The role of information in anticipatory responses

A possible framework for its analysis

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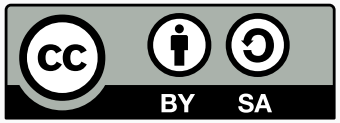
http://blogs.helsinki.fi/senpep-blog/



Outline

Background

An evolutionary viewpoint

- The focus of my presentation will be the sensory abilities of plants from an evolutionary and fitness perspective.
- Fitness represents an *ultimate cause* (a *why* question).
- The physiological and/or molecular mechanisms are *proximate causes* (*how* questions).
- In animal ecology sensory ecology is an important discipline.
- In the case of plants this approach has been rarely used...
- ...based on the assumption that sensory capabilities and specially information processing are very limited in plants.
- Now we know that this assumption does not hold.

Vocabulary: information as an abstraction

- (A technological example is radio broadcasting vs. internet-“radio” vs. radio communication.)
- First a signal (or cue) needs to be sensed or perceived.
- A signal may carry information or not, if it does not carry information we consider it as “noise”.
- To extract information a signal must be decoded.
- Memory is the storage of information.
- Processing is the combination of different bits of information.
- Communication is the exchange of information (there is an emitter and a receiver, can be one-way or two way).

Forecasting: its relation to fitness

- Our everyday life depends on forecasting all sorts of events every minute.
- Sometimes we do this consciously, but most of the time we are not aware of what our brain is doing.
- We use forecasts at very different time scales and to many different ends (e.g. estimating the weight of a cup when lifting it).
- I will we use the abstraction of information, and for a moment I will ask you to forget about how its processing is implemented...
- ...and consider the idea that every organism must have evolved the capacity to “forecast” future events important for fitness.
- How information is processed, “the machinery used”, does not need to be the same as long the information is acquired, transmitted, stored and combined successfully.
- The discussion of the role “future perception” in fitness of plants is current (Novoplansky 2016).

Can plants forecast? Preemptive acclimation

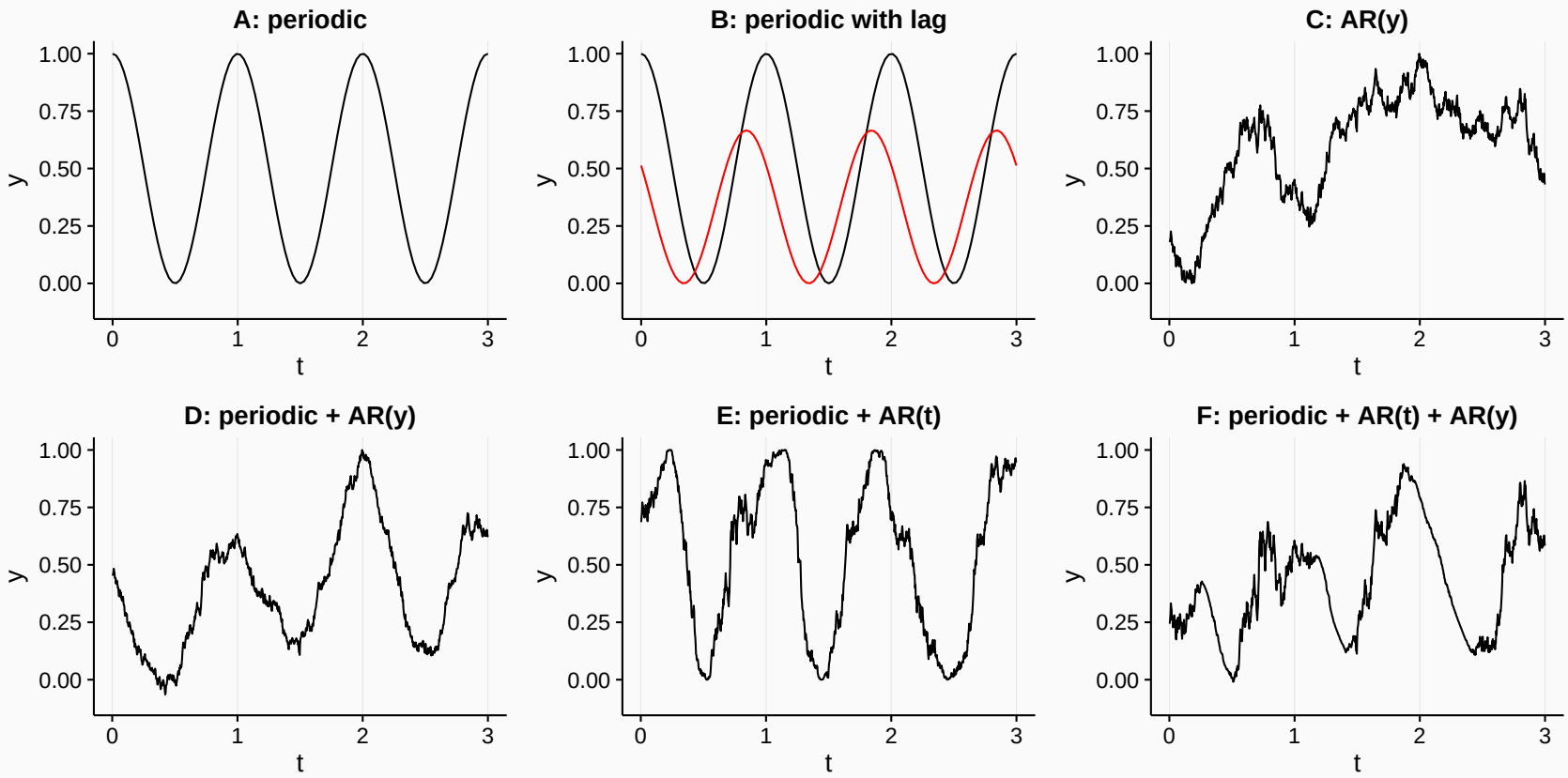
- Several plant responses can be only explained from the evolutive/fitness point of view as being a ‘preparation’ to tolerate or escape future stress events or to take advantage of future favourable conditions.
  - Example 1: Phenology.
  - Example 2: Preemptive shade avoidance as a response to reflected far-red light from neighbouring plants.
  - Example 3: Eavesdropping-on/communicating-with neighbours to preemptively acclimate/prepare for drought, herbivore attacks, even to synchronize flowering among individuals.
  - Example 4: Possibly (a hypothesis) preemptive acclimation to future soil drying in response to high ultraviolet-B irradiance.

