Learning and Creativity in the Global Workspace

Geraint A. Wiggins

Professor of Computational Creativity

Queen Mary, University of London

Aim

- An account of the **phenomenon of mind** which is
  - ‣ mechanistic
  - ‣ empirically supported
  - ‣ credible from an evolutionary perspective

- Uniform **generalist** approach
  - ‣ cf. approaches that focus on specific problems in isolation

- Account for
  - ‣ reasoning
  - ‣ imagination
  - ‣ **creativity**

Evolution of predictive cognition

- In the cognitive context, we must be able to tell a story of how something could evolve

- **Prediction** and **Learning** are the central concepts here
  - an organism which can **predict** is better able to manage a dynamic world than one that cannot
  - an organism which can **learn** is better able to predict a dynamic world than one that cannot

- Consequence: **extreme Ockham!**
  - always choose simplest mechanism to account for an effect, unless there is a reason not to

# Requirements for predictive success

- Learning
  - ‣ perceptual inputs
  - ‣ memory
    - ◎ representations

- Generation
  - ‣ predictions
    - ◎ selection mechanism

- Validation/feedback
  - ‣ determine whether predictions were useful
    - ◎ NB. death or serious damage is **not helpful** as a negative example

- Concomitant requirements (hypothetical)
  - ‣ optimisation of memory vs. representation
  - ‣ episodic segmentation of input
  - ‣ regulation of attention (= processing power)
   - ◉ limited, expensive (in energetic and evolutionary terms)

- Consider an organism that has evolved
  - ‣ to predict the next state of the world
  - ‣ to compare the current state of the world with its expectation

- Emotional response to unresolved expectation
  - ‣ unexpected stimulus leads to enhanced arousal

- More generally, tension and, in extremis, anxiety, fear
  - ‣ Anxious organism = cautious organism = safe(r) organism
  - ‣ Anxious organism = organism ready for f(l)ight = safe(r) organism

- Emotional response to unresolved expectation

  ‣ musical tension

Predictive cognition in music: IDyOM
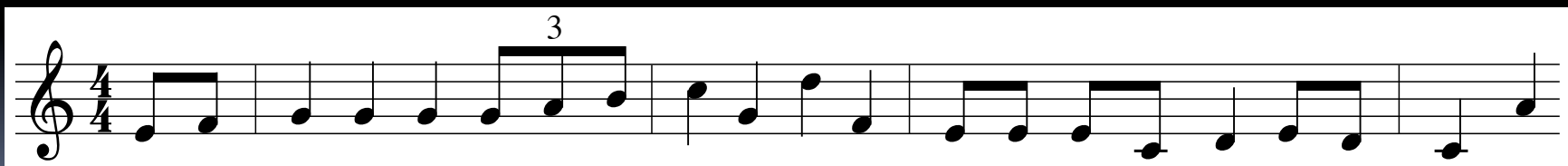
- Middle layer of cognitive model of conscious musical experience

- Designed by Marcus Pearce (2005)

- Unsupervised, implicit learning

- Inputs are sequences of basic percepts
  - notes, with pitch & time features
  - derived percepts, e.g.,
    - interval; tonal centre

- Outputs are
  - distributions of predicted pitches
  - information-theoretic derivatives of distributions

Queen Mary
University of London
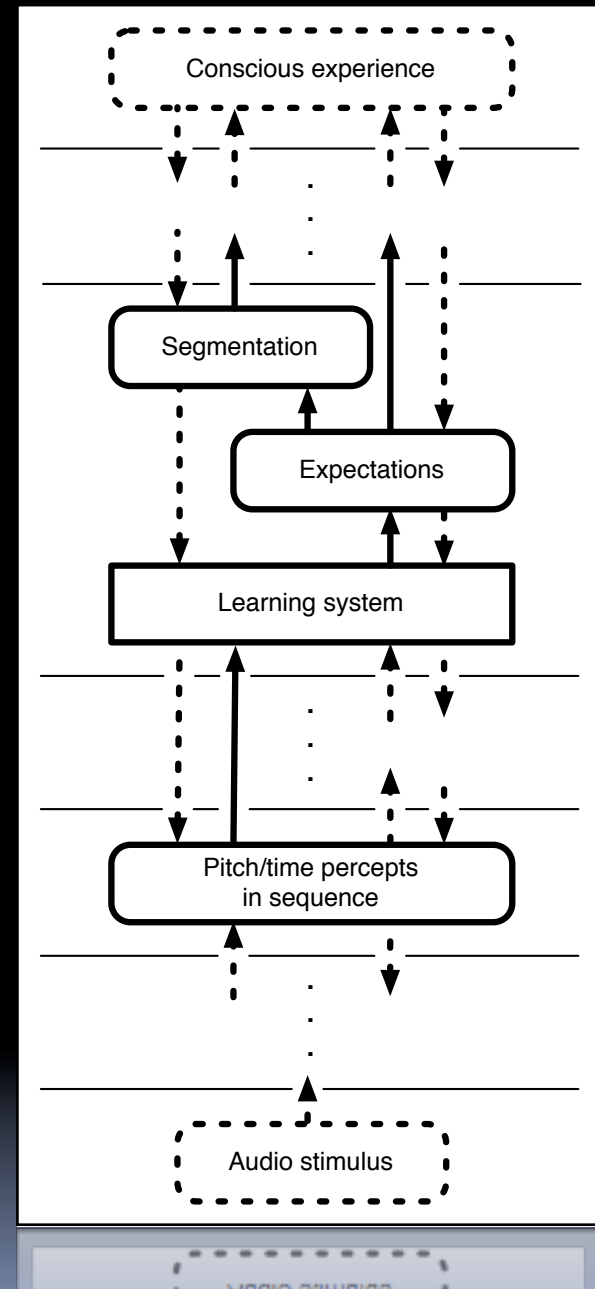
- I use two versions of Shannon's *entropy* measure (MacKay, 2003)

  - the number of bits required to transmit data between a hearer and a listener given a shared data model

