Dealing with the unexpected

- Careful Deliberation
  - Deep perceptual processing and inference
  - Planning optimal response
- Rapid Response
  - Less perceptual processing
  - Reactive
- Emotion: Balancing reaction and deliberation processes
  - Biasing, Interrupt, Suppression/competition

Role of the Amygdala in Fear Responses

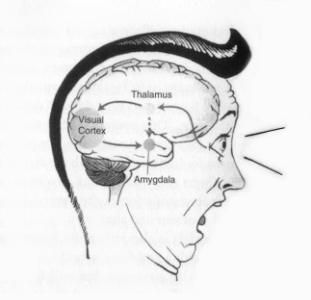


FIGURE 7-3 Visual input to the amygdala.

R F Thompson & S A Madigan, Memory, 2005

Studies of Human Amygdala

- Brain Damage
  - to Amygdala
    - impacts perception of emotional expressions & voices
    - Impacts Fear Conditioning
  - to Hippocampus
    - Impacts fear conditioning to context
- Functional Imaging
  - Fearful/angry faces activate amygdala more than happy ones
  - Fear conditioning leads to increased amygdala activity

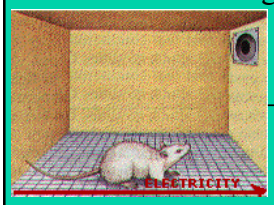
LeDoux's Rat

Fear Conditioning in the Rat (LeDoux)

Background: Classical Conditioning

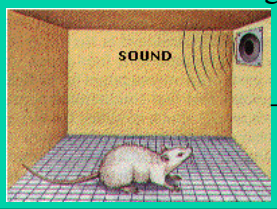
Fear conditioning

Before Conditioning



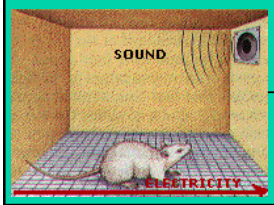
→ Unconditioned Response to electric shock

Before Conditioning



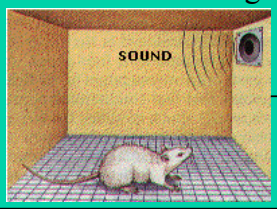
→ No Conditioned Response to neutral stimulus: sound

During Conditioning



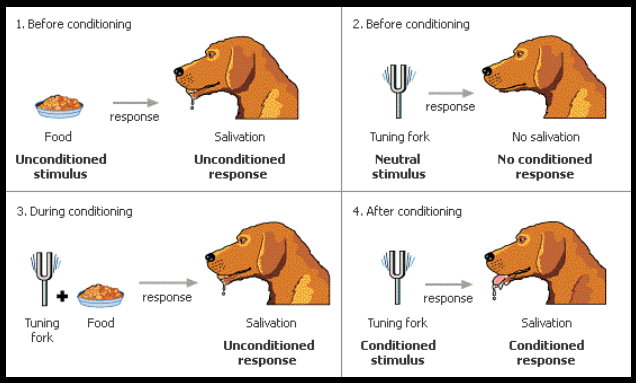
→ Unconditioned Response to shock

After Conditioning



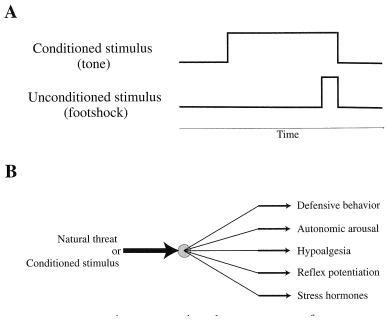
→ Conditioned response to sound

Background: Conditioning

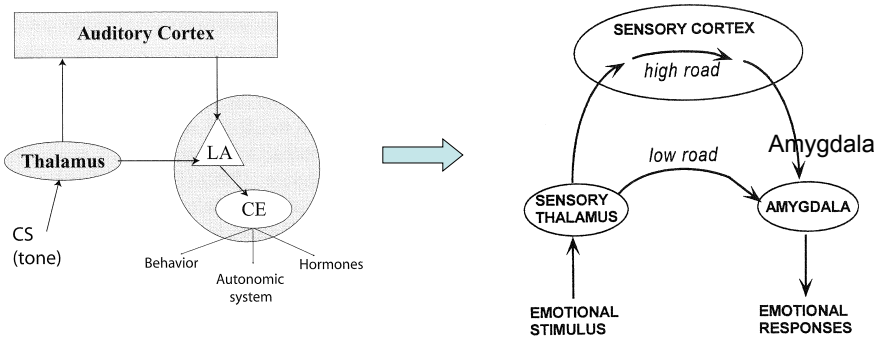


Fear Conditioning

- Neutral stimulus (conditioned stimulus) can acquire affective properties if paired with a biologically significant event (unconditioned stimulus)
- Pair audio tone (conditioned stimulus) with electric shock (unconditioned stimulus)
- Rat eventually learns to react aversively just to tone
- Then study learned pathways and role of various brain regions via
  - Staining of neurons and dissection
  - Impact of lesions on behavior