Why sensory ecology?

The role of information

1. Information sources are crucial to the performance and survival of organims...
2. ...⇒ cross-correlations among variables in their environment and their lags, and autocorrelations, are key sources of information
3. ...⇒ we need to pay attention to 'joint statistical properties of environmental variables'...
4. We need to pay more attention to the sources of information...
5. ...and how sensory mechanisms have been "tuned" by evolution to filter information from noise.

Correlations in the environment



Forecasting

1. Lagged cross-correlations and autocorrelations make it possible the modelling and short-term forecasting of non-deterministic variation.
2. Organisms can generate “correlated variables” through the emission of signals that propagate faster than the event they have perceived.
3. e.g. emission of volatile organic compounds in response to insect herbivory.
4. e.g. release of ABA to the shared soil volume with drought or salinity.
5. e.g. unknown signal in the soil inducing synchronization of flowering.

A possible framework

Proposed theoretical framework (I)

Conceptual framework

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Conceptual framework

Historical correlations

Previous conditions

Current conditions

Proposed theoretical framework (I)

Conceptual framework

Historical correlations

Previous conditions

Current conditions

Genome

Epigenome

Phenome

Proposed theoretical framework (I)

Conceptual framework

Historical correlations

Previous conditions

Current conditions

Future conditions

Genome

Epigenome

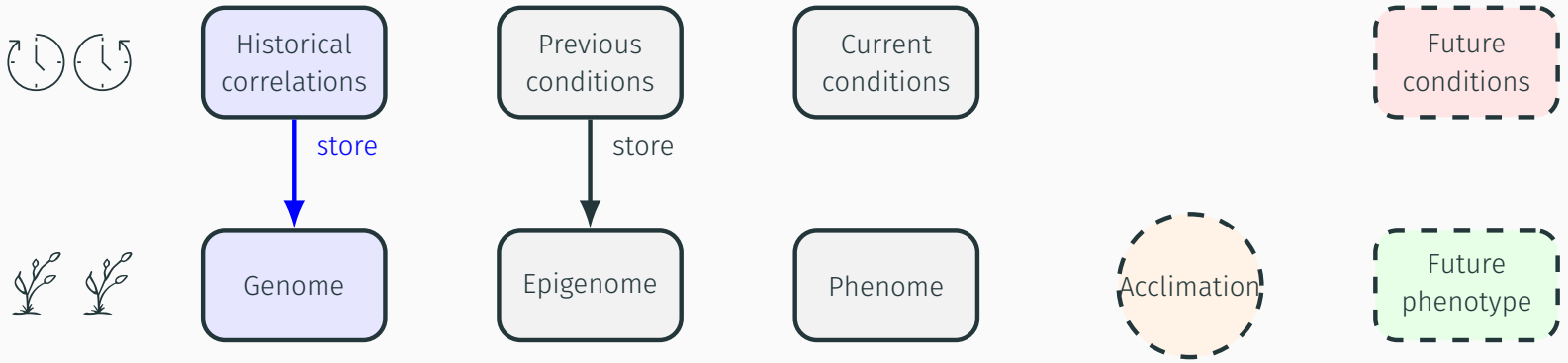
Phenome

Acclimation

Future phenotype

Proposed theoretical framework (I)

Conceptual framework



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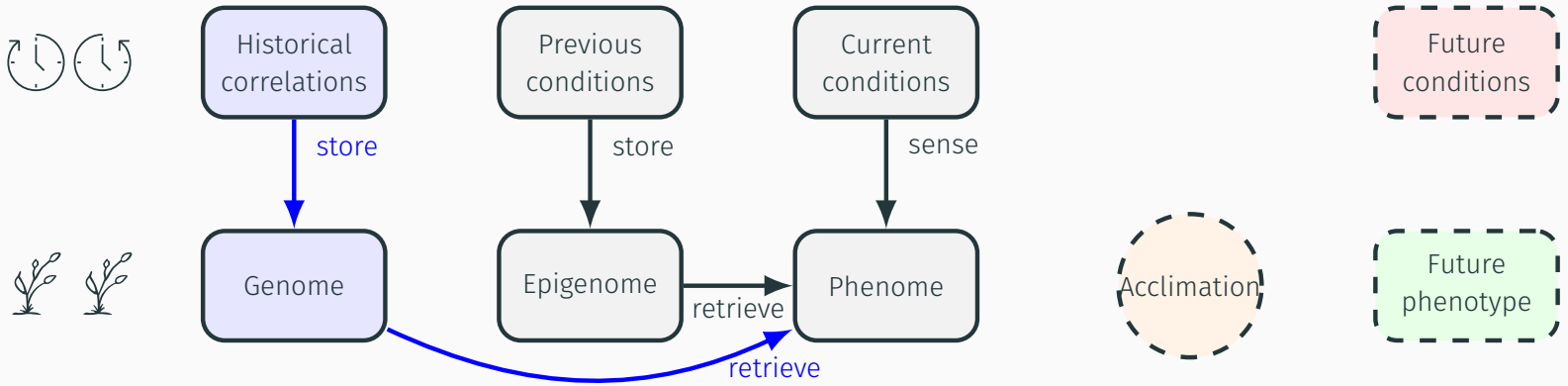
Conceptual framework



