

A Computational Platform for Visual Fear Conditioning

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Motivation



Fear is an important defence mechanism

Sub-conscious priming of the body to react to a threat

Conscious moderation of actions

Adaptive recognition of threats

Can we build an artificial system that can fear?

Test neuroscience hypotheses

Potential for wide application of adaptive threat detection

Relies on low-level sensory processing

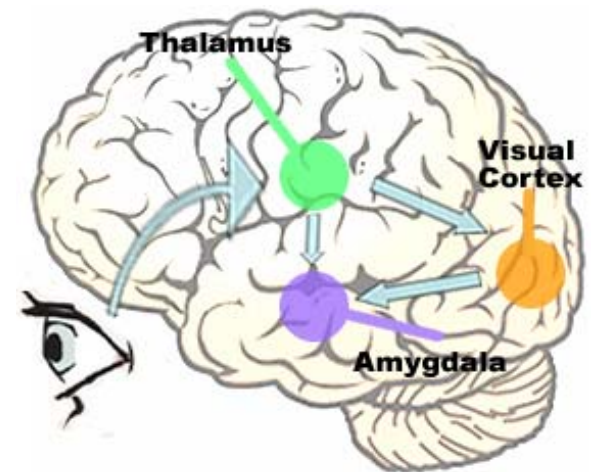
Do we understand sub-cortical processing well enough?