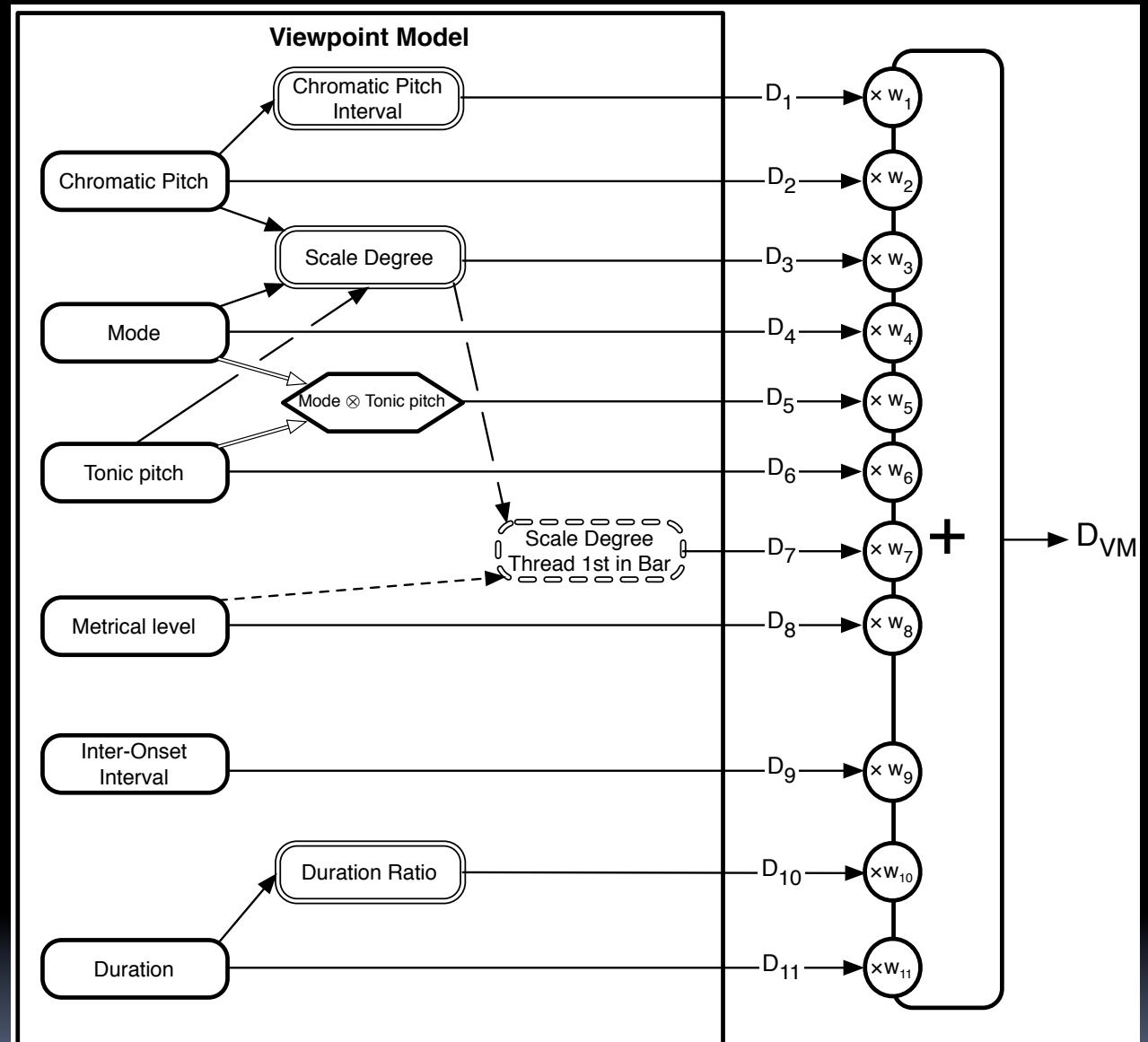 ‣ *information content*: estimated number of bits required to transmit a given symbol as it is received:
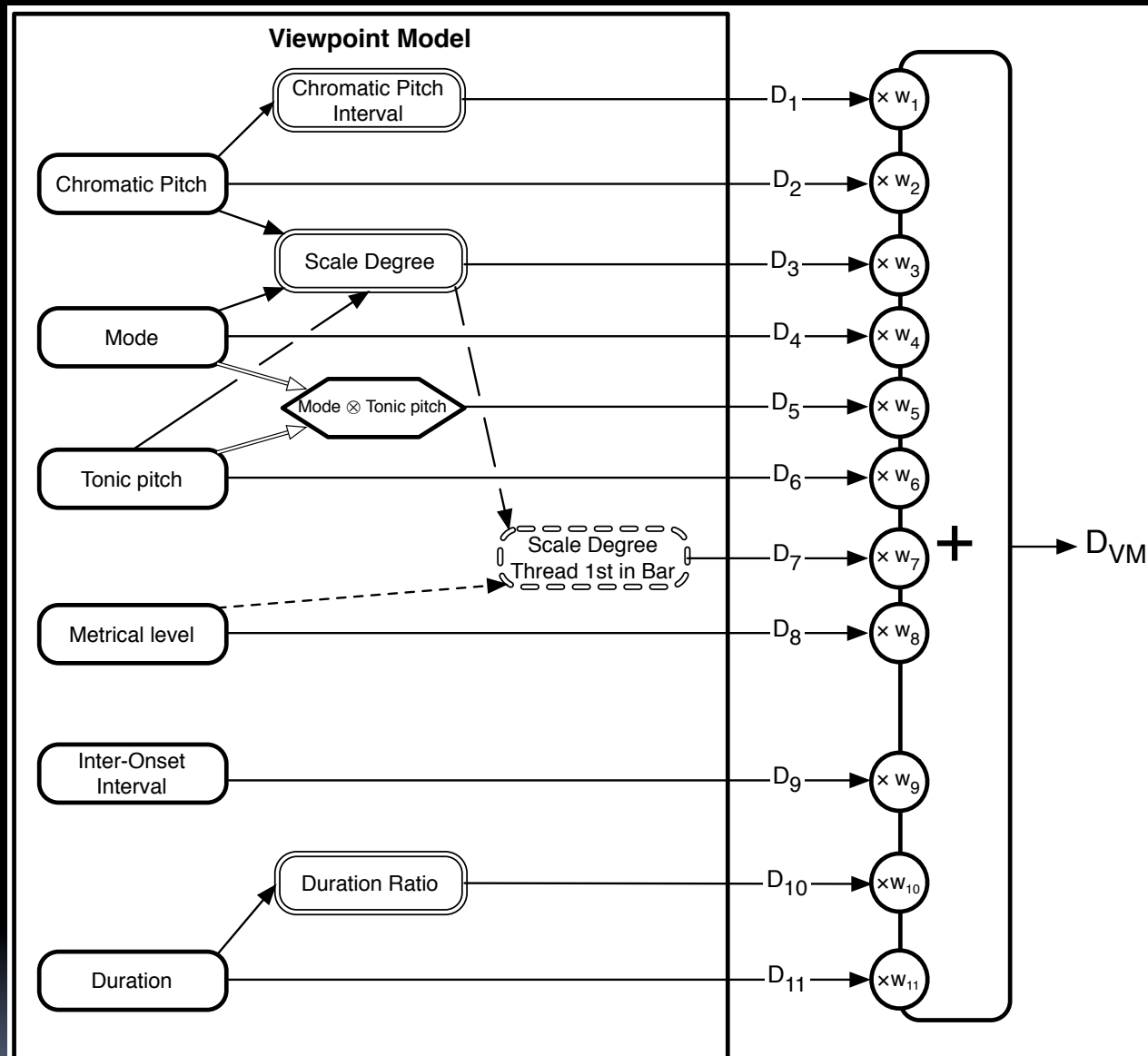
$$h = -\log_2 p_s$$

  - models **unexpectedness**

  ‣ *entropy*: expected value of the number of bits required to transmit a symbol from a given distribution, prior to sending/receipt:

$$H = -\sum_i p_i \log_2 p_i$$

  - models **uncertainty**

  ‣ p_s, p_i are probabilities of symbols; i ranges over all symbols in the alphabet