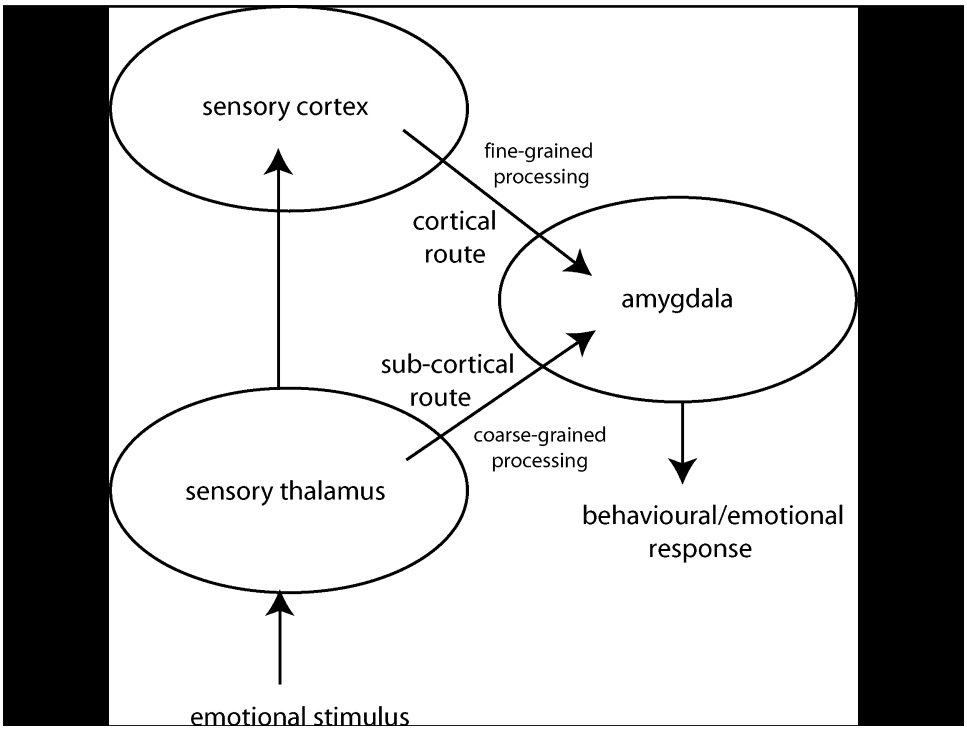
LeDoux's Model of Fear Conditioning: Hi-Lo Roads



- **Low Road**:
  - Thalamus to Amygdala
  - Fast response, shallow processing, pre-attention
- **High Road**:
  - Thalamus to Sensory Cortex to Amygdala
  - Slower response, deeper processing of stimulus in cortex

Key Regions

- Amygdala
  - Forms association of tone with reaction
  - Connects cortical to subcortical (older, reflexive behavior)
- Thalamus
  - Processing of stimuli
- Sensory/Auditory Cortex
  - More sophisticated processing/analysis of stimuli

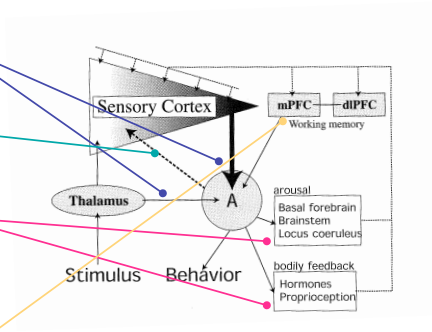


Human Amygdala

Pathways to and from cortical regions

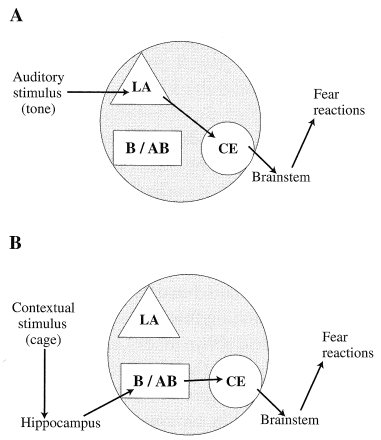
Amygdala once activated by sensory events from thalamus or cortex:

- Regulates cortical areas that project to it
- Influences cortical sensory processing thru arousal networks that innervate cortical areas and bodily feedback that impacts cortical area
- Interacts with medial prefrontal cortex and dorsolateral prefontal cortex that:
  - Influence cognitive function
  - Regulate amygdala



