Slide 1



Plants, Cognition, Time (& Philosophy)

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Slide 2

My Research

- Time
  - Relative scales of time and space
  - Change, Processes, Motion
  - Tradeoffs between Time & Cognition
    - Not in plants but in what they can teach us
- Emergic Behaviour
  - Process vs. Substance
  - Recurrence & Dynamic Systems
- Meta Cognition / Philosophy of Mind (what is:)
  - Thinking, Memory, Attention ...



- http://en.wikipedia.org/wiki/Cognition
- http://en.wikipedia.org/wiki/Dynamical_system
- http://en.wikipedia.org/wiki/Emergence
- http://en.wikipedia.org/wiki/Philosophy_of_mind
- http://en.wikipedia.org/wiki/Process_philosophy
- http://en.wikipedia.org/wiki/Recurrence_relation
- http://en.wikipedia.org/wiki/Recursion
- http://en.wikipedia.org/wiki/Time

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Why Plants?

- Plants are ordinarily thought of as
  - "Dumb" stimulus/response systems
- However, by analyzing plant behaviour at
  - differing time scales, and
  - allowing for other complexities

  one can come to view Plants as smarter than we thought – as information processors!
- What can plants teach us about cognition?
  - Let's take a computational approach
  - After all, hardware (knock on wood) does not matter

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Purpose

- To entertain, inform, challenge & engage
- Meta Cognition (Philosophy of Mind)
  - What do we mean when we say...
- Can plants:
  - Process Information? Make Decisions? Plan? Compute? Think?
  - Have Free Will?
  - Sense? Perceive? Feel? Be Conscious?
  - Learn? Have Memories? Represent? Know? Have Intentionality? Communicate?
- How shall we clarify these terms for humans?

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Plant Motion Categories

- Tropism
  - Directional
  - Positive: towards stimulus
  - Negative: away from stimulus
- Nastic
  - Non-Directional
  - Triggered by stimulus
- Rapid Plant Movement
  - Triggered by stimulus
- Circadian
  - Internal/External stimulus





- http://en.wikipedia.org/wiki/Motility

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Tropism

- Summary
  - Directional movement or growth in response to stimuli
  - Positive: towards stimulus
  - Negative: away from stimulus

Tropism	Stimuli
Chemotropism	chemicals
Gravitropism	gravity
Hydrotropism	moisture or water
Heliotropism	sunlight (tracking)
Phototropism	lights or colors of light
Thermotropism	temperature
Thigmotropism	touch or contact







- http://en.wikipedia.org/wiki/Tropism
- http://en.wikipedia.org/wiki/Chemotropism
  http://en.wikipedia.org/wiki/Chemical
- http://en.wikipedia.org/wiki/Gravitropism
  http://en.wikipedia.org/wiki/Gravity
- http://en.wikipedia.org/wiki/Hydrotropism
  http://en.wikipedia.org/wiki/Moisture
  http://en.wikipedia.org/wiki/Water
- http://en.wikipedia.org/wiki/Heliotropism
  http://en.wikipedia.org/wiki/Sunlight
- http://en.wikipedia.org/wiki/Phototropism
  http://en.wikipedia.org/wiki/Lights
  http://en.wikipedia.org/wiki/Color_spectrum
- http://en.wikipedia.org/wiki/Thermotropism
  http://en.wikipedia.org/wiki/Temperature
- http://en.wikipedia.org/wiki/Thigmotropism
  http://en.wikipedia.org/wiki/Somatic_sensation
  http://en.wiktionary.org/wiki/contact

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Chemotropism

- Movement or growth in response to chemicals
- Likely the most significant tropism for all biological development
- E.g., Pollen tube growth towards the ovules
  - Nerve growth in animals
  - Cellular differentiation due to chemical signalling?