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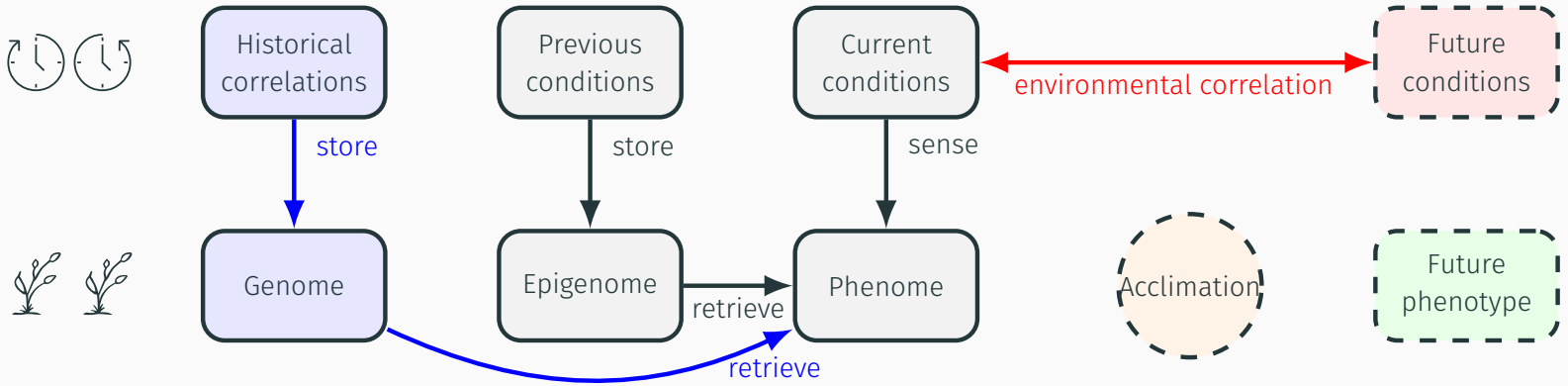

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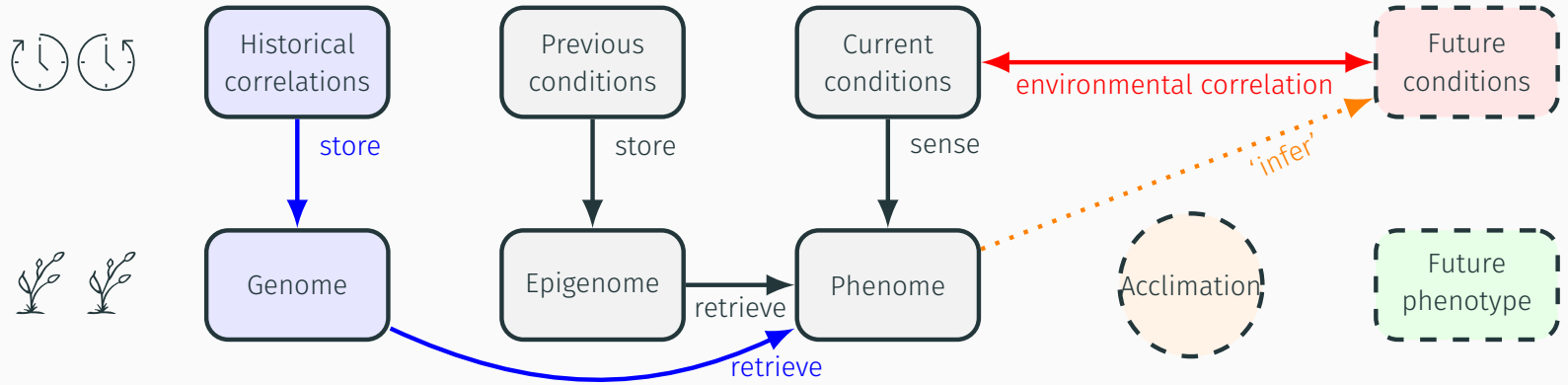

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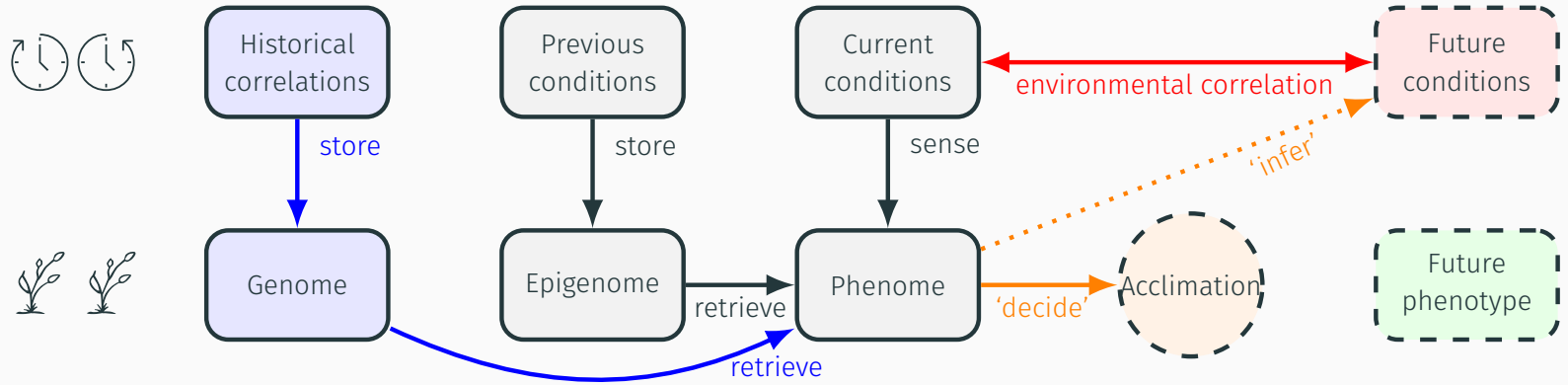

