Étapes de conception d'un modèle de simulation d'épidémies fongiques aérienne en fonction de l'architecture du couvert.

Projet ANR Archidemio 2009-2012

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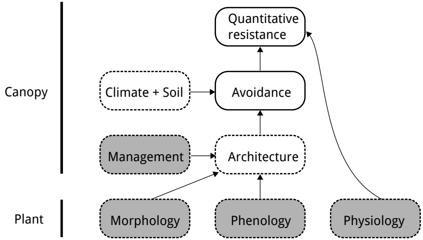
Context

The canopy architecture as a lever to reduce diseases severity

- Chemical-based crop protection for air-borne diseases
- How to reduce treatments ? (economy, ecology, policies)
  - specific resistance : eliminate epidemic
  - quantitative resistance : control (moderate crop injuries)



⇒ Adaptation of the canopy architecture to control the disease

Outline

Biology

- How much does the canopy architecture impacts the epidemic process ?

Methods

- Field experiments and process-based modelling to unravel crop $\times$ pathogen interactions.
- Four architecturally contrasted crop - pathogen systems

Conception

- How to deal with different disciplinary points of view ?
- Which level of architectural representation to adopt ?

Design methodology

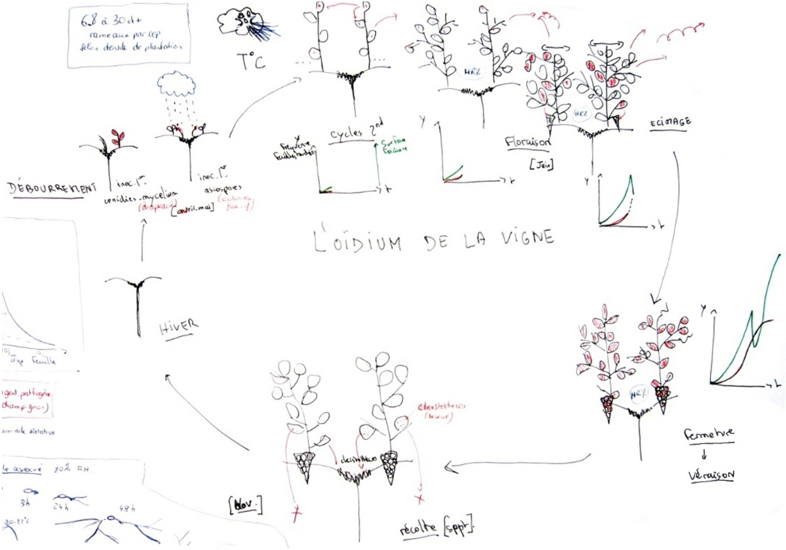
Define different modelling roles

- Applied mathematics modellers :
  - propose model framework (conceptual model)
  - propose equation shapes (formal model)
  - build interaction tool (software + formation)
- Thematic modellers :
  - define processes to include
  - adjust, parametrize equations (data or expertise)
  - propose elements for qualitative (behaviors) et quantitative (data) evaluations

Analogy with *top-down* systemic approaches :
observations → [share model] ← concepts

