The evolutionary ecology of information acquisition in plants

The basis of brainless forecasting

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and

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Background

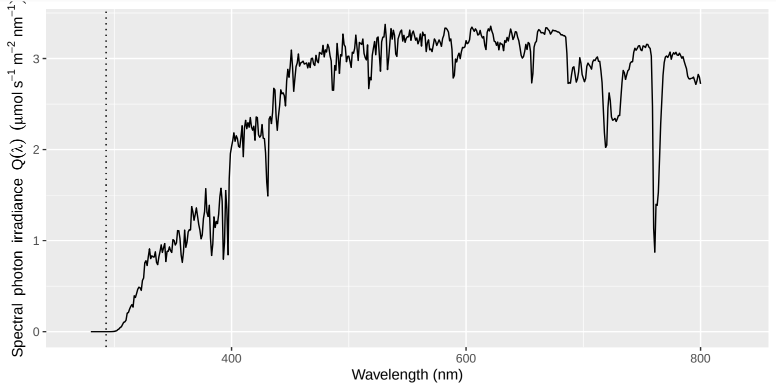
Warning

- Much of my talk is based on reshuffling my ideas together with Ariel's...
- ...combined with some fundamental insights I gained here from Alex's talks.
- Main one being, that much of what we heard from Alex about control systems and evolution, is applicable also to acclimation.
- Here I will not attempt to describe evolution as a control system...
- ...but rather think of light perception as the input boundary of a physiological/developmental control system.

Acclimation depends on plasticity

- Responses take time $\Rightarrow$ must be triggered in advance.
- Slow responses need to be triggered earlier than fast ones.
- Enhanced readiness to respond allows delaying full commitment.
- Prediction of future environment is error-prone.
- Cost of response is deterministic, benefit is stochastic.
- Acclimation is based on syndromes rather than individual responses (?).

Sunlight

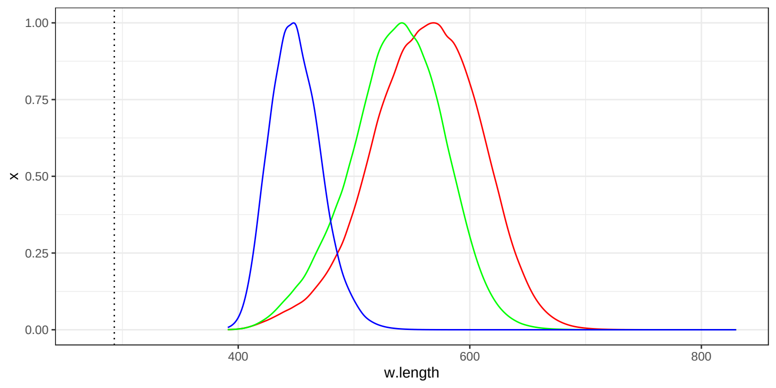


Spectral photon irradiance Q(λ) (µmol s⁻¹ m⁻² nm⁻¹)
3
2
1
0
400
600
800
Wavelength (nm)

Perception of daylight by humans vision

- Wavelengths from 380 to 720 nm are visible.
- Three photoreceptors $\rightarrow$ 1 million colours.
- The photoreceptors are sensitive to red (R), green (G) and blue photos (B).
- Colour sensation is the result of information processing...
- ...which maps the excitation of the three photoreceptors into “expected” colours.
- i.e., colour TV, film photogarphy, digital photography, most colour printing, mixing to pigments by artist, all target human vision.

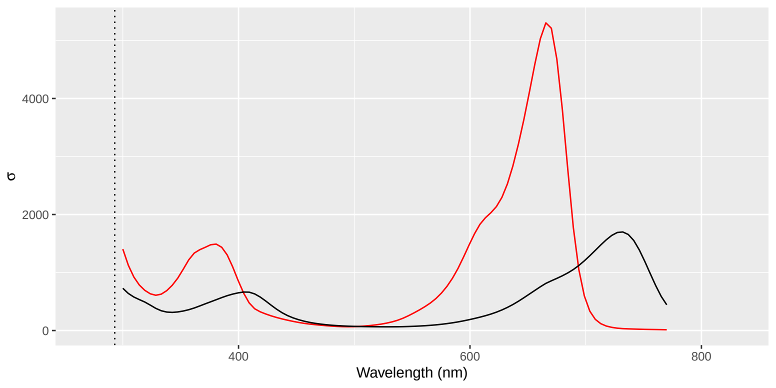
Human (cone fundamentals)