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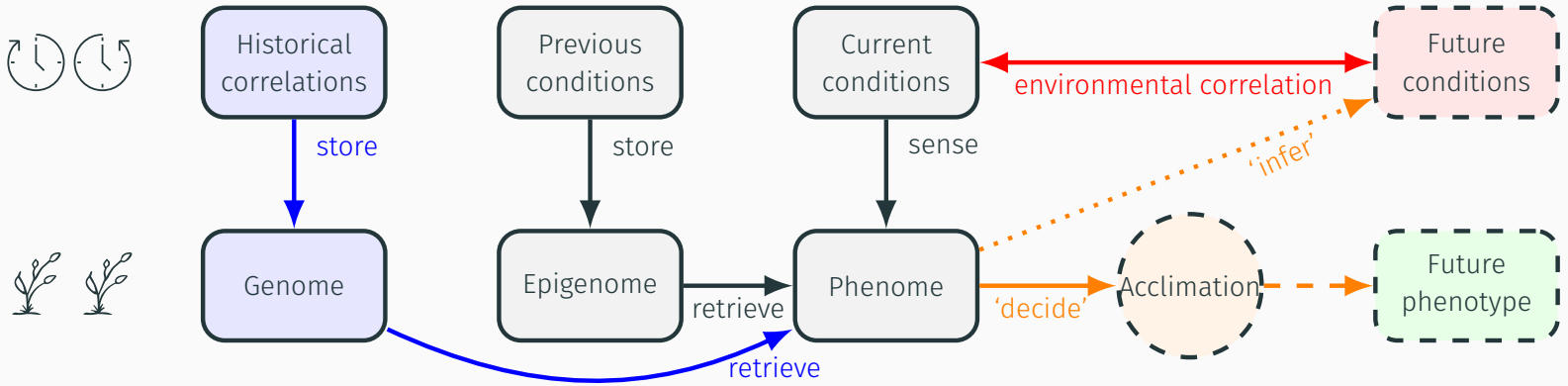

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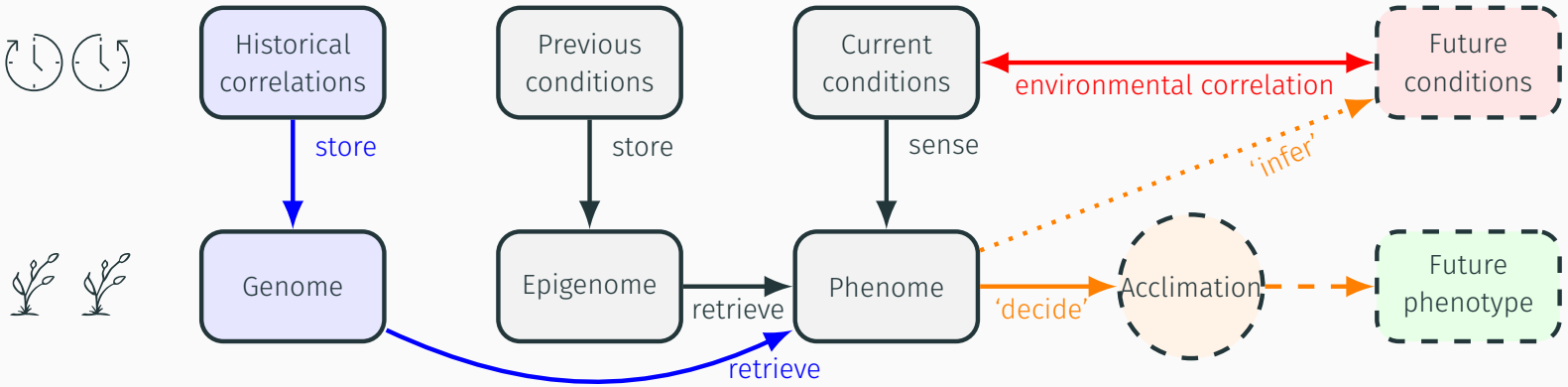
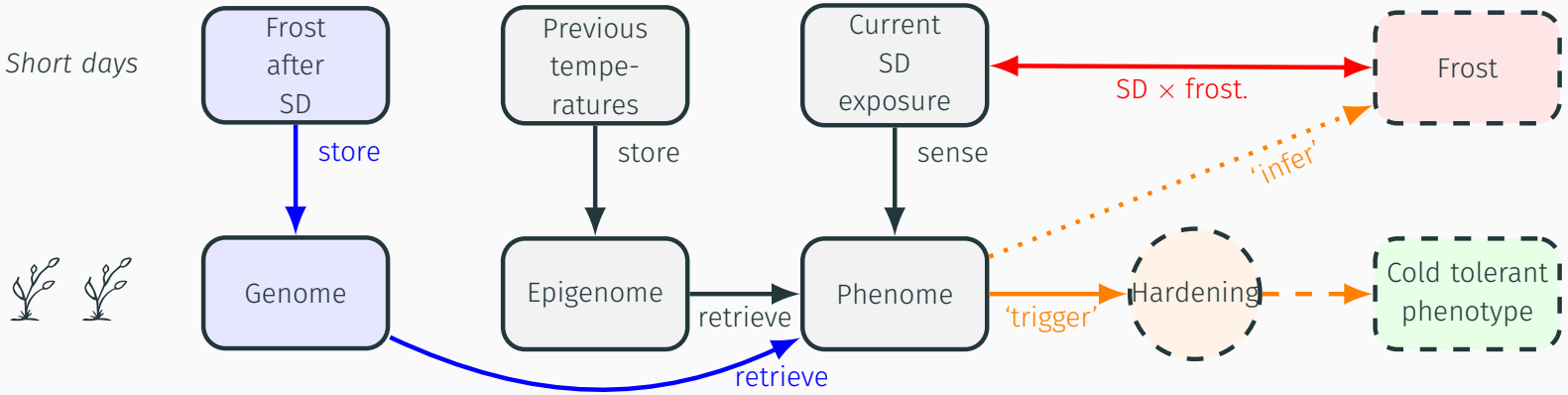
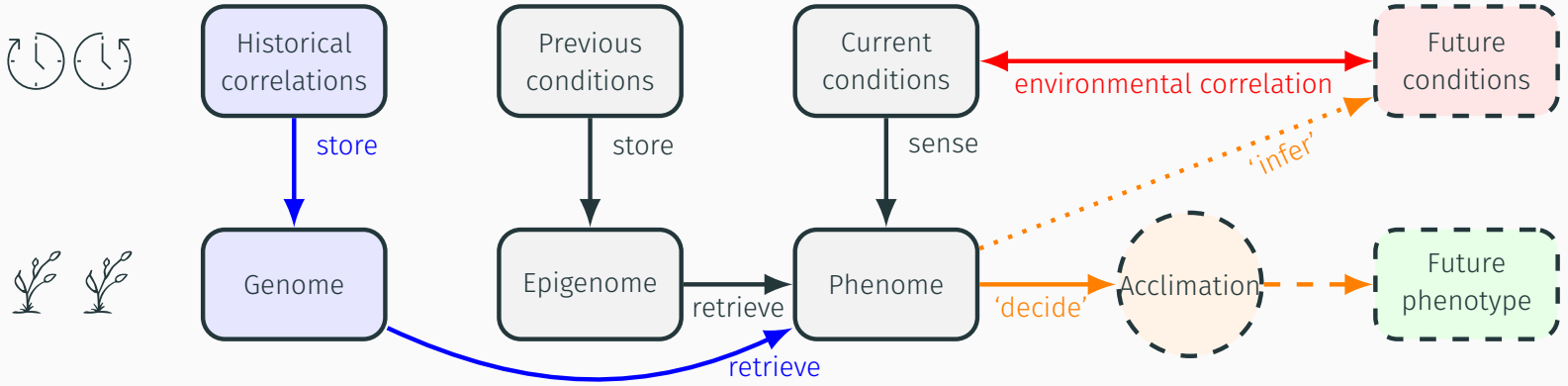