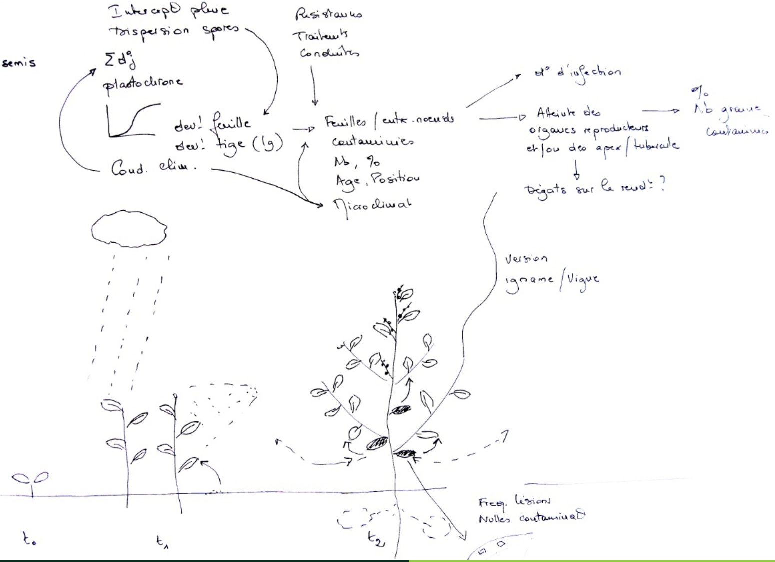
Grapevine conceptual model

focus : grapevine - powdery mildew disease cycle ; pathologist view



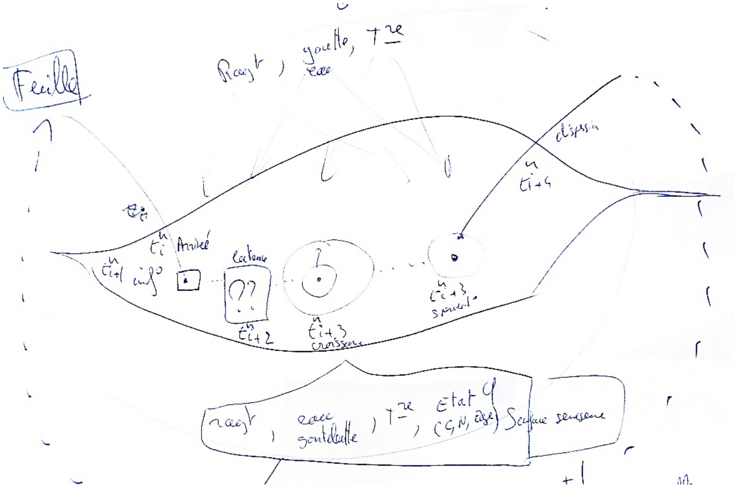
Yam conceptual model

focus : integration of epidemic processes ; ecophysiologist view



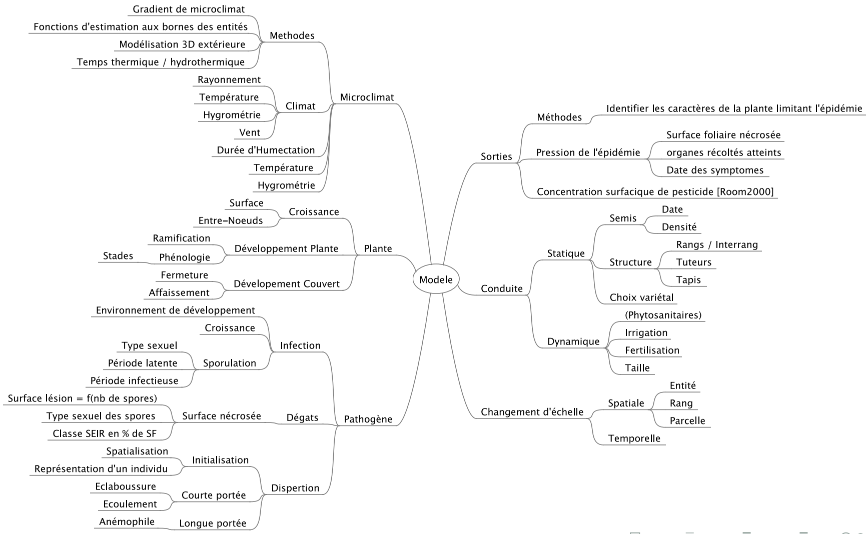
Disease conceptual model

focus : local scale disease development ; bioclimatologist view



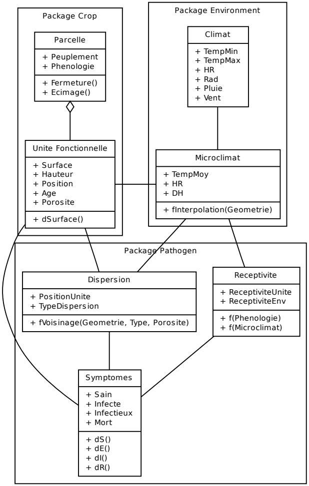
General conceptual model

global view on pathosystems



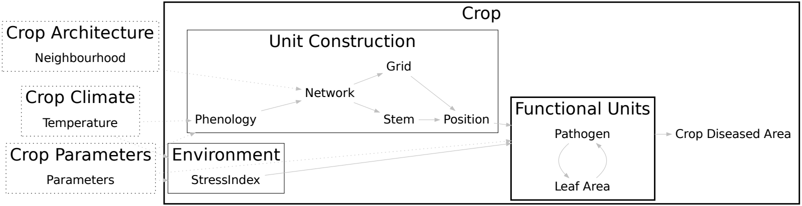
General UML conceptual model

focus : identification of main processes