Information Dynamics of Music

- **Efficient implementation of simple Markov chains**
  - ‣ but with multi-dimensional symbols
  - ‣ select feature sequences (*viewpoints*)
    - ◎ basic
    - ◎ derived
  - ‣ calculus of viewpoints
    - ◎ differentiation (delta)
    - ◎ cross-product (pairing)
    - ◎ thread (sub-sequence selection)

Viewpoint Model

Chromatic Pitch Interval — D_1 → $\times\, w_1$

Chromatic Pitch — D_2 → $\times\, w_2$

Scale Degree — D_3 → $\times\, w_3$

Mode — D_4 → $\times\, w_4$

Mode $\otimes$ Tonic pitch — D_5 → $\times\, w_5$

Tonic pitch — D_6 → $\times\, w_6$

Scale Degree Thread 1st in Bar — D_7 → $\times\, w_7$

Metrical level — D_8 → $\times\, w_8$

Inter-Onset Interval — D_9 → $\times\, w_9$

Duration Ratio — D_{10} → $\times\, w_{10}$

Duration — D_{11} → $\times\, w_{11}$

$+$ → D_{VM}

- Predictions made by
  - matching current context with strings in memory
  - all orders between 0 and maximum available
  - all contribute to final distribution
  - Feature predictions combined as linear sum weighted by entropy

Information Dynamics of Music
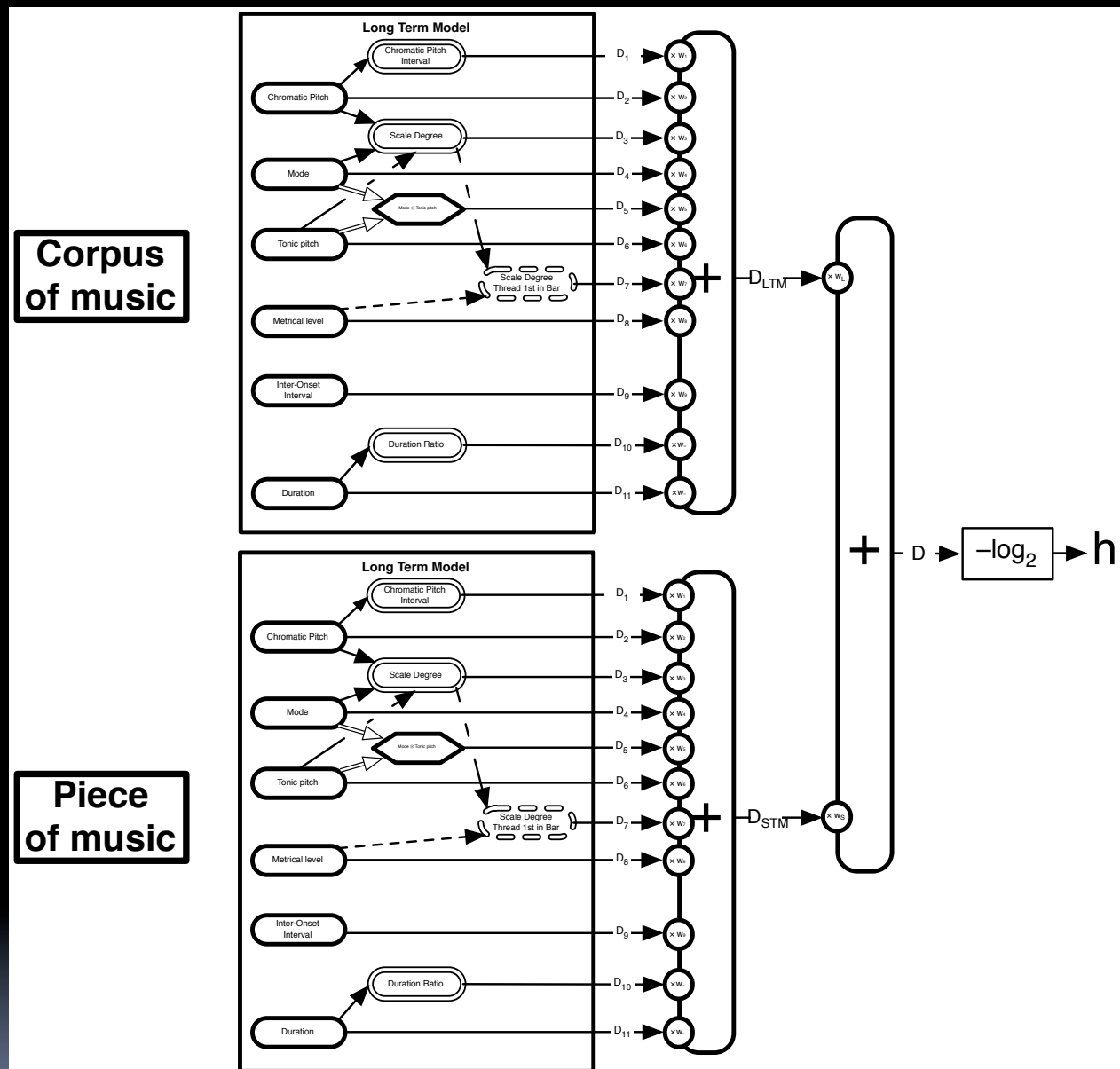
- **Combined outputs of two models**
  - one exposed to corpus of "enculturation" data
  - one exposed only to current melody
  - Combination is by entropic weighting, as before

- **Model is "optimised"**
  - inefficient viewpoints are discarded
  - model with lowest average information content is used

- **IDyOM predicts**
 - ‣ listener's expectations of next note in melody
    - ◎ 4 studies; up to r=.91 correlation
    - ◎ 1 study; very high correlation with musicologists' predictions
  - ‣ melodic segmentation
    - ◎ 2 studies; κ = 0.58
    - ◎ vs musicologist judgements

Information Dynamics of Music

Queen Mary
University of London

- IDyOM predicts
  - listener's expectations of next note in melody
    - 4 studies; up to r=.91 correlation
    - 1 study; very high correlation with musicologists' predictions
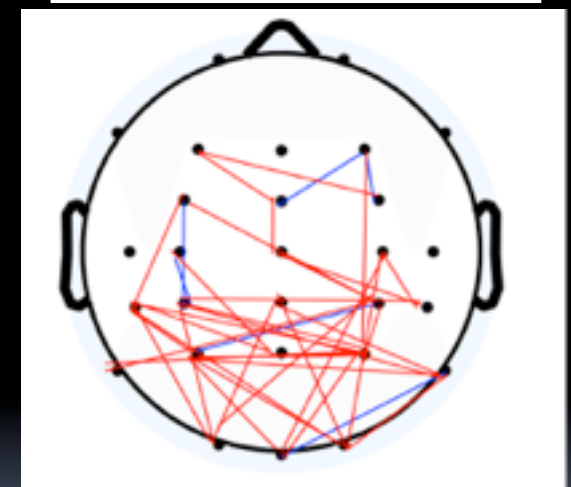 - melodic segmentation
    - 2 studies; κ = 0.58
    - vs musicologist judgements
  - neural activation with unexpectedness
   - centro-parietal region
    - strong sync. in beta-band