- http://en.wikipedia.org/wiki/Chemical
- http://en.wikipedia.org/wiki/Chemotropism
- http://en.wikipedia.org/wiki/Pollen_tube
- http://www.neurosci.tufts.edu/research_asst_profs/lovy_wheeler/alenka.html
- http://en.wikipedia.org/wiki/Axon_guidance
- http://en.wikipedia.org/wiki/Cellular_differentiation

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Gravitropism

- Movement or growth in response to gravity
  - Positive Gravitropism
    - Toward Stimulus
    - Roots
    - E.g., Corn Root
  - Negative Gravitropism
    - Away from Stimulus
    - Shoots & Stems
    - E.g., Coleus Shoot

- http://en.wikipedia.org/wiki/Gravitropism
- http://en.wikipedia.org/wiki/Gravity
- http://plantsinmotion.bio.indiana.edu/plantmotion/movements/tropism/gravitropism/rootgrav/graviroot.html
- http://plantsinmotion.bio.indiana.edu/plantmotion/movements/tropism/gravitropism/coleus/coleusgravi.html

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Phototropism

- Movement or growth in response to lights or colours of light
- E.g., corn phototropism + gravitropism
- Decisions? Free Will?

- http://plantsinmotion.bio.indiana.edu/plantmotion/movements/tropism/phototropism/corn/cornworship.html
- http://en.wikipedia.org/wiki/Phototropism
- http://en.wikipedia.org/wiki/Color_spectrum
- http://en.wikipedia.org/wiki/Lights

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Heliotropism

- Movement or growth in response to sunlight, specifically solar tracking
- E.g. Young sunflowers tracking east to west
- Circadian control "anticipates" sunrise by facing east
- Memory?
- Aboutness?

- http://en.wikipedia.org/wiki/Heliotropism
- http://en.wikipedia.org/wiki/Sunlight
- http://plantsinmotion.bio.indiana.edu/plantmotion/movements/tropism/solartrack/solartrack.html

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Thigmotropism

- Movement or growth in response to touch or contact
- Slow movement in vine growth shown later
- Rapid movement in Donkey Trigger Plant

- http://www.gdaywa.com/wildflowers/triggerplants.php
- http://en.wikipedia.org/wiki/Stylidium

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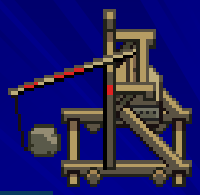
Pollen Ejection

- Dogwood *(Cornus canadensis)*
  - 10,000 Frames Per Second
  - 2000 Gs
  - 4m/s



Smart Design, not Smart Execution

- http://www.williams.edu/Biology/explodingflower/movies.html
- http://en.wikipedia.org/wiki/Cornus_canadensis
- http://the-titan.deviantart.com/art/Trebuchet-90218221?moodonly=24

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Nastic Movements

- Summary
  - Non-directional responses to stimuli

Nastic Movement	Stimuli
Chemonasty	chemicals
Gravinasty	gravity
Hydronasty	moisture or water
Nyctinasty	onset of darkness, circadian clock
Photonasty	lights or colors of light
Thermonasty	temperature
Thigmonasty	touch or contact







- http://en.wikipedia.org/wiki/Nastic_movements
- http://en.wikipedia.org/wiki/Response
- http://en.wikipedia.org/wiki/Stimulus_(physiology)
- http://en.wikipedia.org/wiki/Nyctinasty
- http://en.wikipedia.org/wiki/Circadian_clock
- http://en.wikipedia.org/wiki/Thigmonasty

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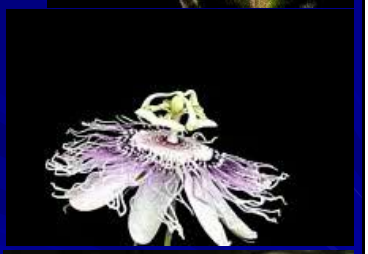
Photonasty

- Non-directional response to (colours of) lights
  - Morning Glory (5am)
- Often combined with Circadian Clocks
  - Passion flower (1pm)
  - Moon Flower (6pm)
  - Cereus (9pm)

- http://plantsinmotion.bio.indiana.edu/plantmotion/flowers/flower.html
- http://en.wikipedia.org/wiki/Moon_Flower
- http://en.wikipedia.org/wiki/Morning_glory
- http://en.wikipedia.org/wiki/Nightblooming_cereus
- http://en.wikipedia.org/wiki/Passion_flower

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Photoperiodism

- Sensing length of days (nights)
- Used by some plants to decide when to flower
  - Long day plants (short nights), e.g., carnation
  - Short day plants (long nights), e.g., strawberry

- How computed?
  - Remember time of night start vs. night end
  - Combine with temperature
    - What's the difference between season start & end?
  - Decision making, memory, representation?