Formal model : general structure

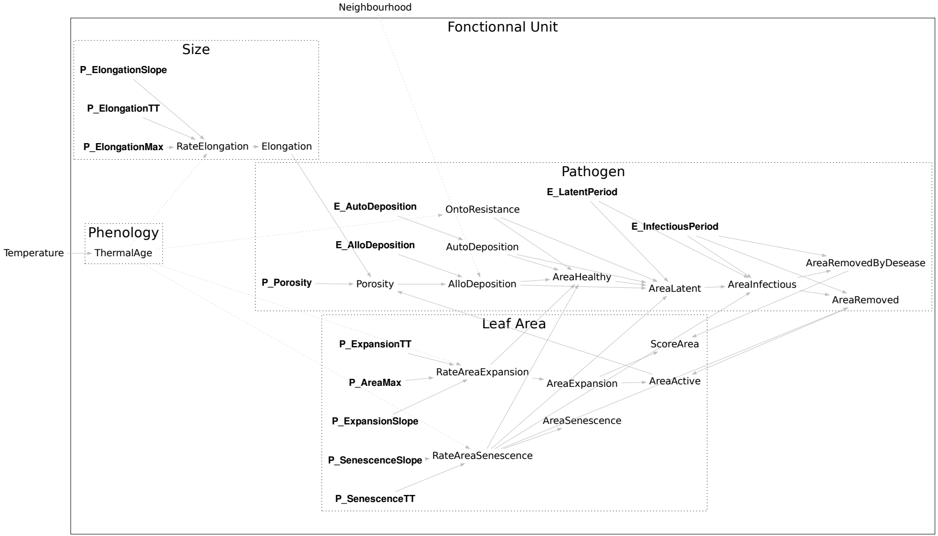
Setting a generic description of 4 pathosystems



- Controller model (structure) + individual model (fonction)
- Pathosystem-specific parametrization
  - functional units : homogeneous architectural element
  - network of connections : crop architecture and dispersion type

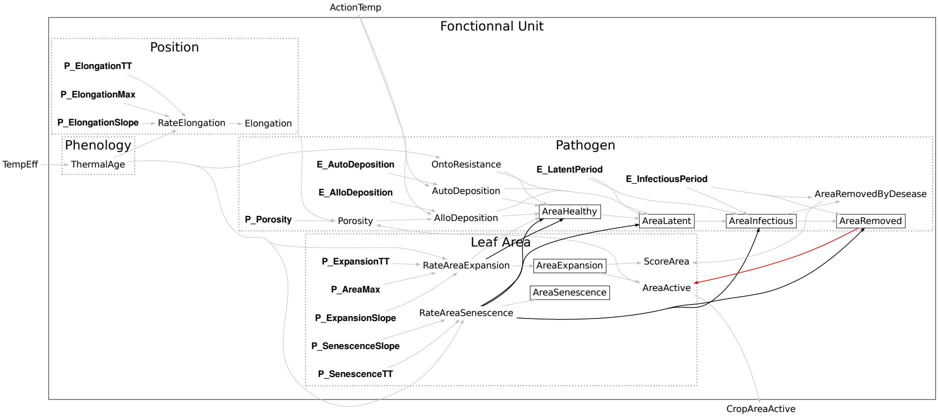
Formal model : structure of functional unit

crop (logistic function) + epidemiological (SEIR) models



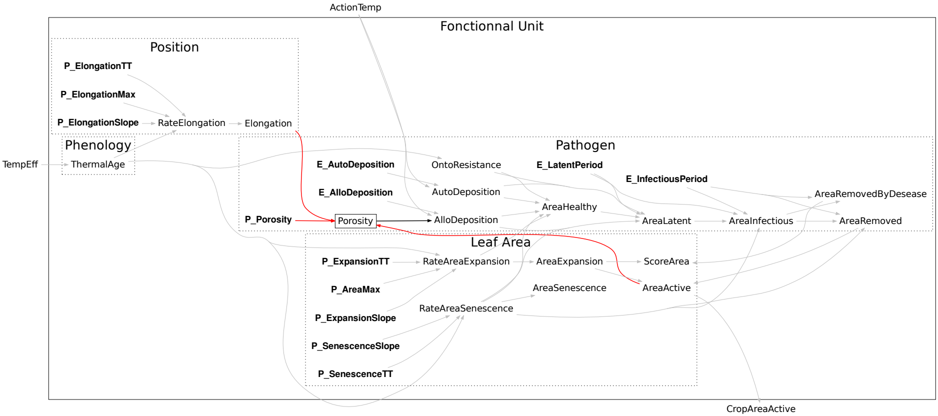
Formal model : structure of functional unit