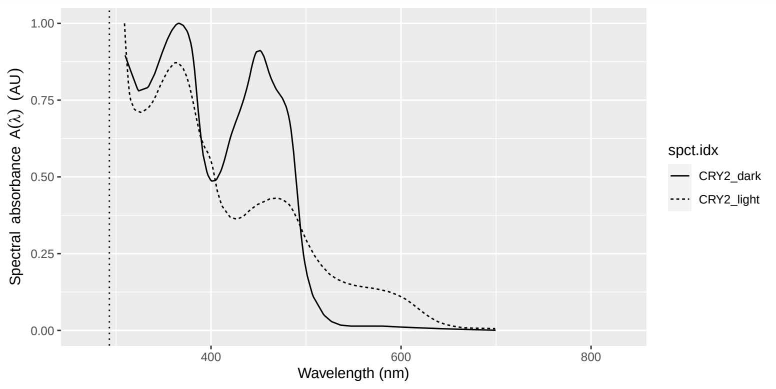
Perception of daylight by plants

- Wavelengths from ≈ 270 nm to ≈ 800 are perceptible.
- About 14 photoreceptors $\rightarrow$ RGB, far-red (FR) and ultraviolet (UV); only 5 colours (??!!).
- Some photoreceptors have different modes of action leading to different sets of responses.
- Photoreceptors can function as wavelength-ratio detectors, as flux detectors or time-domain-integrators.

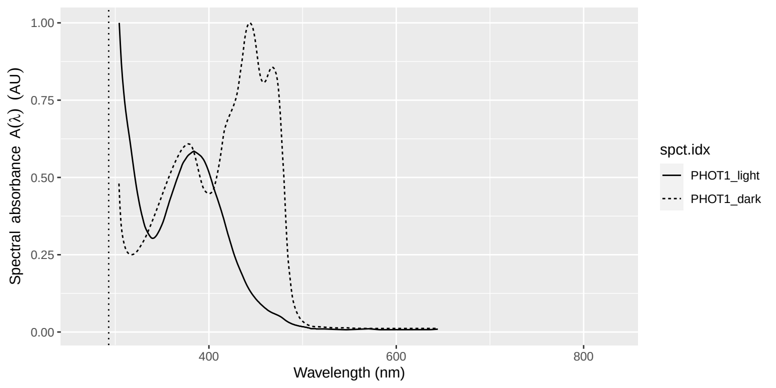
Plants (phytochromes)



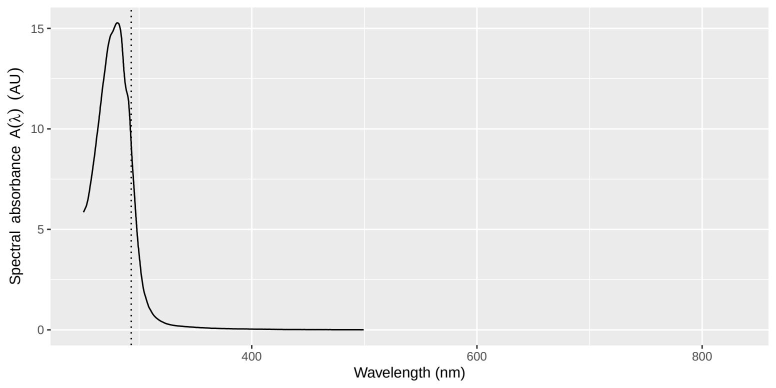
Plants (cryptochromes)