Example: Frost hardening



Proposed theoretical framework (II)

Conceptual framework



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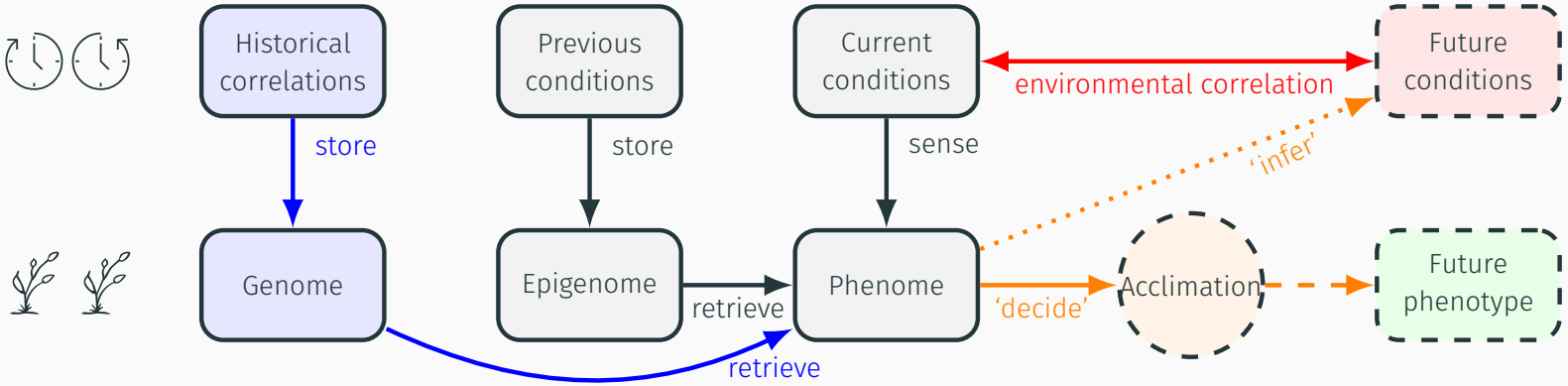
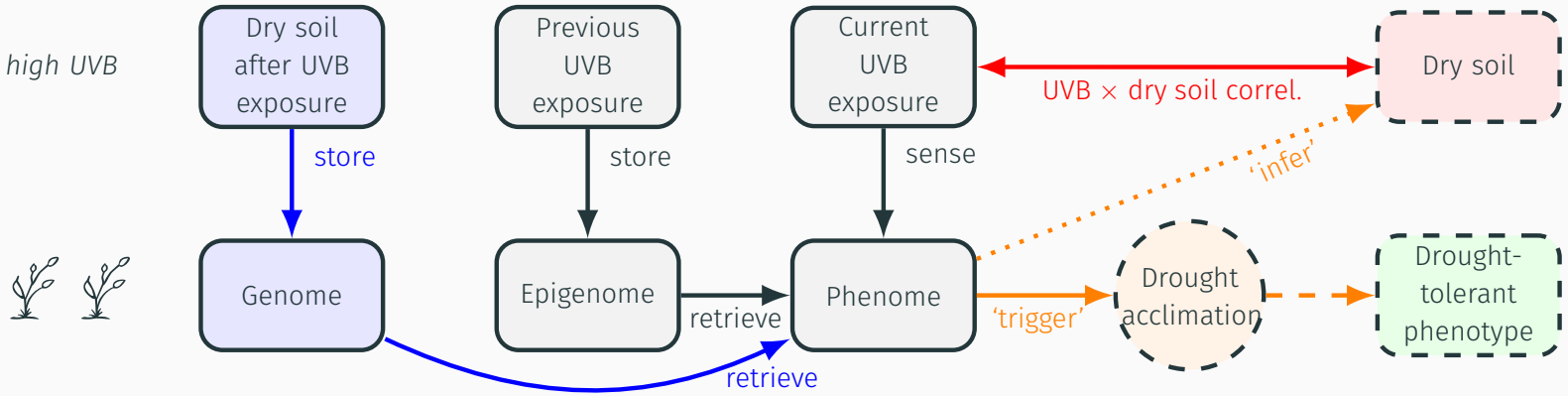