Expected Pitch

Unexpected Pitch

Unexpected – Expected

Information Dynamics of Language
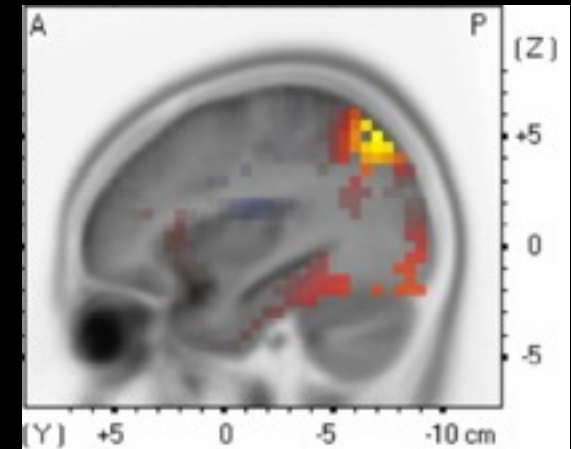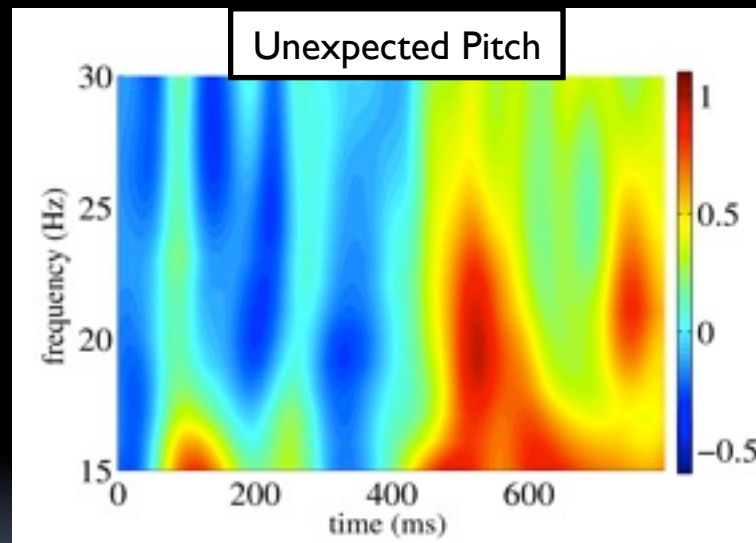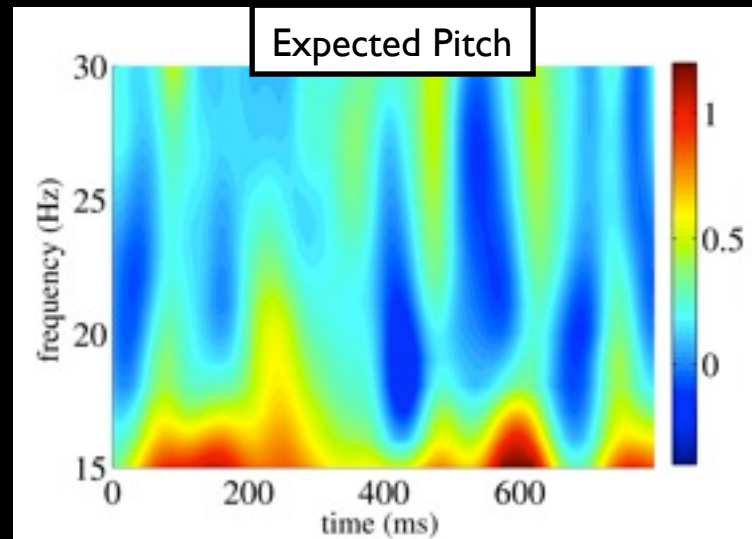
- Replace pitch/time representation with
  - phonetic symbols (quasi IPA)
  - stress symbols (none, weak, strong)
  - try sentence segmentation – expect morphemes or syllables

- Expose model to TIMIT meta-data
  - intended for audio-speech recognition, but just use comparison data
  - compare results with syllable segmentation supplied with TIMIT