- http://en.wikipedia.org/wiki/Photoperiod
- http://en.wikipedia.org/wiki/Dianthus_caryophyllus
- http://en.wikipedia.org/wiki/Long_day_plant

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Thigmonasty

- Touch response

- Smarter?
  - Plant or
  - Animal
- Note: animal well inside before trap springs

- http://en.wikipedia.org/wiki/Thigmonasty

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Venus Flytrap Counts to 2

- Needs 2 critical touches
- Computationalism?
- Memory?
  - Current Count
  - Elapsed Time
- Representation?
- Aboutness?


- http://plantsinmotion.bio.indiana.edu/plantmotion/movements/nastic/flytrap/flytrap.html

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Thigmonasty - Mimosa

- Two response
  - Leaf closing
  - Action Potential
    - Information?
    - Representation?
    - Aboutness?
- Sense?
  - Perceive?
  - Feel?
  - Conscious?

- http://plantsinmotion.bio.indiana.edu/plantmotion/movements/nastic/mimosa/mimosa.html
- http://en.wikipedia.org/wiki/Thigmonasty

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Nutation

- Active Search
  - Plan?
  - Decision Making?
  - Free Will
  - Learning?
- Nutation: bending motion due to unequal growth, e.g., twining of Morning Glory vines
- When vine touches post, it's tendrils curl around the post via a thigmotropic response (directed towards post)

- http://en.wikipedia.org/wiki/Nutation_in_plants
- http://en.wikipedia.org/wiki/Thigmotropism
- http://biology.kenyon.edu/edwards/project/steffan/b45sv.htm
  - Can be ten times more sensitive to touch than humans

Slide 20

Navigating Environmental Maze

- Branches growing through gaps
  - How to detect in windy locations?
- Good soil exploited
  - Bad soil avoided, rhizome thinned
  - Growth accelerated to find richer patches
- Roots avoid each other
  - Likely by leaving chemical breadcrumbs/cookies
  - An interaction with the environment
  - Extended mind; Epistemic Structures (like ant pheromones)
- Actively forage and explore

- http://aob.oxfordjournals.org/cgi/content/full/92/1/1
- http://www.sce.carleton.ca/~schandra/web/research-theory.html
- http://en.wikipedia.org/wiki/Ants
- http://en.wikipedia.org/wiki/Extended_mind
- http://en.wikipedia.org/wiki/HTTP_cookie
- http://en.wikipedia.org/wiki/Pheromone

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Circadian Rhythm

- E.g., been leaf here, flowering elsewhere
- Entrained by an exogenous (Zeitgeber) cue (light)
- Endogenous process operates after stimuli removed
- Learning? Memory? Intentionality?

- http://plantsinmotion.bio.indiana.edu/plantmotion/movements/leafmovements/bean/beansleep.html
- http://en.wikipedia.org/wiki/Endogeny (internal)
- http://en.wikipedia.org/wiki/Entrainment_(chronobiology) (phase/period alignment)
- http://en.wikipedia.org/wiki/Exogenous (external)
- http://en.wikipedia.org/wiki/Zeitgeber (time giver)

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Plant Communication - Symbiants

- A billion Rhizobia bacteria fix nitrogen in each root nodule of symbiotic legumes
  - Rich set of interactive sign and symbol based two-way communication
  - Biosemiotics: uses terms such as syntax, semantics and pragmatics but with different usage than linguistics. Nevertheless,
- Can plants
  - Understand, Know
  - Have Intentionality?
  - Young kids don't?