interaction between crop and pathogen growth



Formal model : structure of functional unit

leaf area density (LAD) affects pathogen dispersion



Software model

A link between model levels of abstraction

conceptual

healthy = expansion − local infection − remote infection − senescence

formal

$$\Delta H = \Delta E - \left(\tau_u \cdot I \cdot \frac{H}{E} \cdot \rho_d \cdot \theta_d\right) - \left(\delta i_d \cdot \frac{H}{E} \cdot \rho_d \cdot \theta_d\right) - \left(\Delta S \cdot \frac{H}{A}\right)$$

code

```
// Healthy area dynamic
AreaHealthy = fmax(
   AreaHealthy(-1)
   -InitQuantity()
   +RateAreaExpansion()
   -(RateAutoDeposition() * AreaInfectious(-1) * AreaHealthy(-1)/AreaExpansion(-1)) * Receptivity()
   -(InDeposition() * AreaHealthy(-1)/AreaExpansion(-1)) * Receptivity()
   -(RateAreaSenescence() * AreaHealthy(-1)/AreaActive(-1)),0);
```

Design constraints

Scope statement governing the design choices

aims
- focus on the system functioning : comprehensive approach
- focus on environmental and management uncertainties : analytic approach

knowledge
- differences in the modelling states among pathosystems : "lowest common denominator"

complexity
- link physiology and structure at the organ level : physical pathogen dispersion
- bypass explicit plant architecture : graph-based dispersion

evaluation
- define specific system behaviours to be reproduced by the model

Design constraints

Chosen design options, test-driven development

aims	▸ focus on the system functioning : comprehensive approach ▸ focus on environmental and management uncertainties : analytic approach
knowledge	▸ differences in the modelling states among pathosystems : "lowest common denominator"
complexity	▸ link physiology and structure at the organ level : physical pathogen dispersion ▸ bypass explicit plant architecture : graph-based dispersion
evaluation	▸ **define specific system behaviours to be reproduced by the model**

A model to promote discussion on epidemic management at the canopy scale

A simple model with complex behaviors regarding plant diseases

- minimizing computing time (low complexity, efficient software implementation)
- suitable for large numerical exploration (e.g. sensitivity analysis)

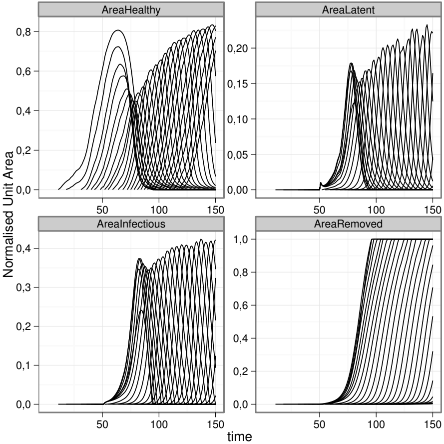
Identification of shared concepts among case studies

- comparative epidemiology : common view, distinct systems

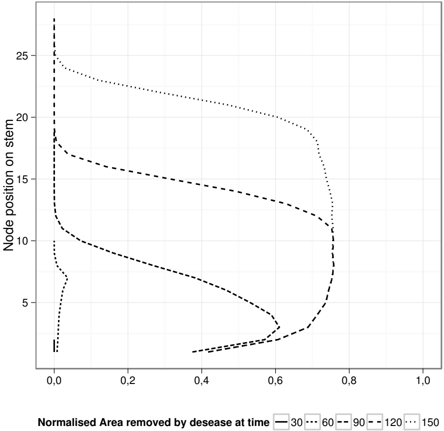
Qualitative model evaluation : vertical epidemics

Impact of crop development on disease profiles

Individual growth



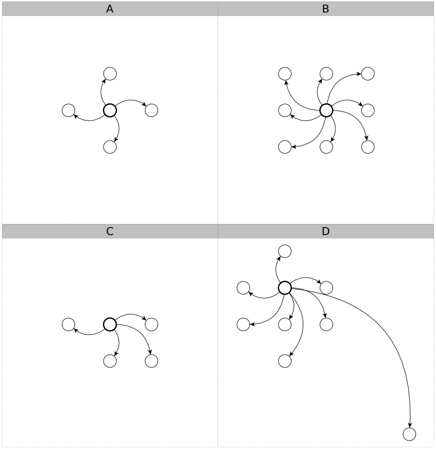
Disease profiles



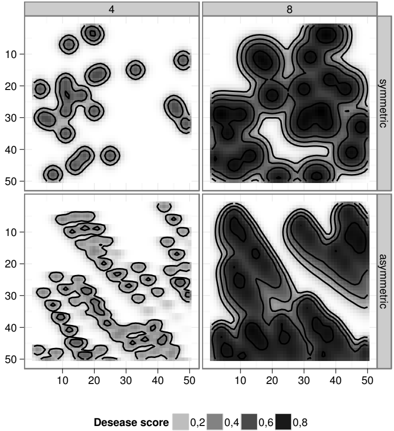
Qualitative model evaluation : spatial epidemics