# Speech segmentation
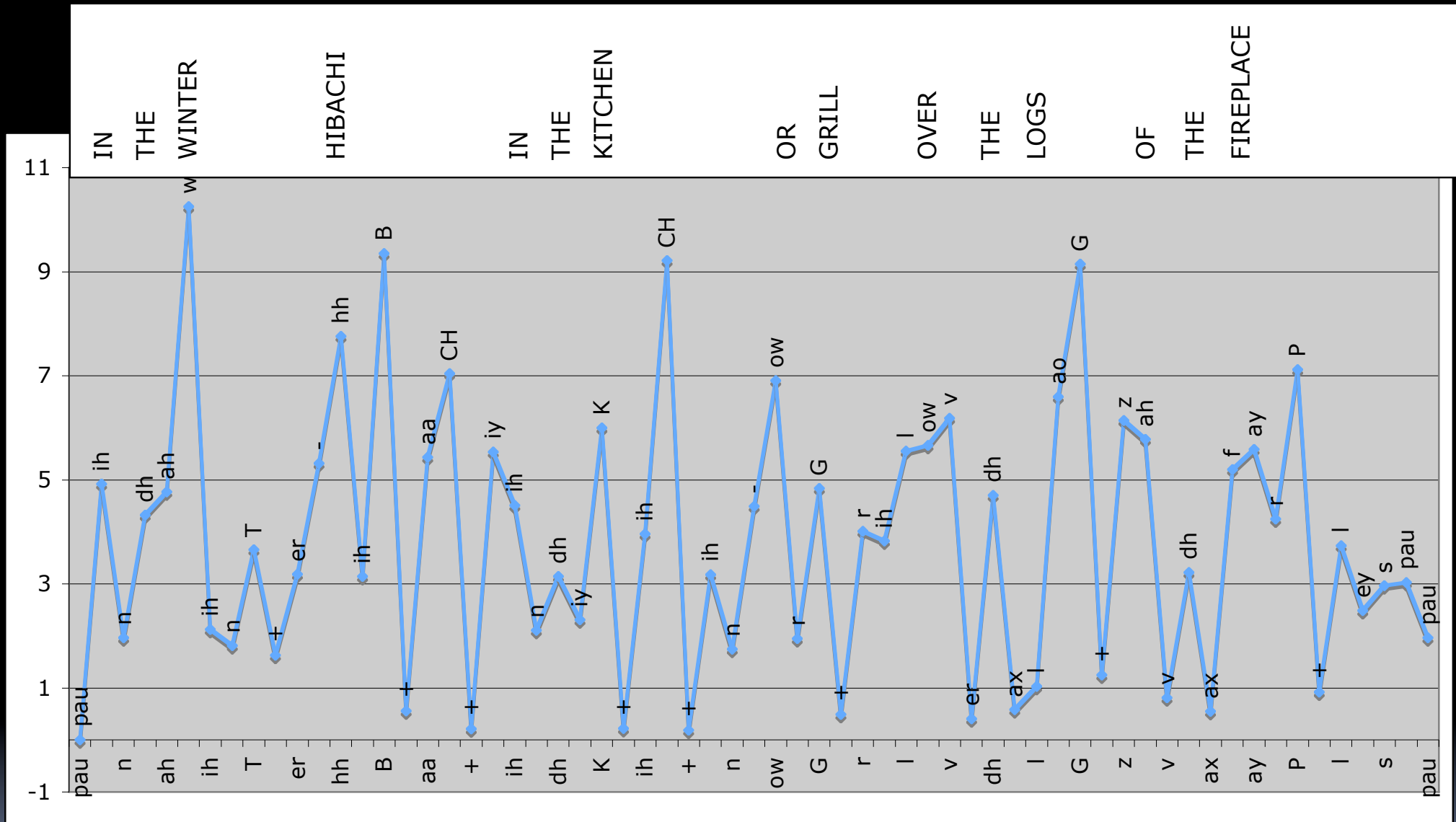
Predictive cognition in general

- Information theoretic properties of data determine perceptual segmentation
  - future work: *exactly* how?

- Information theoretic properties of data determine cognitive representation
  - future work: *exactly* how?