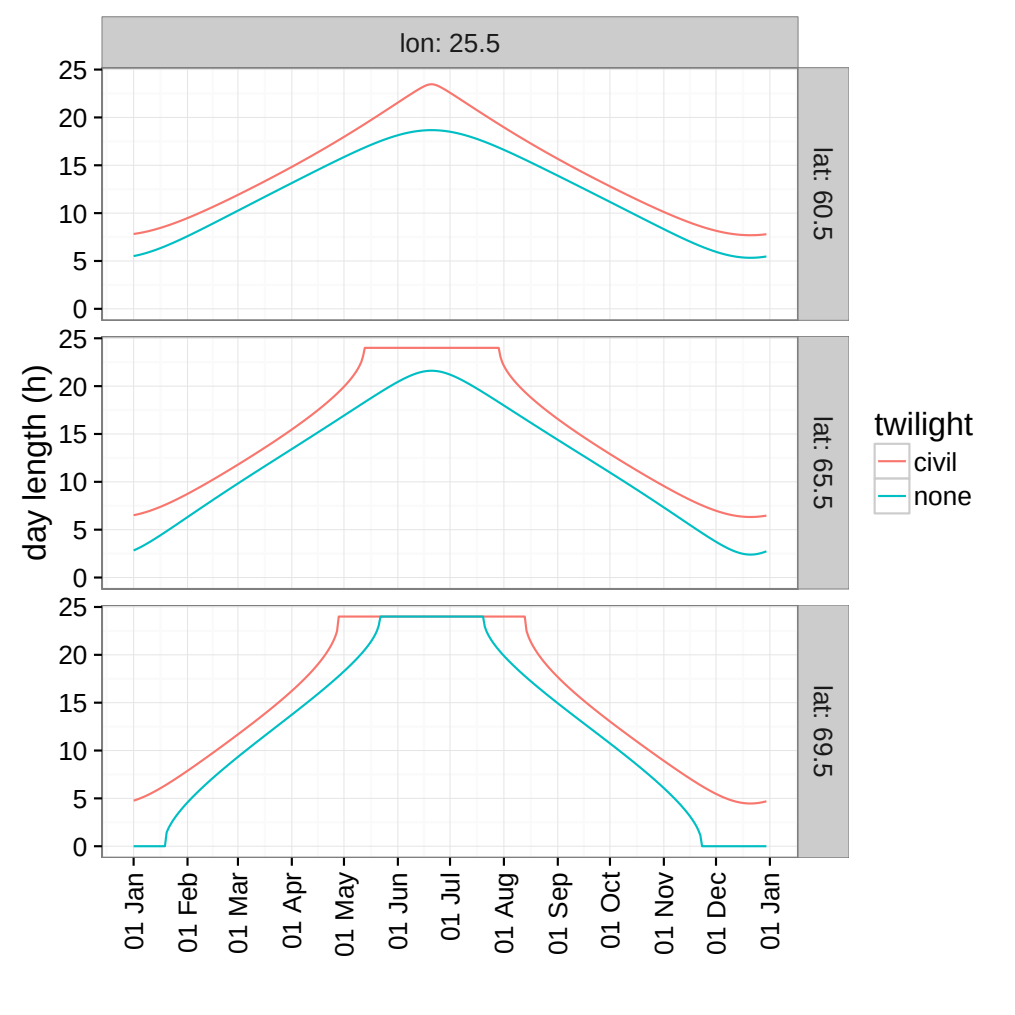
UVB example



Some familiar variables

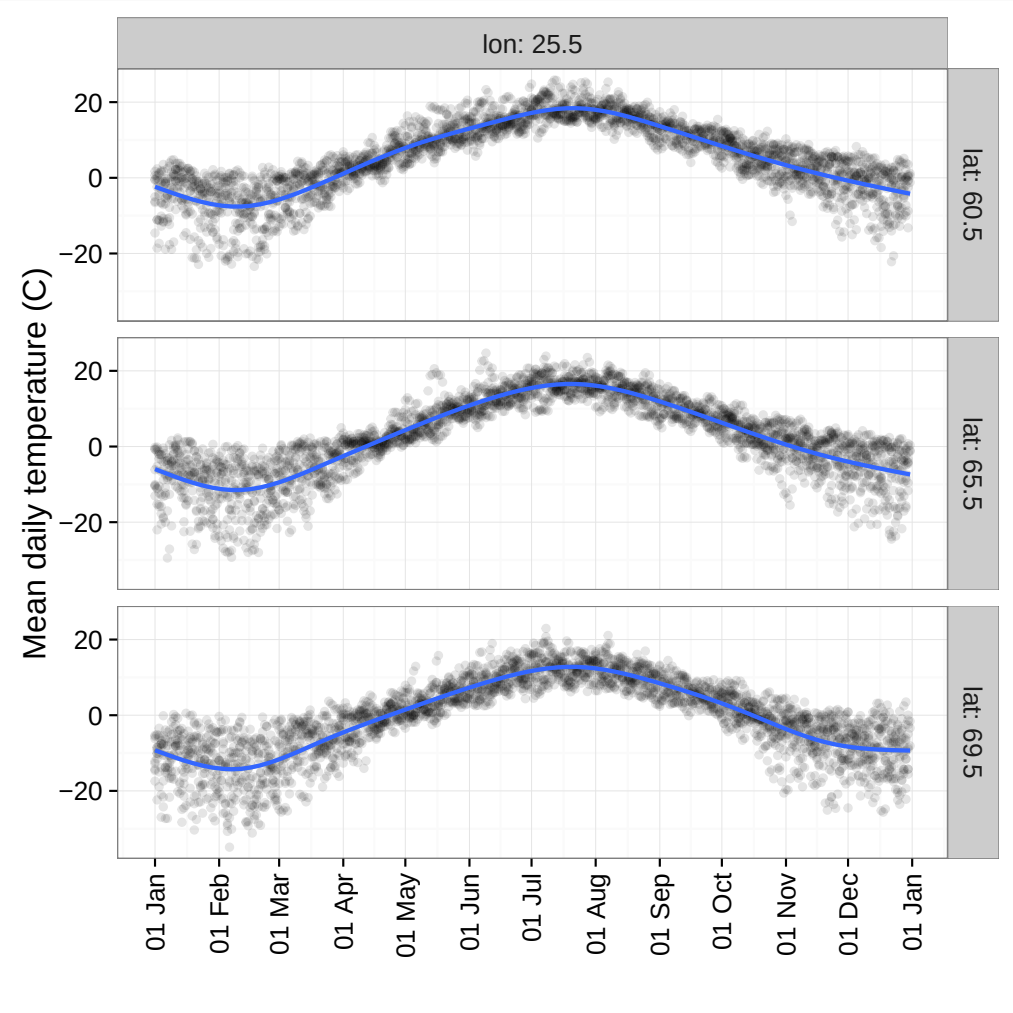
Day length and twilight

Almost deterministic at each of three latitudes in Finland.