Impact of local neighborhood parametrization on disease severity

Local neighborhood



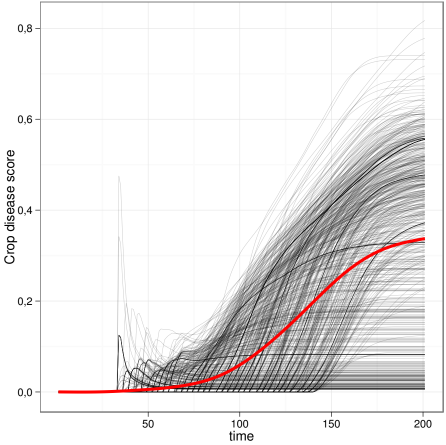
Resulting disease map



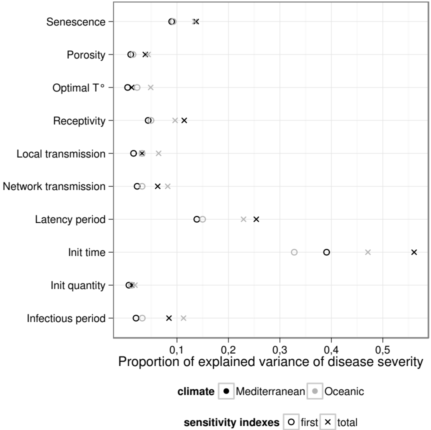
Quantitative model evaluation : sensitivity analysis

Impact of canopy characteristics (18 - 24%) on the dynamic of disease severity

Epidemic variability (n=1k)



Sensitivity analysis (n=10k)



Ideotype design : towards a model-assisted breeding ?

Crop ideotype ≈ plant architecture + crop management | environment

Connection with quantitative genetics (session 5)

- Plant architectural traits
- Physiological traits

Connection with integrated pest management (session 6)

- Representation of canopy architecture is too crude.
  - mainly temporal effects (avoidance, senescence, latency)
  - limited management actions (sowing, spatial organisation)

⇒ Combine *in vivo* and *in silico* experiments
⇒ Participative modelling

A challenging integration of different scales

Sub-plot scale : process representation and simplicication

- Light and spore interception : 3D architecture (e.g. L-Systems)
- Dispersion : wind and splash dispersal physical models
- Microclimate : energy balance models

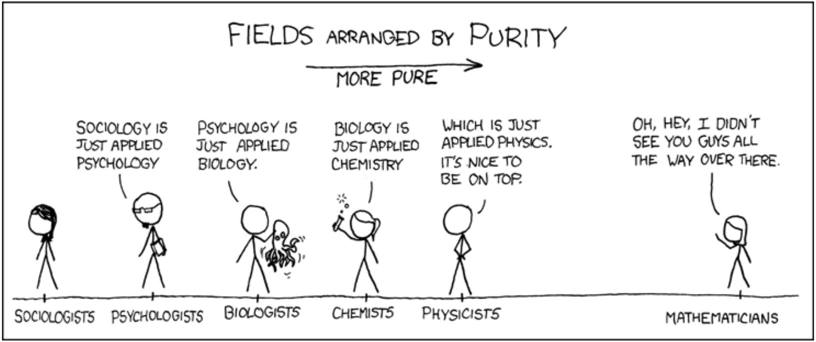
Landscape scale : robustness assessment

- Spatialisation (GIS, decision modelling)
- Aggregation and optimisation methods

$\Rightarrow$ Modelling platform should facilitate model coupling between scales or formalisms

Integration in real work condition

Why modellers should not (only) be mathematicians



source : xkcd.com, a web comic about romance, sarcasm, math and language

Thank you all !

- Amélioration des Plantes et Biotechnologies Végétales (APBV) - INRA GAP, Ploudaniel
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- Santé Végétale (SV) - INRA SPE, Bordeaux
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