A Graph-based Markov Decision Process framework for Optimising Collective Management of Diseases in Agriculture: Application to Blackleg on Canola

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Spatio-temporal dynamics of disease, control and economic criteria

Spatio-temporal crop layout

$\Rightarrow$ *Spatial disease dynamics*

- Dynamics
  - Pathogen dynamics
  - Crop cycle
  - Cultural practices
- Control method
  - Chemical control
  - Genetic control
  - Cultural control
- Criteria
  - Economic return
  - Production quality and quantity
  - Ecological impact

Durable collective management strategies of blackleg on canola crops

Epidemiology of blackleg on Canola

- Fungus pathogen
- One of the main diseases on canola worldwide
- Significant yearly yield losses (5%-20% in France)
- Spreads by spore dispersal

Durable collective management strategies of blackleg on canola crops

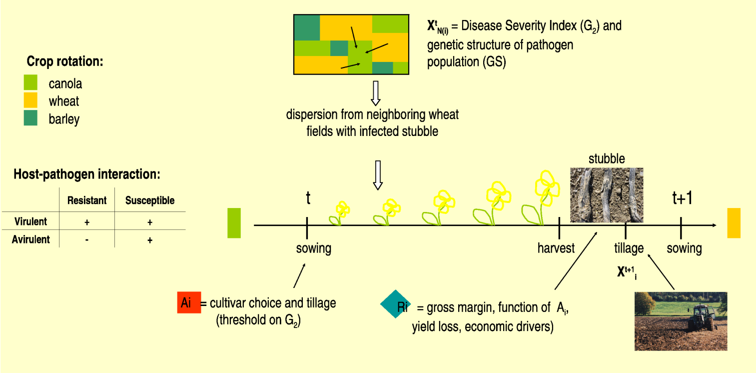
Control methods

- Genetic control
  - Choice of canola cultivar (resistance)
  - Genetic resistance can break down
- Chemical control (uncertain)
- Cultural control
  - Layout of canola fields (regional level)
  - Stubble management (ploughing after harvest)

Problem studied here

⇒ How to optimize the use of cultivars and ploughing levels at a regional scale

Spore dispersal and crop management of canola fields



State variables

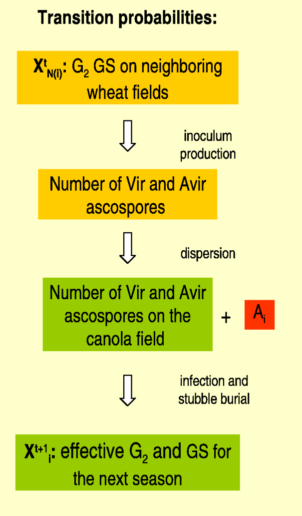
- Current crop ($C \to W \to B$)
- Stubble infection severity ($G2$)
- % of virulent spore (GS)

Action variables

- Cultivar choice (resistant ?)
- Ploughing threshold τ

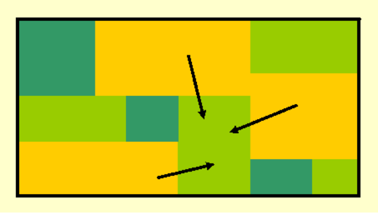
(ploughing if $G2 > \tau$)

Annual dynamics of blackleg



Three steps in the dynamics

- Inoculum production
- Ascospores dispersion
- Infection type and intensity



Markov Decision Processes (MDP)

Definition

A MDP is defined as a 4-tuple $<\mathcal{X}, \mathcal{A}, p, r>$ *:*

- $\mathcal{X} = \{x^1, \ldots, x^n\}$*: possible states of the system*
- $\mathcal{A} = \{a^1, \ldots, a^m\}$*: allowed actions*
- $p(x'|x, a)$*: transition probabilities*
- $r(x, a)$*: immediate reward function*

- Policy: $\delta : \mathcal{X} \rightarrow \mathcal{A}$
- Trajectory: $\tau =< x_0, \delta(x_0), x_1, \delta(x_1), \ldots, x_t, \delta(x_t), \ldots >$, $t \in H \subseteq \{1 \ldots +\infty\}$
- Criterion: $V_\delta(x_0) = E\left[\sum_{t \in H} \gamma^t r_t(x_t, \delta(x_t))\right]$, $0 \leq \gamma \leq 1$

Find an optimal policy δ^*, such that $V_{\delta^*}(x) \geq V_\delta(x), \forall x$

Graph-based Markov Decision Processes (GMDP)