- Need a mechanism by which predictions are made and regulated
  - **Global Workspace Theory**
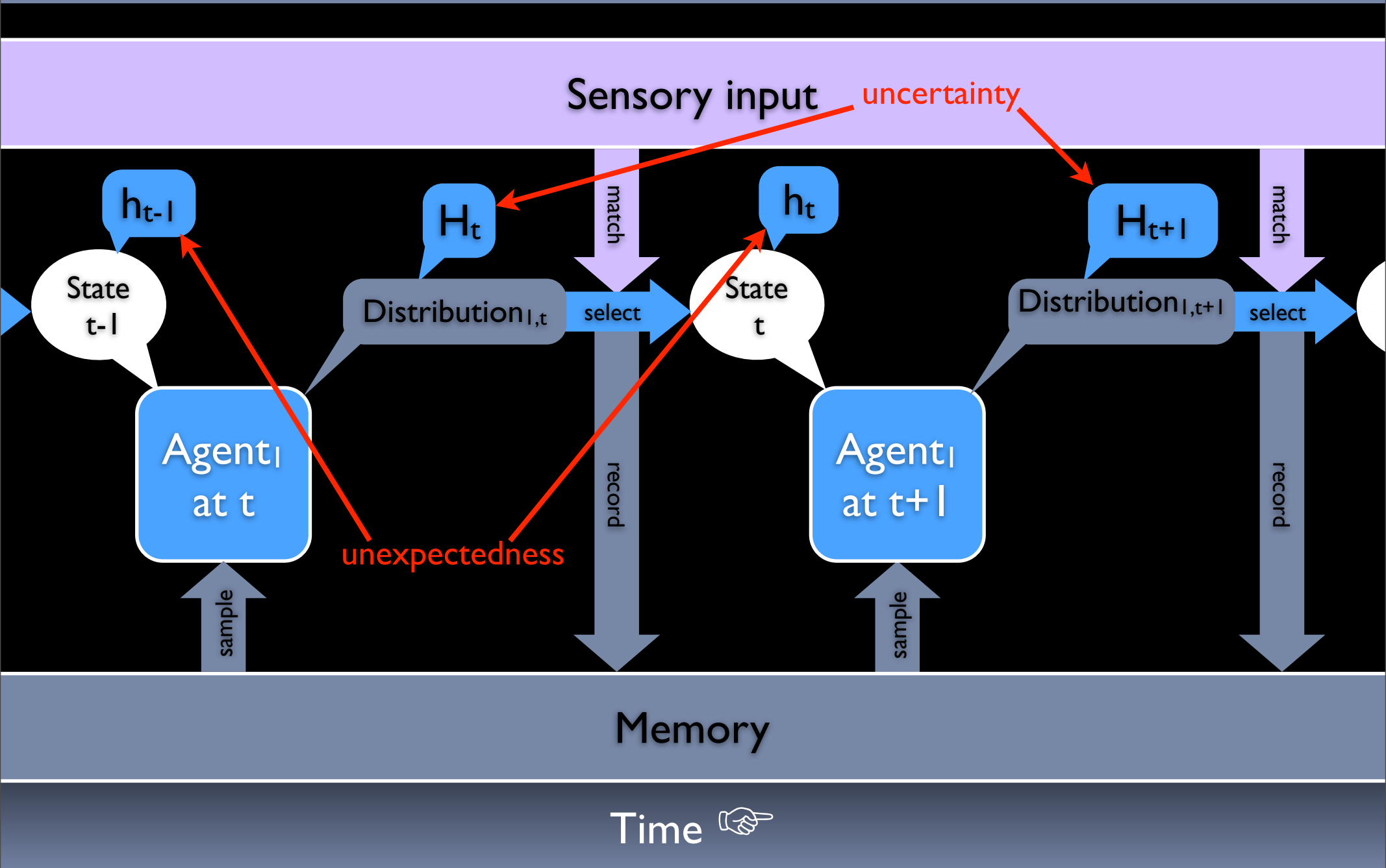 - cf Hippolyte Taine (1871!!)
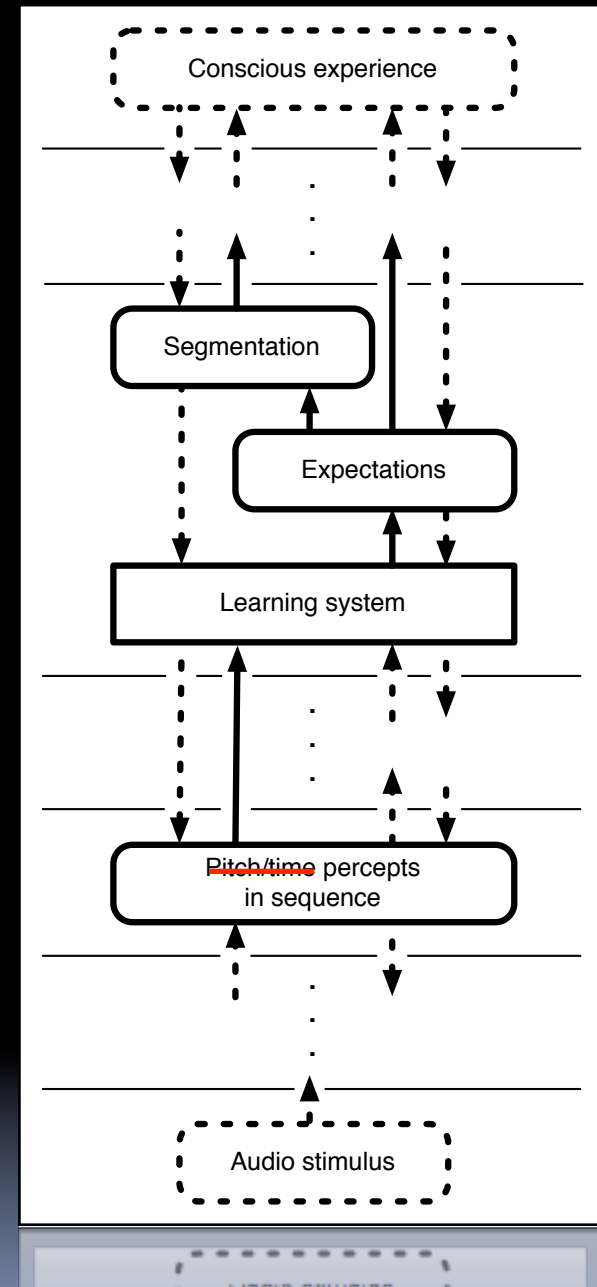
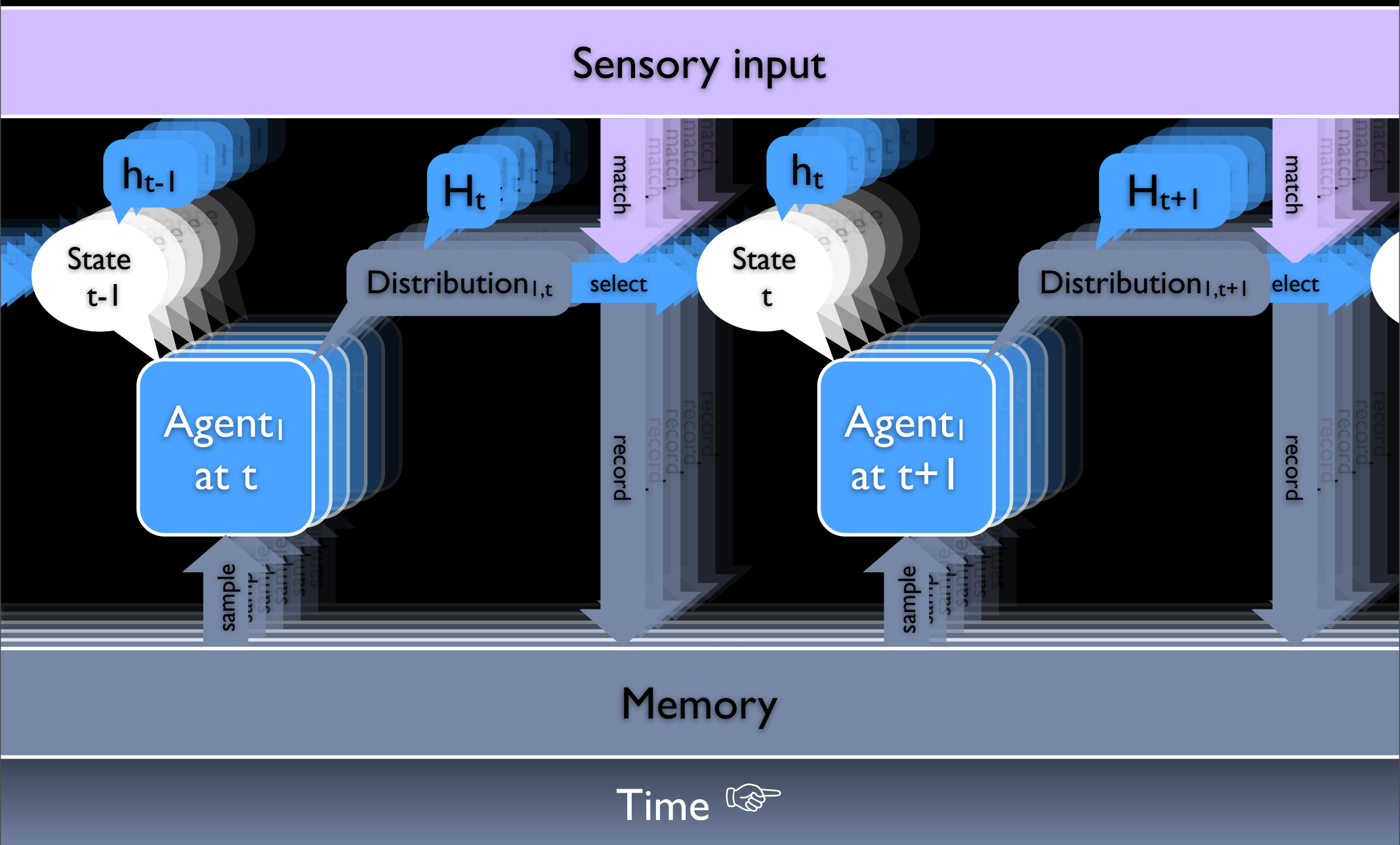# Baars' (1988) Global Workspace Theory
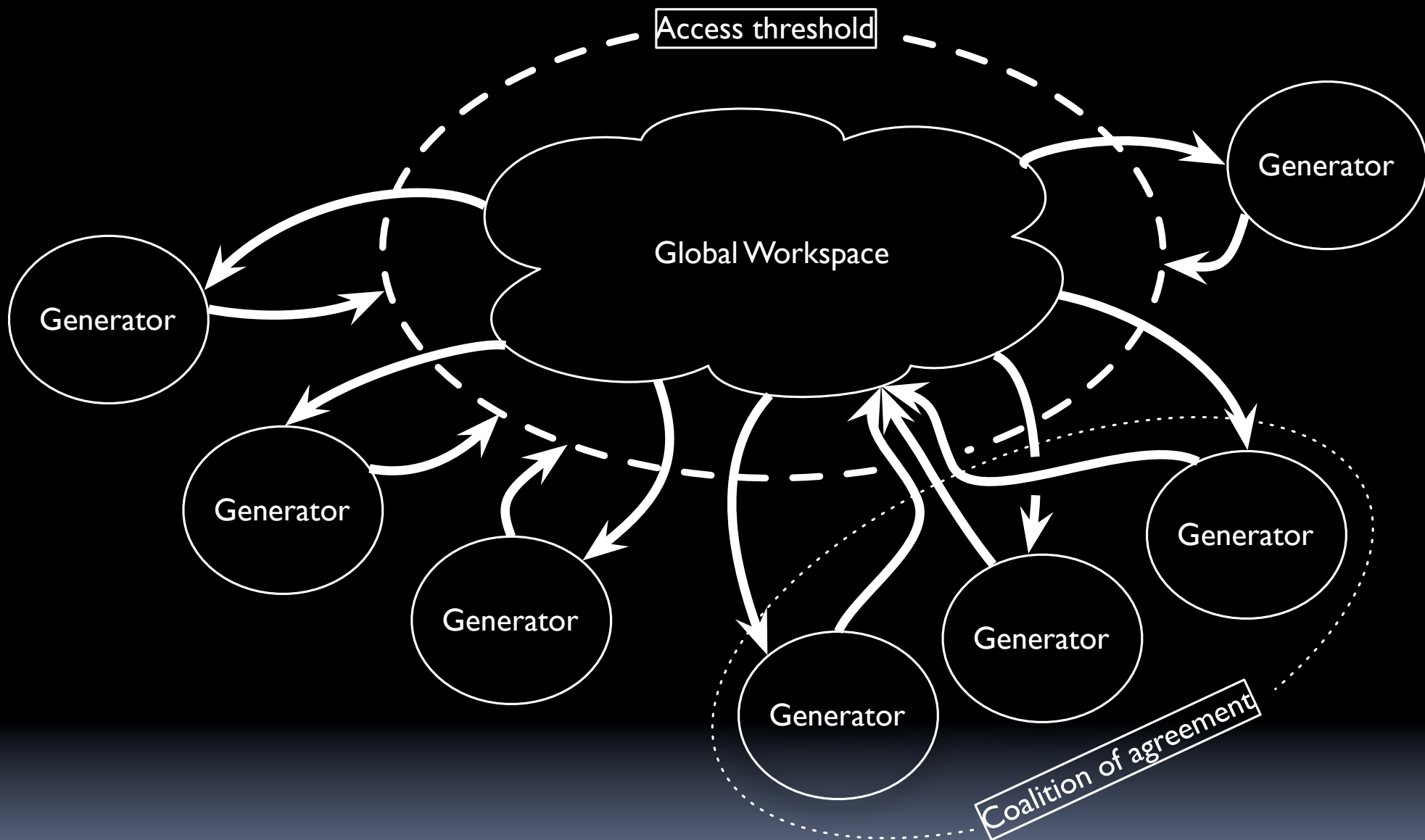
- Compare:
  - ‣ Multiple-agent system communicating via blackboard
  - ‣ Genetic algorithm (breeding replaces blackboard)
  - ‣ Minsky-type Society of Mind (hierarchical management replaced blackboard)
  - ‣ others...