Contextual Fear Conditioning

- Hippocampus also plays role
  - Forms memory representations of different situations.
  - Provides amygdala with contextual information
  - Allows response to be conditioned to given stimulus in given situation.
- Thus emotional reaction will be appropriate for that context
- Example: Rat's fear response elicited when returned to chamber where shock was delivered



Points

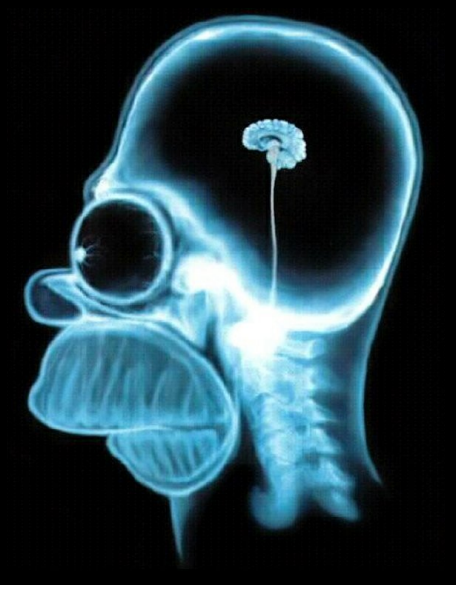
- Emotions involve primitive circuits
  - Preserved across evolution
- Coupling between emotion and cognition circuits is complex
- Components complex
  - Amygdala has 12 centers (nuclei) and sub-nuclei
- Linked to memories
  - Emotional memories persistent
  - Non-emotional can extinguish emotional

Points (cont)

- Parallel routes of processing of emotional stimuli
  - Thalamic-amygdala
    - Fast
    - Not Attention Bound (eg can interrupt – Simon 58)
    - Prepares for response (e.g., ANS and hormones)
  - Cortical-amygdala
    - likely regulates fast route
    - Count to 10
- Separate inputs to emotional eval
  - Fear:
    - Simple stimuli (LA-CE)
    - Complex stimuli (hippocampus-B/AB-CE)

Models

- Improve/test theories of human intelligence
  - Capture "essence" of human emotional processes
  - Criteria for success
    - Falsifiable
    - Generate novel predictions
      - ablate the model
      - Construct novel stimuli
- Improve Artificial Systems



Models

- As a means to test theory…

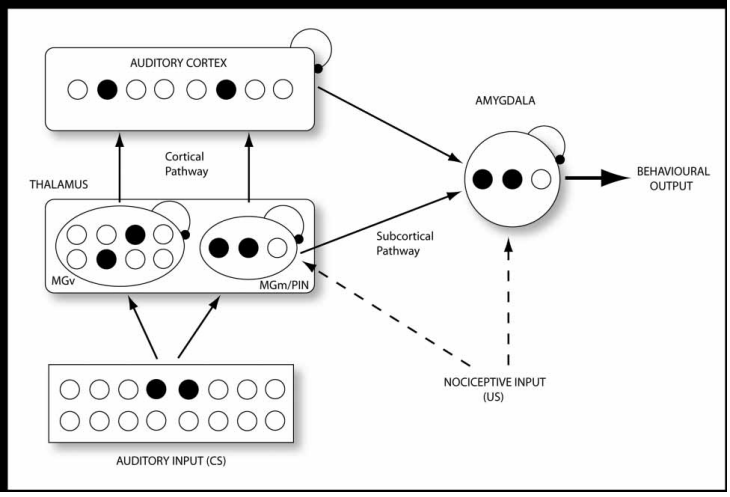
Armony et al. model of fear conditioning

- Anatomically inspired model of the fear circuit
  - Goal: Improve theories of brain function
  - Approach: Connectionist
  - Scope: Modeling specific emotional phenomenon

Armony et al. neural network model

- Set of identical computational units representing neural structures of fear circuit
- Feedforward excitatory connections between modules.
- Units within module inhibitory

Simple Abstract Model
- Attempts to be accurate about information flow
- Not accurate in terms of imformation content/ computation



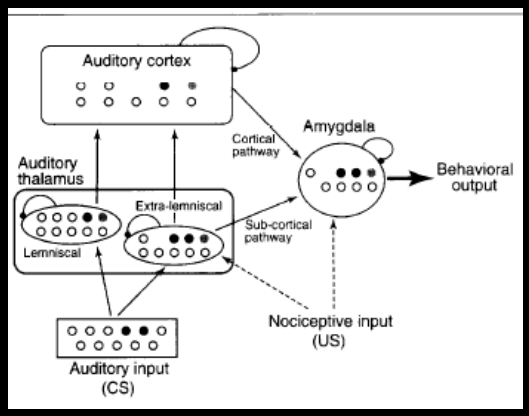
Armony et al. neural network model

- **Development.** All the input patterns were presented in a random order in each epoch, and the network weights were updated following each input presentation.