Temperature and its variability: 2004–2014

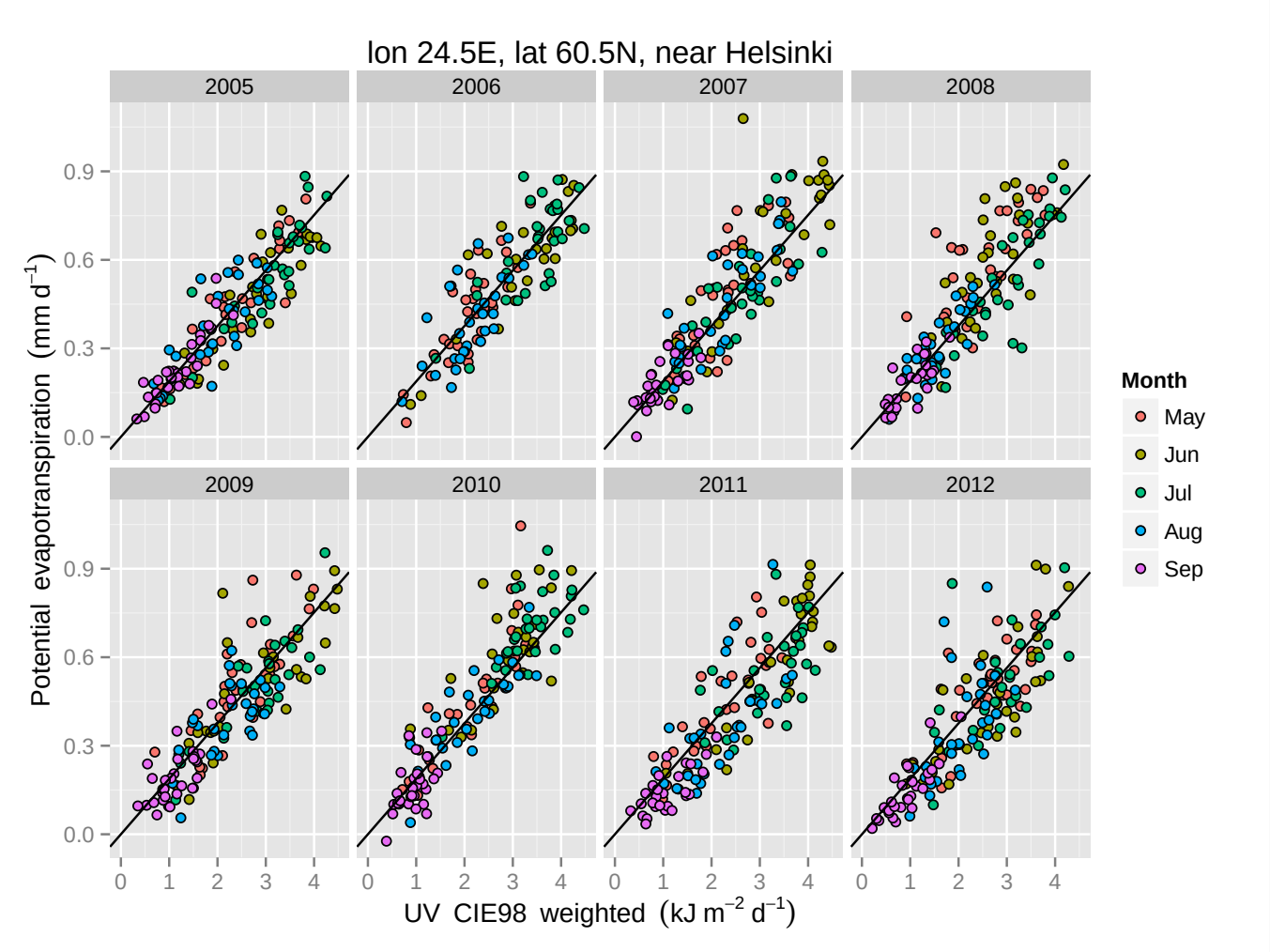
Large day to day variation at different latitudes (three grid points in Finland).



(P. J. Aphalo, A. Lindfors, unpublished)

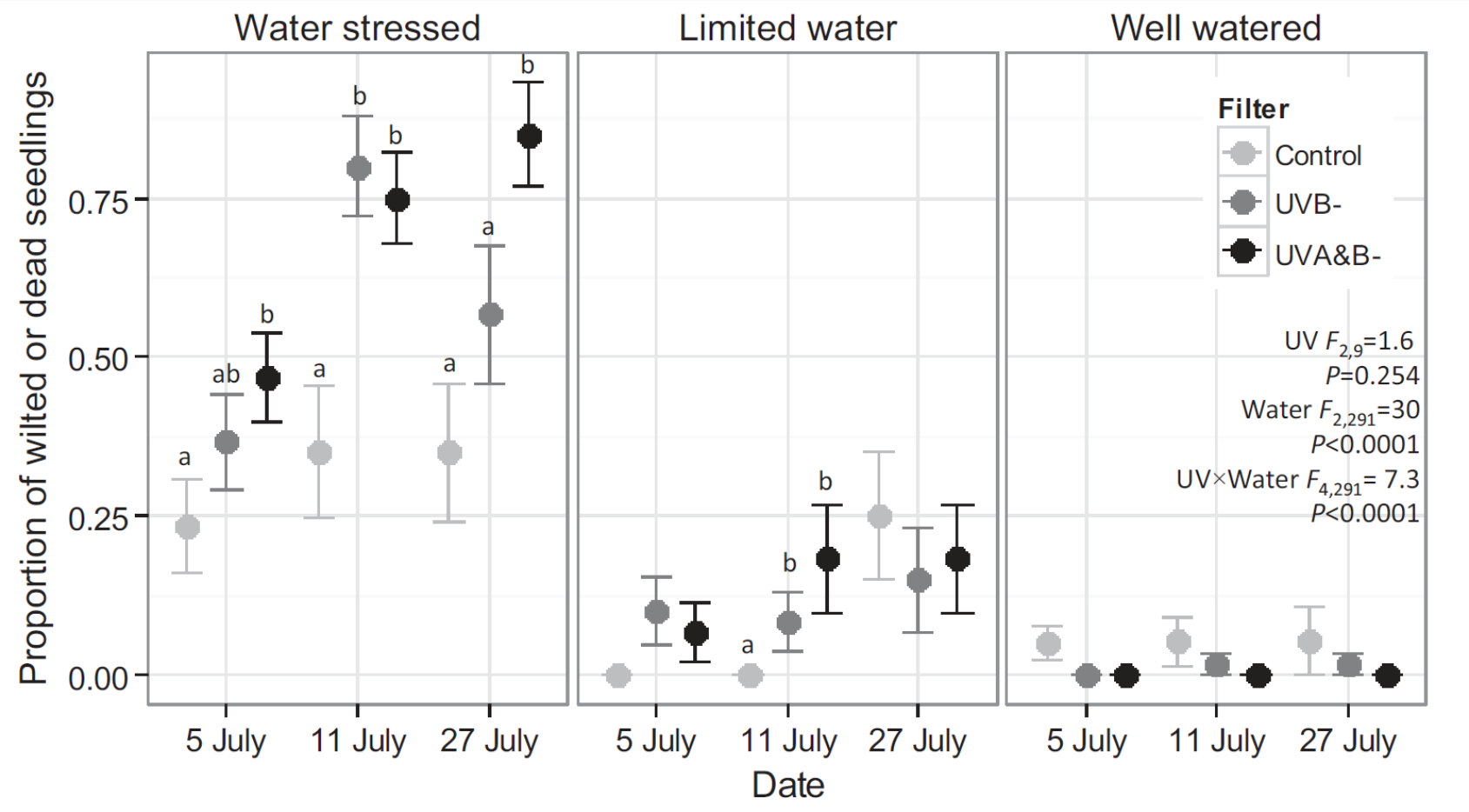
Drought acclimation under UVB: available evidence