- Neuroscientific evidence for multiple-generator idea
  - ‣ "idling noise" in brain
  - ‣ freewheeling generation when consciousness disengaged
    - ◎ sleeping = dreams
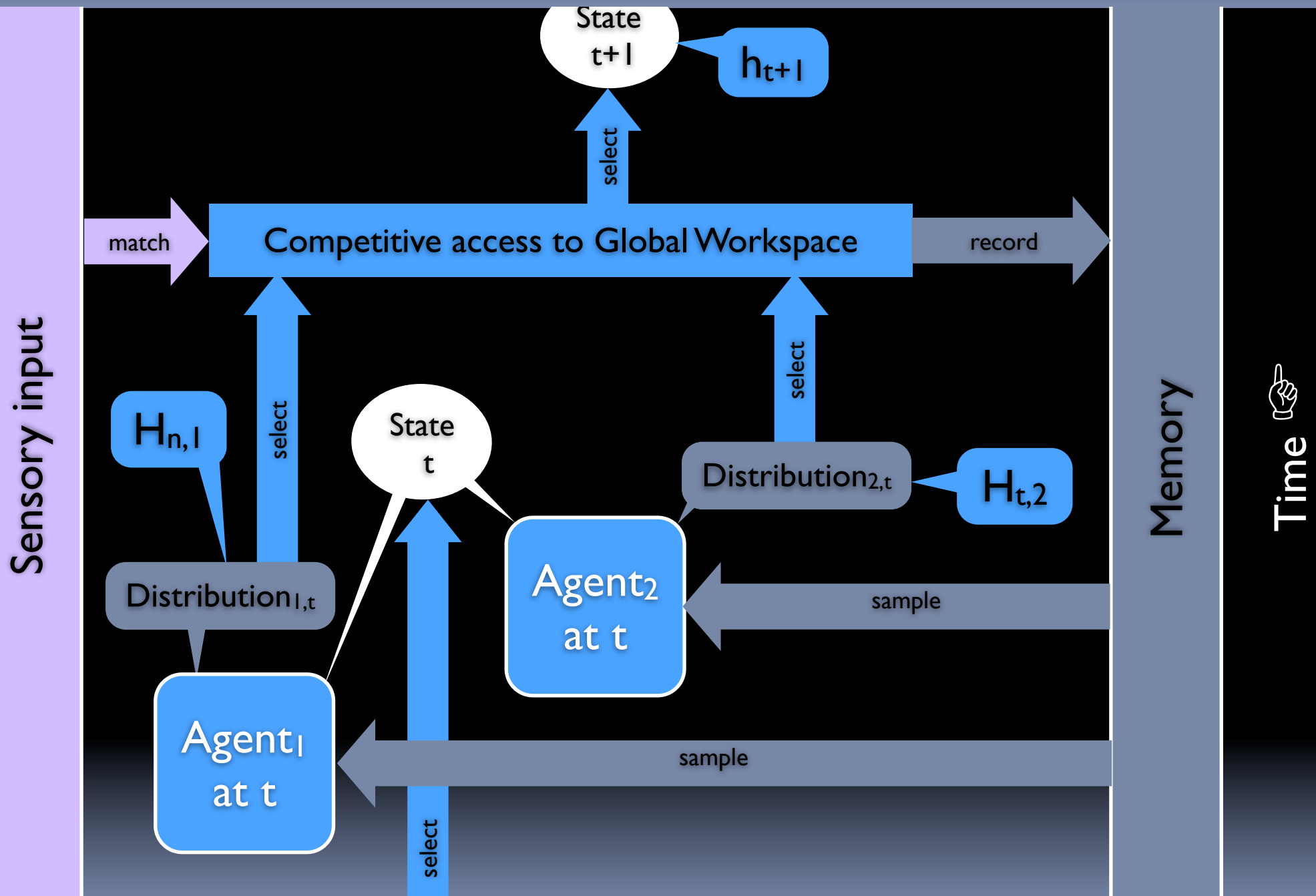   - ◎ high/pathological = hallucinations

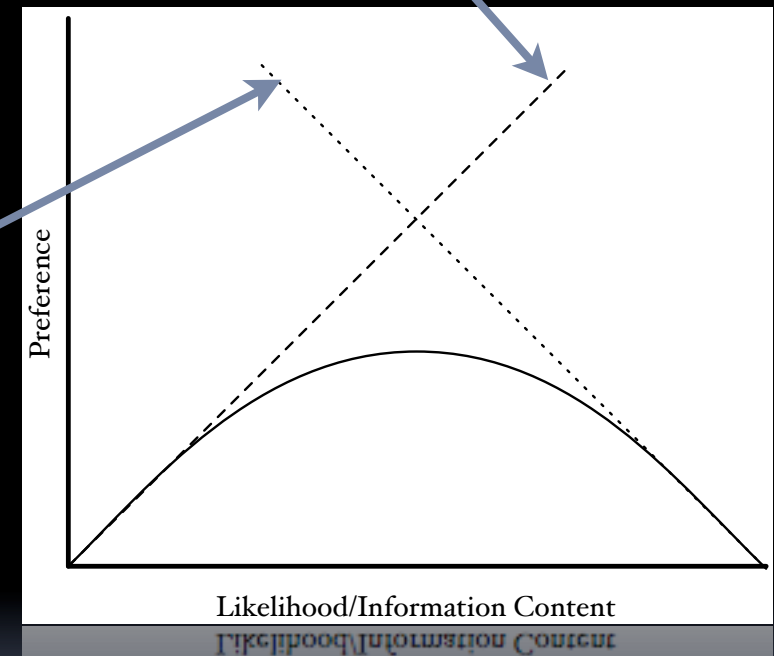# Anticipatory agent

Anticipatory agents

Competitive access to Global Workspace

- Agents produce (musical) structure representations

- Probability of structure (in learned model) increases priority

  ‣ likely structures are generated more often

  ‣ multiple identical predictions are "additive"

  ‣ avoid "recruitment" question in model

    ⊙ need fewer agents?