- http://en.wikipedia.org/wiki/Bacterium
- http://en.wikipedia.org/wiki/Communication#Plants_and_fungi
- http://en.wikipedia.org/wiki/Biosemiotics
- http://en.wikipedia.org/wiki/Legumes
- http://en.wikipedia.org/wiki/Rhizobia
- http://en.wikipedia.org/wiki/Root_nodule
- http://en.wikipedia.org/wiki/Sign_(semiotics)
- http://en.wikipedia.org/wiki/Symbiosis
- http://en.wikipedia.org/wiki/Symbol
- http://blog.lib.umn.edu/denis036/thisweekinevolution/2007/06/dinosaurfin_soup.html

More info:

- http://www.sciencemag.org/sciext/plantvolatiles/

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Plant-Plant Communication

- Emits volatiles ("pheromones") that warn other plants of herbivory attacks inducing their defences
  - Also attracts herbivore predators & parasites



- http://en.wikipedia.org/wiki/Herbivory
- http://en.wikipedia.org/wiki/Pheromones
- http://en.wikipedia.org/wiki/Volatile
- http://www.sciencemag.org/cgi/content/abstract/311/5762/812
- http://www.plantphysiol.org/cgi/content/full/146/3/818#BIB42
- http://www.pnas.org/content/104/13/5467.abstract

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Plant Decision Making

- Multiple Stimuli
  - Gravitational and mechanical interactions
  - Arabidopsis Root Waving
- Will Overshoot/Undershoot
  - But apply goal oriented error correction (hence cycles)
  - Dynamic control system
- Philosophy
  - What is a decision?
  - Can plants make decisions?
  - Do plants have free will?


- http://aob.oxfordjournals.org/cgi/content/full/92/1/1
- http://www.oeb.harvard.edu/faculty/holbrook/projects/arabidopsis/arabidopsis.htm
- http://www.plantphysiol.org/cgi/content/full/135/3/1822

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Plant Learning

- Plants remember pre-treatments to mild water stress or cold even after stimuli removed

  - Later on, they are more drought or cold resistant
- What is memory?
  - Representation?
- Learn optimal stem thickening due to local wind sway conditions

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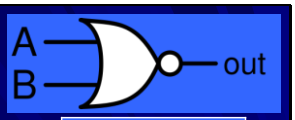
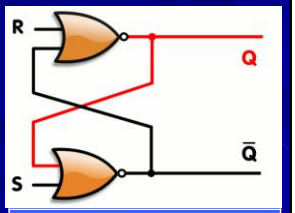
NOR Gate



NOR Gate		
A	B	out+
0	0	1
0	1	0
1	0	0
1	1	0

- The NOR gate is a pure Stimulus-Response element.
  - It's output is completely dependant on its current input.
  - It has no memory
  - Nevertheless, in a flip-flop design permanent memory emerges (much like in circadian rhythms)
  - It is a universal gate and can be configured to implement any computer (Turing Machine)
  - In other words, if the goal of cognitive science is a computational model of the mind, this can be completely expressed via NOR gates
  - i.e., a human is nothing more than a configuration of NOR gates (really not much different than neurons)
- Plants have much Stimulus-Response behaviour, but we have seen more complex patterns emerge as well.
- Perhaps it is time to stop defining intelligence in terms of whether a life form is limited to SR behaviour or not.
- Experimental paradigm tries to control for all factors and manipulate just one. At this point, internal strategies averaged away and you only see a response to a stimuli.



Flip-Flop		
S	R	Q+
0	0	Q (Memory)
0	1	0
1	0	1
1	1	N/A

- http://en.wikipedia.org/wiki/Latch_(electronics)
- http://en.wikipedia.org/wiki/Nor_gate

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Prime References

- The following sources have been greatly used in this presentation
  - http://plantsinmotion.bio.indiana.edu
  - Trewavas, A. (2003) Aspects of Plant Intelligence. Annals of Botany 92:1-20
  - http://en.wikipedia.org
- They and others are diligently annotated in the (hidden) notes.
  - Just click on the hyperlink

- http://en.wikipedia.org/wiki/Hyperlink
- http://plantsinmotion.bio.indiana.edu
- http://en.wikipedia.org
- http://aob.oxfordjournals.org/cgi/content/full/92/1/1

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Questions

- Are you more or less confused?
- Too many animated icons?
  - Imagine plants getting zillions of stimuli continuously and simultaneously. Don't they have to be smart to process all that?
- What have you learned?
- My Research?