Definition

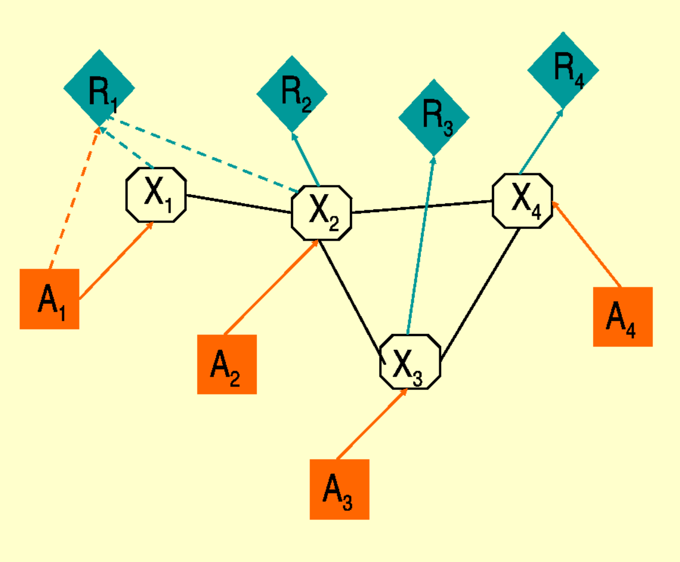
A GMDP is a 5-tuple $< \mathcal{X}, \mathcal{A}, p, r, G >$:

- $\mathcal{X} = \mathcal{X}_1 \times \ldots \times \mathcal{X}_n$: *multidimensional state space*
- $\mathcal{A} = \mathcal{A}_1 \times \ldots \times \mathcal{A}_n$: *multidimensional action space*
- p *and* r: *local transition and reward functions*
- $G = (V, B)$: *directed graph with vertices* $V = \{1, \ldots, n\}$ *and edges* $B \subseteq V^2$ *expressing variables dependencies*

Neighbourhood of a vertex i:

$$N(i) = \{j \in \{1, \ldots, n\}, (j, i) \in B\}$$

Graphical representation



Locality of a Graph-based Markov Decision Process

Definition (Local process)

The process is said to be local if $p(x'|x,a)$ writes:

$$\forall x, x' \in \mathcal{X}^2, \forall a \in \mathcal{A}, p(x'|x,a) = \prod_{i=1}^{n} p_i(x'_i|x_{N(i)}, a_i)$$

Definition (Local reward)

A reward function $r : \mathcal{X} \times \mathcal{A} \to R$ is said local iff

$$\forall x, a \in \mathcal{X} \times \mathcal{A}, r(x,a) = \sum_{i \in V} r_i(x_{N(i)}, a_i)$$

Definition (Local policy)

A policy $\delta : \mathcal{X} \to \mathcal{A}$ is said local iff $\delta = (\delta_1, \ldots, \delta_n)$ where $\delta_i : \mathcal{X}_{N_{(i)}} \to \mathcal{A}_i$ and $\delta_i(x_{N(i)}) = a_i \in \mathcal{A}_i$, $\forall x_{N(i)} \in \mathcal{X}_{N_{(i)}}$

A GMDP model for the control of blackleg on canola

State variables

- x_i represents:
  - Crop (canola, wheat barley)
  - Infection intensity $G2(i)$ of stubbles if crop is wheat

  - Genetic structure $GS(i)$ of pathogen on stubbles if crop is wheat

- x_i can take 17 values (for each field!)

Action variables (for canola fields)

- Cultivar choice $CC(i)$
- Ploughing threshold $TS(i) \in \{1, \ldots, 4\}$
- a_i can take 8 values (for each field)

A GMDP model for the control of blackleg on canola

Transition probabilities

- If $x_i = barley, x_i' = canola$
- If $x_i = wheat, x_i' = barley$
- If $x_i = canola, x_i' = \big(wheat, infection = (G2(i), GS(i))\big)$

$p_i(x_i' | x_{N(i)}, a_i)$ is computed through 3 steps:

1. Inoculum production: on $x_j, j \in N(i)$
2. Dispersion: depends on $x_{N(i)}$
3. Infection: depends on a_i

A GMDP model for the control of blackleg on canola

Local reward function $R_i(x_{N(i)}, a_i) = GM_i$

$$GM_i = \beta_i * \left[Y_{pot}(CC(i)) * RYL(\hat{G}_2(i)) * \pi_c - (C_{0i} + C(W_i))\right]$$

GM_i	gross margin for field i
β_i	field i surface (ha)
π_c	market price of 100kg of canola seeds
$Y_{pot}(CC(i))$	potential yield for cultivar $CC(i)$
$RYL(G2(i), TS(i))$	relative yield loss
C_{0i}	cost of basic operations
$C(W_i)$	cost/ha of ploughing

Concluding remarks

A GMDP model for management of blackleg of canola

- Spatio-temporal controled process
- Graph-based Markov Decision Process framework
- Durable collective management
  (handles break down of specific resistance)
- GMDP model implemented

Work to do

- Running optimization on real data
- Analysis of output strategies (simulation)
- Improving the action model