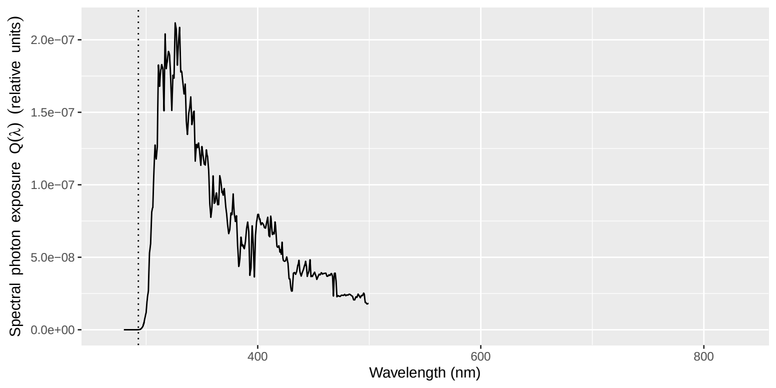
Plants (phototropins)



Plants (UVR8)



Plants (UVR8 × sunlight)



Vocabulary: information as an abstraction

- Information is encoded in one or more carrier.
- e.g. radio broadcasting vs. internet-“radio”.
- First a signal (or cue) needs to be sensed or perceived.
- To extract information a signal or cue must be decoded.
- The components of a signal or cue that we cannot decode into information we call “noise”.
- Memory is the storage of information.
- Processing is the combination of different bits of information.
- Communication is the exchange of information (between 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.
- Perception of cues and memories are sources of information.
- e.g. estimating the weight of a cup when lifting it.

Forecasting: its relation to fitness

- I 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 its 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.

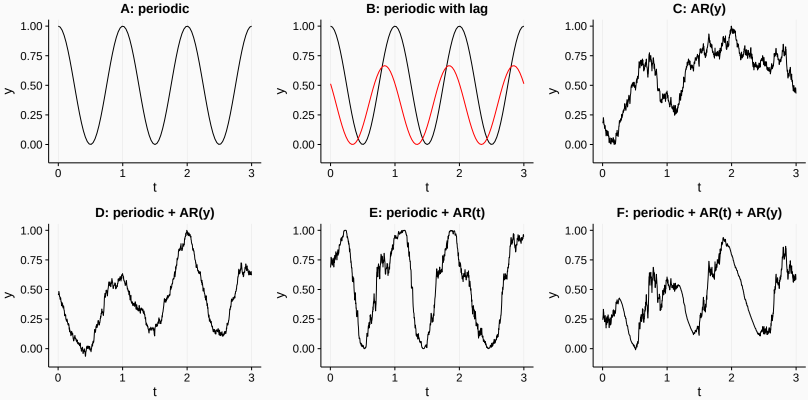
Information as a paradigm

1. Information and big data are the buzz-words or our time.
2. Given us a paradigm that “asks to be applied”...
3. ...but care is needed.
4. Much like the machine paradigm from the industrial revolution failed to explain life...
5. ...the use-of-information paradigm will not be enough to explain it.
6. However, it is able to explain some aspects of life.

Forecasting for economic investment

1. There are reliable and unreliable sources of information.
2. Forecasting can depend on a single reliable predictor or...
3. ...on a combination of several less reliable predictors.
4. Predictors *do not need* to have a direct cause-effect relationship.
5. Forecasts are subject to errors...
6. ...with outcomes that can be described by probabilities.
7. A dynamic context requires repeated-tuning of models.

Correlations in the environment



Cues and signals as sources of information

1. Cue/signal and predicted event need to be correlated.
2. Cross-correlation and autocorrelation both work.
3. The sign of correlation is irrelevant.
4. Cue/signal should precede the predicted event…
5. …long enough for acclimation to take place.
6. Correlation can be spatial, temporal or both.
7. “Random noise” in spatial/temporal cues/signals can be “smoothed out”.

Listener perspective

1. Contribution to own fitness
2. Own response
3. Decoding of information
4. Perception
5. Available cues/signals

Emitter perspective

1. Contribution to own fitness
2. Response from listener
3. Encoding of information
4. Emission
5. Broadcasted signals

Data processing mechanism in plants I

- We know something on how decoding works…
- …for some individual cues or signals.
- A frequent *naive model* is a linear chain of events.
- Cue/signal perception $\rightarrow$ direct decoding of information $\rightarrow$ response
- Low R:FR $\rightarrow$ "means shade" $\rightarrow$ shade avoidance response
- Can frequently describe responses to single cues or signals

Data processing mechanism in plants II

- We know almost nothing on how decoding works...