- Unexpectedness increases priority

  ‣ information content predicts unexpectedness

- Uncertainty decreases priority

  ‣ entropy predicts uncertainty
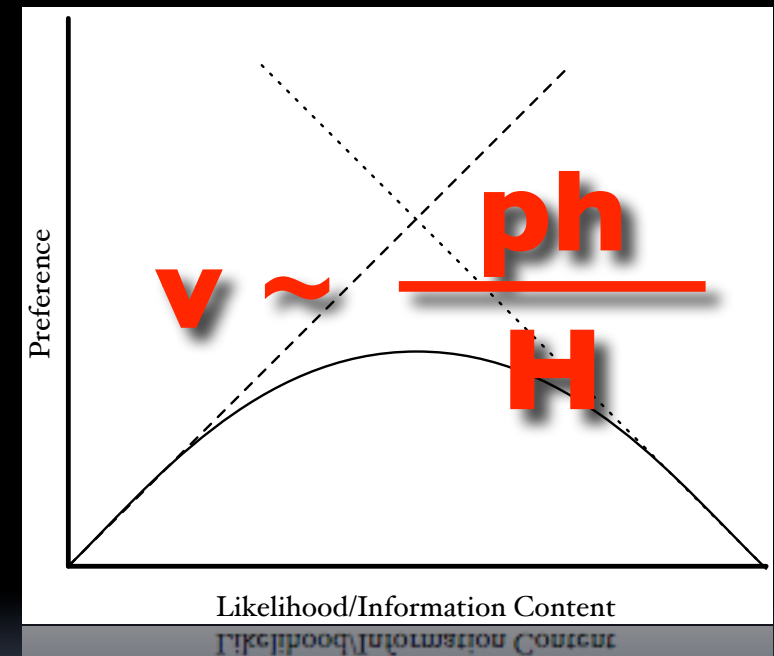
Selecting agent outputs

Competitive access to Global Workspace

- Agents produce (musical) structure representations

- Probability of structure (in learned model) increases priority

  ‣ likely structures are generated more often

  ‣ multiple identical predictions are "additive"

  ‣ avoid "recruitment" question in model

      ◉ need fewer agents?

- Unexpectedness increases priority

  ‣ information content predicts unexpectedness

- Uncertainty decreases priority

  ‣ entropy predicts uncertainty

$$v \sim \frac{ph}{H}$$

Selecting agent outputs

Competitive access to Global Workspace

- Agents produce (musical) structure representations

- Probability of structure (in learned model) increases priority

  - likely structures are generated more often

  - multiple identical predictions are "additive"

  - avoid "recruitment" question in model

    - need fewer agents?

- Unexpectedness increases priority

  - information content predicts unexpectedness

- Uncertainty decreases priority

  - entropy predicts uncertainty

- Predictions matched with sensory input, but can compete without it

$$v \sim \frac{ph}{H}$$

Preference

Likelihood/Information Content

Creativity by default
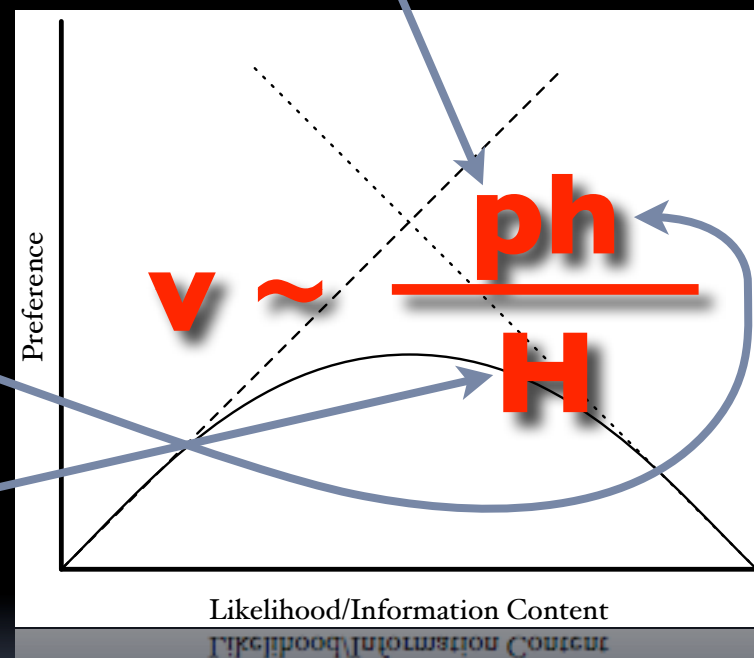
- In the absence of distracting perceptual input, generators freewheel

- Predictions are produced from memory, spontaneously

- Some may be prioritised enough to enter consciousness as "ideas"
  - ‣ cf. Wallas (1926) "illumination"
  - ‣ the "Aha!" moment

- Such ideas can be selected...

Mozart's explanation (Holmes, 2009)

When I am, as it were, completely myself, entirely alone, and of good cheer – say traveling in a carriage, or walking after a good meal, or during the night when I cannot sleep; it is on such occasions that my ideas flow best and most abundantly.   Whence and how they come, I know not; nor can I force them. Those ideas that please me I retain in memory, and am accustomed, as I have been told, to hum them to myself.

All this fires my soul, and provided I am not disturbed, my subject enlarges itself, becomes methodized and defined, and the whole, though it be long, stands almost completed and finished in my mind, so that I can survey it, like a fine picture or a beautiful statue, at a glance.   Nor do I hear in my imagination the parts successively, but I hear them, as it were, all at once.   What a delight this is I cannot tell!   All this inventing, this producing takes place in a pleasing lively dream.   Still the actual hearing of the toutensemble is after all the best. What has been thus produced I do not easily forget, and this is perhaps the best gift I have my Divine Maker to thank for.

- Creativity is a slippery concept in humans
  - ‣ how can we evaluate the model?

- Doing this with music is in a sense easier than with language or other kinds of knowledge
  - ‣ no real-world inference necessary

- **Build the beast and see what it does!**
  - ‣ does it produce novel and interesting (musical) ideas?
  - ‣ does its behaviour match human behaviours,
    - ◉ directly?
    - ◉ tangentially?
  - ‣ use Amabile's (1999) Consensual Assessment Technique to assess creativity and quality of outputs

- Full (long) paper published this week:

  ‣ Wiggins, G.A. (2012) The Mind's Chorus: Creativity before Consciousness. *Cognitive Computation*, 4(3), 306–319.

- International Conference on Computational Creativity

- Sydney, Australia

- 12-14 June 2013

- computationalcreativity.net