Modelling sub-cortical processing is essential

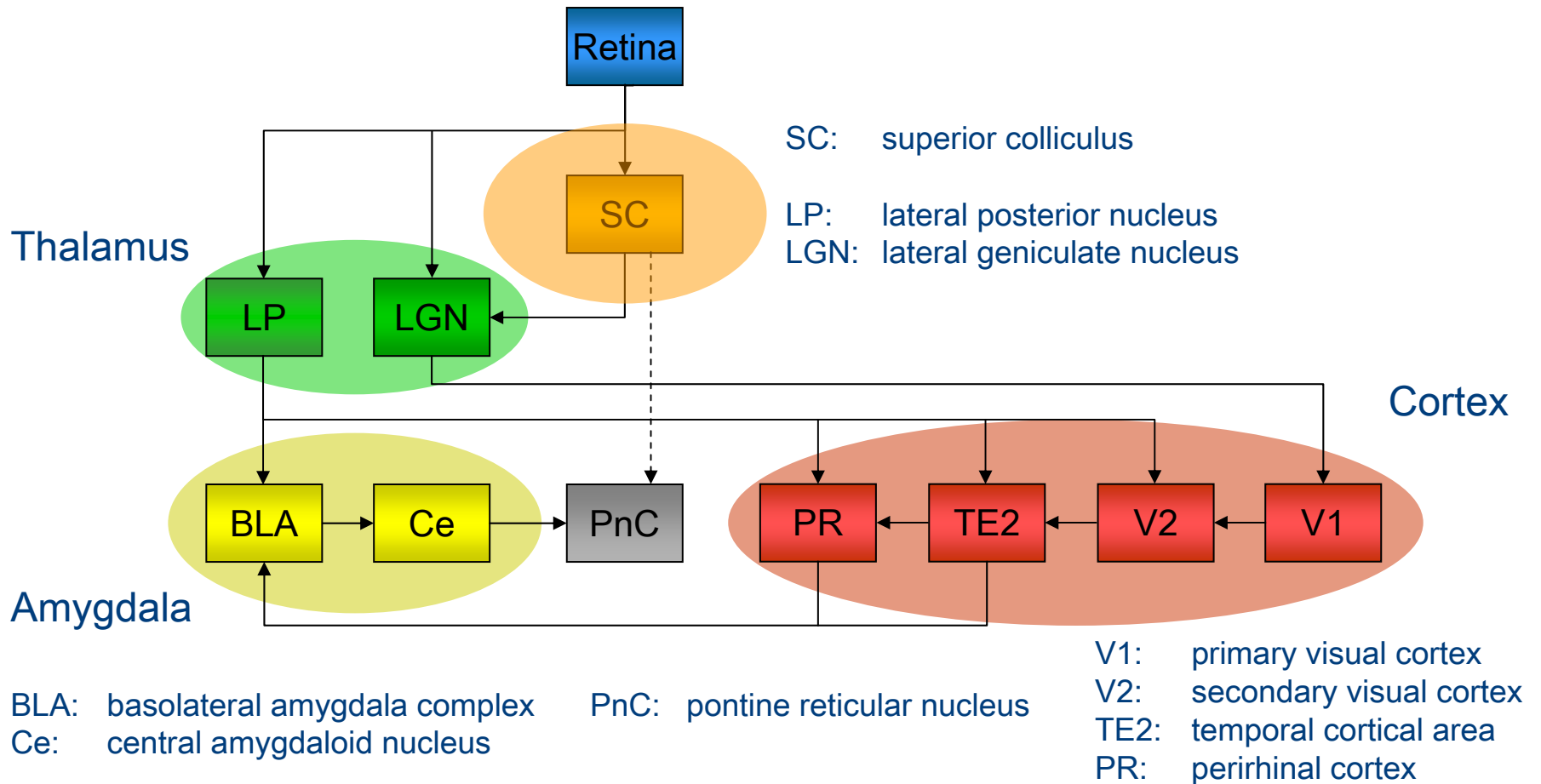


Rough Guide to Fear

- Evaluation of threats performed by the **amygdala** [2]
 - Connectivity explored through behavioral [3], lesion and fMRI studies [4]
- Classical **conditioning** [1] used to explore behavior
 - Pairing together of stimuli to condition behavior
 - Neutral input: conditioned stimulus (CS), e.g. food, lights, faces
 - Aversive input: unconditioned stimulus (US), e.g. foot shock
- Dual **sensory pathways**
 - Auditory well-understood [3, 5]
 - Visual not so well-understood [11]
- Masking and imaging
 - Used to explore **visual pathways** [4, 9]

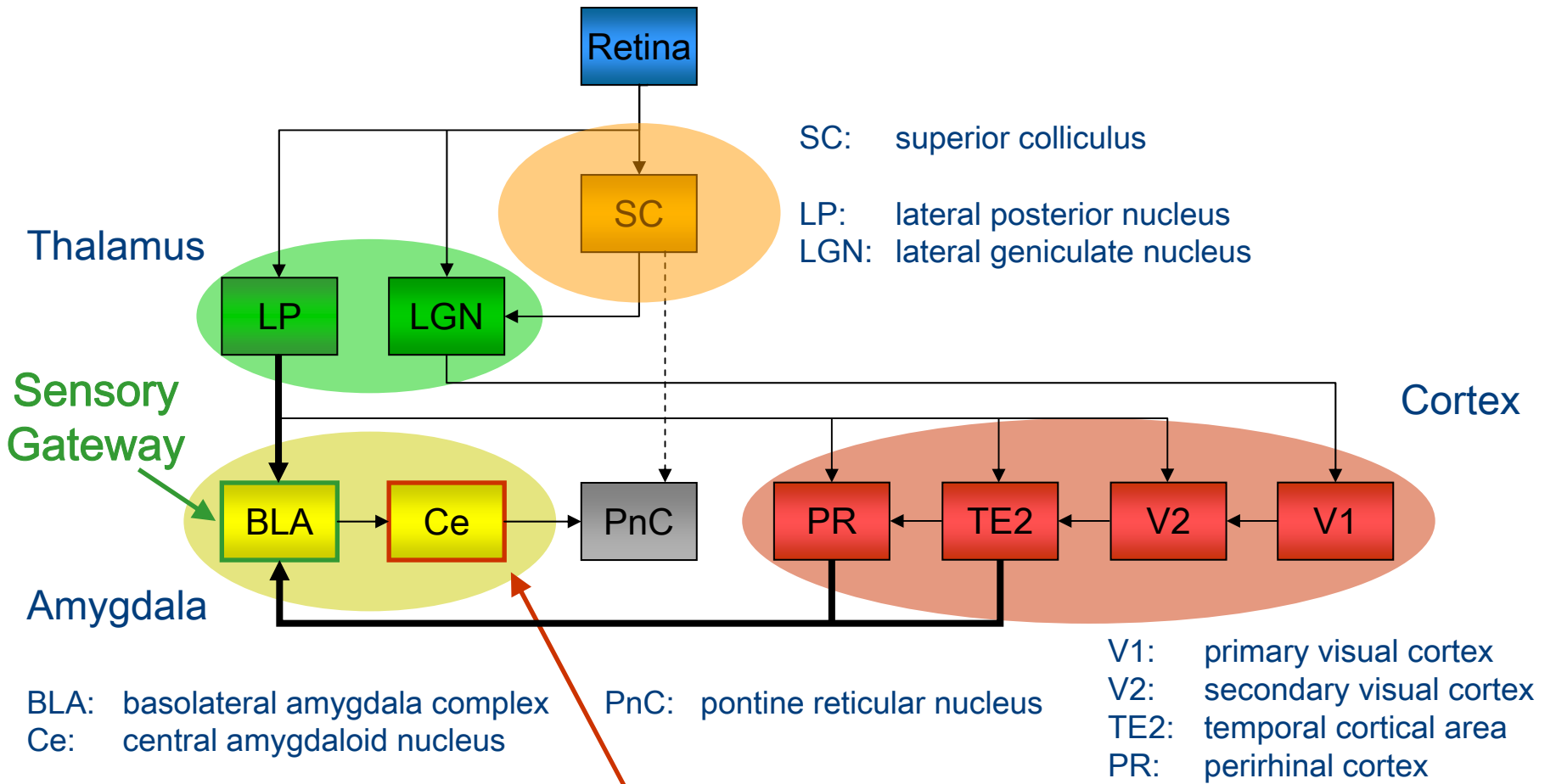


Visual Pathways



Constructed from [11, 21]