  ...for sets of cues or signals.
- A complex and realistic (?) model is a network of interactions, memories and feedback loops.
- Synchronous and asynchronous perception of cues/signals $\rightarrow$ ...

  complex decoding of information (1) $\rightarrow$...adjustment of ready-ness to respond.
- Synchronous and asynchronous perception of cues/signals $\rightarrow$ ...

  complex decoding of information + readiness state $\rightarrow$ response.

A possible framework

Information-based framework for acclimation

Conceptual framework

Information-based framework for acclimation

Conceptual framework

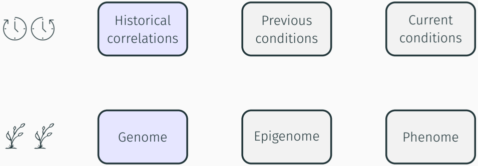
Historical correlations

Previous conditions

Current conditions

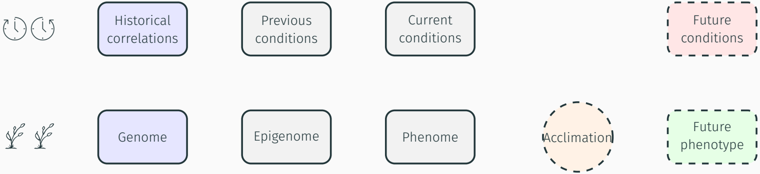
Information-based framework for acclimation

Conceptual framework



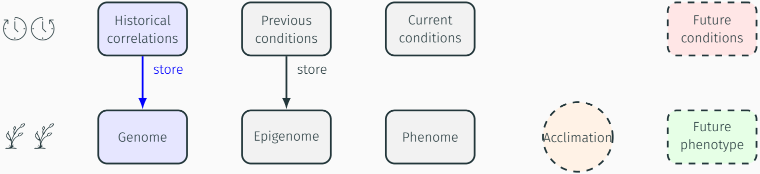
Information-based framework for acclimation

Conceptual framework



Information-based framework for acclimation

Conceptual framework



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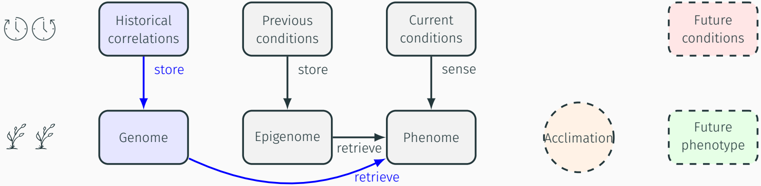
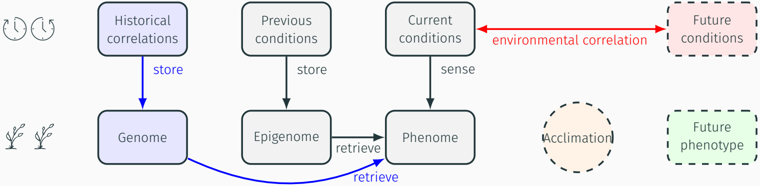


Information-based framework for acclimation

Conceptual framework



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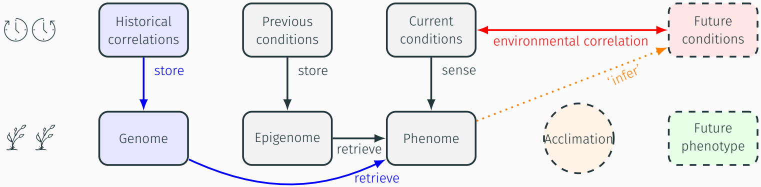
Conceptual framework