- **Conditioning.** Following the development phase, the cycle of input pattern presentations was continued, but this time one pattern was chosen as the conditional stimulus (CS) and paired
- with the unconditioned stimulus (US) whenever it was presented.

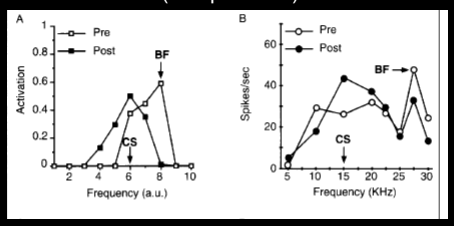
- **Testing**. After both phases, the input patterns were repeated once more (without weight changes or pairing with the unconditioned stimulus) to establish:

1. the RF of each unit;
2. 'behavioural response' – the total activation of all amygdala units following each input interpreted as the degree of behavioural vigour in response to that tone;
3. 'acquisition' – the response of the amygdala units to the conditioned stimulus input;
4. stimulus generalisation gradient (SGG) – the change in behavioural response after the conditioning phase (rats generalise auditory fear conditioning to tones close to the CS in frequency, so the model should show an increase in total activation at and around the CS input).



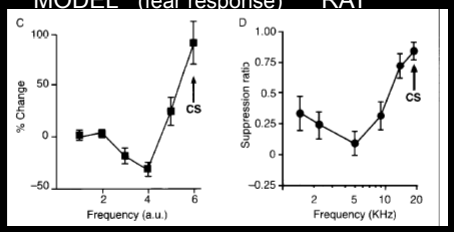
- Validate at single cell & behavioral levels:
  - Is model consistent with data?
- Model and Rats show similar shift in receptive fields after conditioning
- Model and Rats show similar behavioral response

MODEL (receptor field) RAT

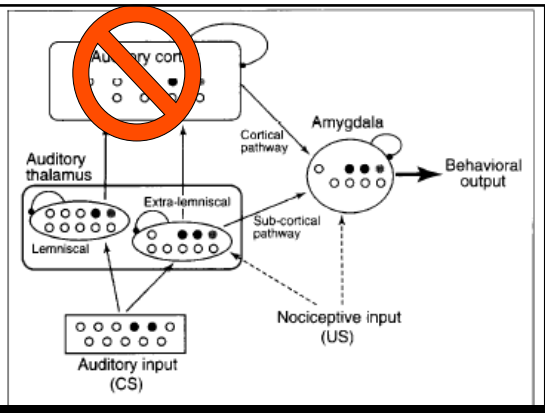


Model and rat behavior before/after conditioning

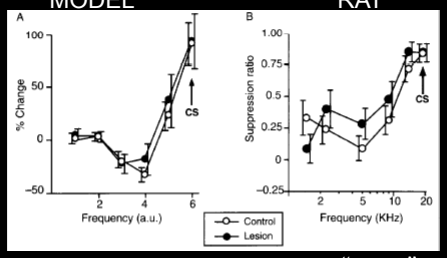
MODEL (fear response) RAT



- Exploration
- "Lesion" model
- Make novel predictions
- Test prediction
- Hypothesis: Predicted receptor field would be less discriminating w/o cortex.
- Both model and Rats showed no deficit
- Argue that thalamus may process more information than they believed
- Perhaps low-road is interrupt mechanism
  - Not subject to attentional filtering
  - In line with Simon



MODEL RAT



Model and rat behavior before/after "lesion"

Functional Points

- Thalamus-Amygdala Pathway
  - Less processing
  - Less selectivity
  - Connection to behavior
  - Perception modified by fear conditioning
- Thru-Cortical Pathway
  - More processing
  - Greater selectivity (more units)
  - Indirect connection to behavior
  - Stability

Methodological Points

- Validate
  - Single cell and behavioral levels
- Then explore
  - Lesion
- Concurrent use of simulation and "empirical"
  - Lesion the auditory cortex in the rat
  - Perception modified by fear conditioning

Critiques/Alternatives

- Lowe , Humphries b & Ziemke: *The dual-route hypothesis: evaluating a neurocomputational model of fear conditioning in rats*
  - Lowe , Humphries b & Ziemke
  - Could reduce amydala to single unit
  - Couldeven reduce network to a single unit
  - What is benefit of dual pathway
- See also Morén, J. and Balkenius, C. *A Computational Model of Emotional Learning in the Amygdala,*