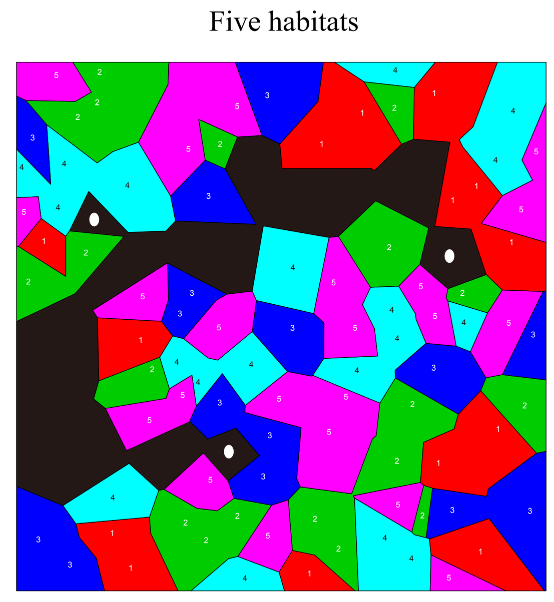
MF-Model I for Corridor

Temporal Scheduling — Model I
Bridge — + Linkage Constraints
Spatial Connection — + Maximum Flow Constraints
Spatial Continuity — + Sequential Triangle Connection
Habitat Connection — + Corridor Flow Constraints

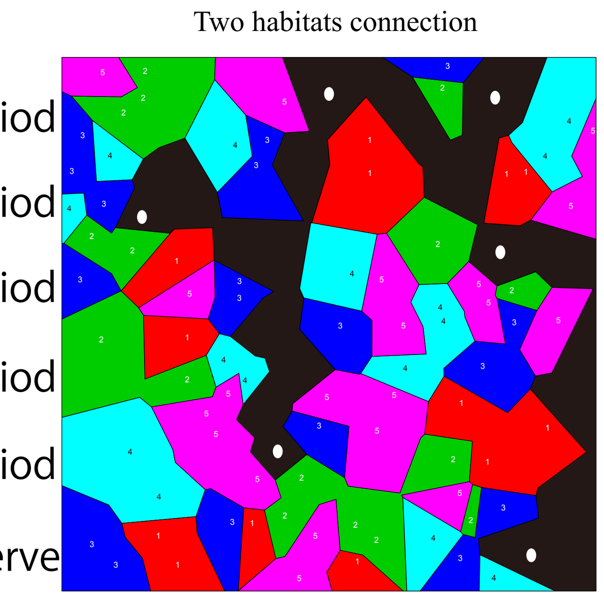
Optimal habitat connection


Five habitats


Two habitats connection


Three habitats connection

1 period
2 period
3 period
4 period
5 period
Preserve


Five habitats connection