Is there an environmental correlation? Yes



(P. J. Aphalo, A. Lindfors, unpublished)

Can exposure to UV-B trigger drought-acclimation? Yes



(Robson et al. 2014)

What about gene expression?

From gene ontology (GO) terms enriched after UV-B exposure for 6 h.

- “water transport”: genes including AT1G01620 (PIP1-3), AT2G37170 (PIP2B), AT3G16240 (TIP2-1), AT3G53420 (PIP2-1), AT3G61430 (PIP1-1), AT3G11820 (SYP121) and AT5G06530 (ABCG22).
- “response to water deprivation”: genes including AT1G20450 (ERD10), AT1G76180 (ERD14), AT2G30870 (ERD13), AT2G22430 (ATHB6), AT2G39800 (ATP5CS, proline synthesis), AT2G45960 (PIP1B), AT3G11410 (AHG3, ABA signalling), AT3G14050 (ATRSH2, ABA signalling), AT3G21780 (UGT71B6, ABA catabolism), AT5G57050 (ABI2, ABA, stomata).

Drought acclimation under UVB: possible implications

Take home message from our research on UV

If our hypothesis holds for a range of species then there would be much to rethink:

- reduced growth under UV-B exposure could improve fitness instead of being deleterious,
- phenotyping for drought tolerance of dryland crops in the absence of UV-B could lead to little progress,
- what should we do with field crops under irrigation: do we need to breed out some of the UVB responses?,
- what about rain shelter experiments: should we supplement with UVB when it is cloudy or raining?
- What about climate change: should we acknowledge that changes in rainfall will correlate with changes in UVB due to cloud cover?

Overall take home message

- If we use a higher level abstraction...
- ...we can more easily see the parallels between different anticipatory responses...
- ...and their commonalities, in the spirit of the general systems theory.
- Use more consistent research approaches.
- More easily apply what we already know or will learn in the future about responses like the annual cycle of trees, or the shade avoidance response, to “newly” discovered or hypothesized anticipatory responses.

A *caveat*

- The model I presented is mainly dealing, at least in my examples, with relatively “normal business”, events that could take place every year to not more than a few generations apart.
- But boreal trees and plants have also survived as species very exceptional extreme events.
- This has also shaped the current genotypes, so do we need to also consider risk analysis when analysing the use of information by plants? and how?

Acknowledgements

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A new umbrella organization at our campus.

My employer.

For funding, decisions 252548, 16775.

References

- Novoplansky, A. (2016). “Future Perception in Plants”. In: *Anticipation Across Disciplines*. Springer, pp. 57–70.
- Robson, T. M., S. M. Hartikainen, and P. J. Aphalo (2014). “How does solar ultraviolet-B radiation improve drought tolerance of silver birch (*Betula pendula* Roth.) seedlings?” In: *Plant, Cell & Environment* 38, pp. 953–967. DOI: 10.1111/pce.12405.

Vocabulary: other terms

- “Plant neurobiology”.
- “Plant intelligence”.
- In my view they are not useful.
- They are not abstract enough.
- They have an everyday meaning that is at odds with the proposed use.
- They distract us from the actual phenomena under study.

Some connections to earlier talks

- Veikko Koski's reference to "Heisenberg's uncertainty principle" triggered some thoughts: 1) the plants perceive the state of the environment but modify it, but also 2) in experiments we modify the environment, rather drastically, to study the responses of plants.
- In the discussion after Outi Savolainen's talk about the quantitative traits and the difficulties of dealing with many alleles the discussion centred on study methods. Later in the evening I started thinking whether having so many alleles could have a function in fitness. I came out with two ideas, at least the first one not original at all: 1) a smooth "continuous" range of possible daylength thresholds is good for fine tuning during "normal business", but 2) could this also be advantageous in "extreme years" as a way of preventing the loss of any alleles from the population even if a significant part of population with a non-hardy phenotype died.

The origin of what I will present today

- BSc Agronomy with emphasis in crop breeding (Genetics + Ecology + Statistics + Meteorology)
- MSc Plant Production (Ecophysiology + Sensory photobiology + Simulation modelling + General Systems Theory)
- - Computing programming + Systems analysis
- - Electronics + Instrumentation
- PhD in “Science” (Ecophysiology + Sensory photobiology + Instrumentation + Simulation modelling)
- METLA - seedling—seedling interactions + photobiology + growth regulators
- U. Joensuu - roots + cold + UVB radiation + Instrumentation + Computer Programming + Mineral Nutrition + Secondary metabolites
- U. Jyväskylä - statistics + time series analysis + UVB + Secondary metabolites
- U. Helsinki - add Heikki, molecular biology, a few additional plant species, a pinch of metabolomics and shake well