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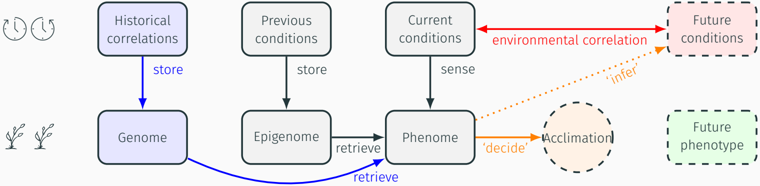

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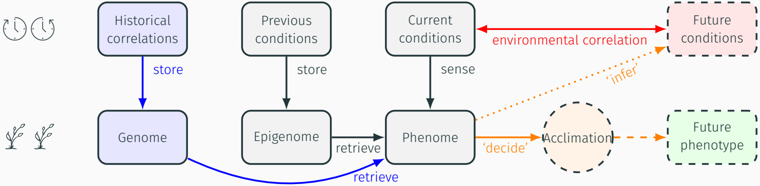
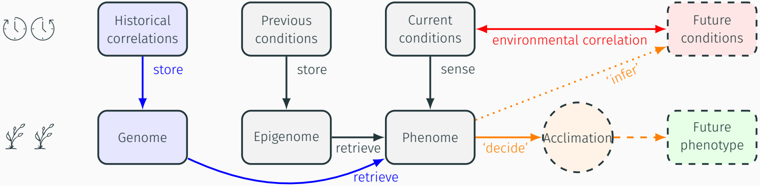
Conceptual framework

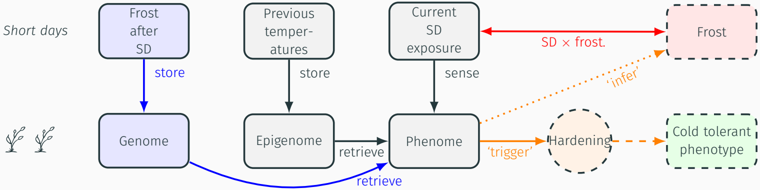


Information-based framework for acclimation

Conceptual framework

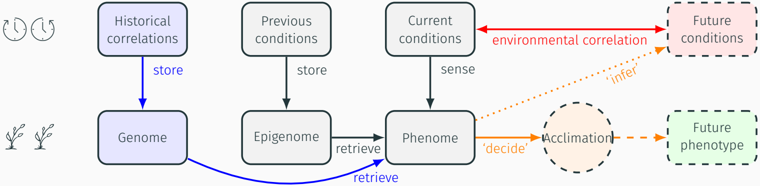


Example: Frost hardening



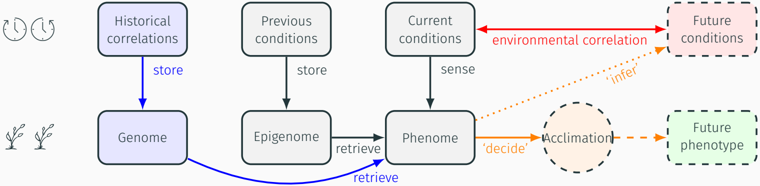
Proposed theoretical framework (II)

Conceptual framework

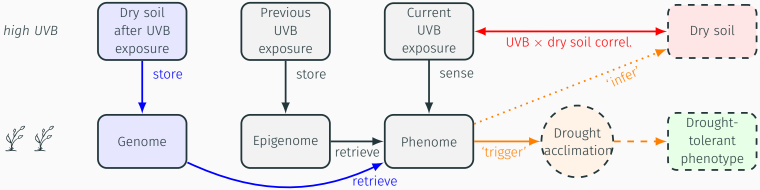


Proposed theoretical framework (II)

Conceptual framework



UVB example



Implications

Context matters for signalling

1. Components of signalling networks can be best teased out in unnatural contexts including single factor experiments.
2. Regulation and signalling interactions can be meaningfully described only in real or realistic contexts preferably using factorial experiments.
3. Real contexts are variable, so ample replication is needed.
4. Describing a syndrome requires in most cases parallel measurements at different levels of organization.
5. Time courses of response need to be followed.

Data analysis and interpretation

- Search for patterns of response across mutants and treatments/conditions.
- Be careful about quality of gene annotations.
- Be very careful about gene ontology (GO) terms.
- With PCR have enough reference genes.