Visual Pathways



Threat Reaction
(linked to memory)

Constructed from [11, 21]



Approach

- Armony et al [6] modeled **auditory** pathways
 - 1-d input representing auditory frequency
 - Series of connected modules, each with 1-d layer of neurons
 - Winner-take-all Hebbian learning (cf. [16]) with conditioning
 - Successfully used to evaluate pathways [20]
 - But not capable of scaling up to visual stimuli
- We extended this for **visual** input [12]
 - 2-d input representing visual stimuli
 - Series of connected modules, but with a 2-d map of neurons
 - Lateral inhibition through neighborhoods (cf. [18])
 - Forms topographic maps through receptive fields (cf. [13, 14])
- Explore the visual pathways through **masking**
 - Traditional psychophysics technique for exploring sub-conscious
 - Rate-coding: introduce a **time delay** in the input: mask and target



Topographic Conditioning Maps



- Neuron output

$$u_{ij} = \sum_{k=1}^m x_k w_{kij}(t),$$

$$y_{ij} = \begin{cases} f(u_{ij}) & \text{if } \|c_{ij} - c_{win}\| < h(t) \\ f(u_{ij} - y_{win}) & \text{otherwise} \end{cases}$$

$$f(u) = \begin{cases} 1 & u \geq 1 \\ u & 0 < u < 1 \\ 0 & u \leq 0 \end{cases},$$

- Weight update (normalised Hebbian)

$$w'_{kij}(t+1) = w_{kij}(t) + \epsilon(t)x_k y_{ij}$$

$$w_{kij}(t+1) = \frac{w'_{kij}(t+1)}{\sum_{l=1}^m w'_{lij}(t+1)}$$

- Neighbourhood and learning rate decrease

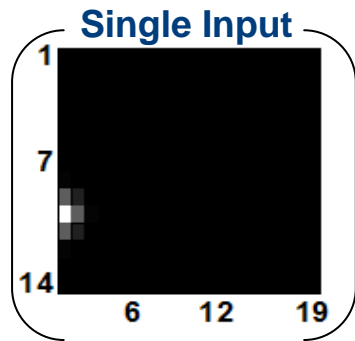
$$h(t) = r_{min} + (r_{max} - r_{min})e^{-\left(\frac{(t/t_e)^2}{2r_s^2}\right)}$$

$$\epsilon(t) = l_{min} + (l_{max} - l_{min})e^{-\left(\frac{(t/t_e)}{2l_s^2}\right)}$$

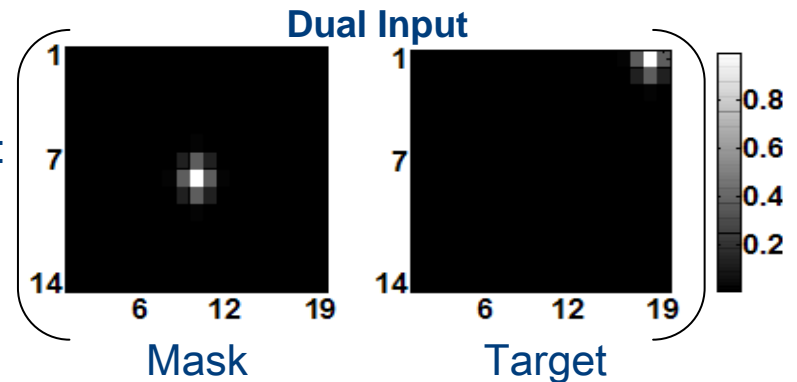
Input Representation

- Abstract stimuli to test organisation and conditioning
 - Visual scene representing a single stimulus at intervals of 10°
 - Locations vary with azimuth $[-90^\circ, 90^\circ]$ and elevation $[-65^\circ, 65^\circ]$
 - 266 possible inputs in a 14 by 19 grid

Experiment 1:
Organisation and
Conditioning



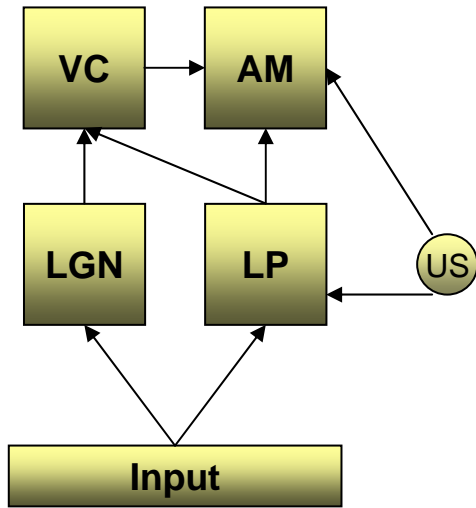
Experiment 2:
Masking



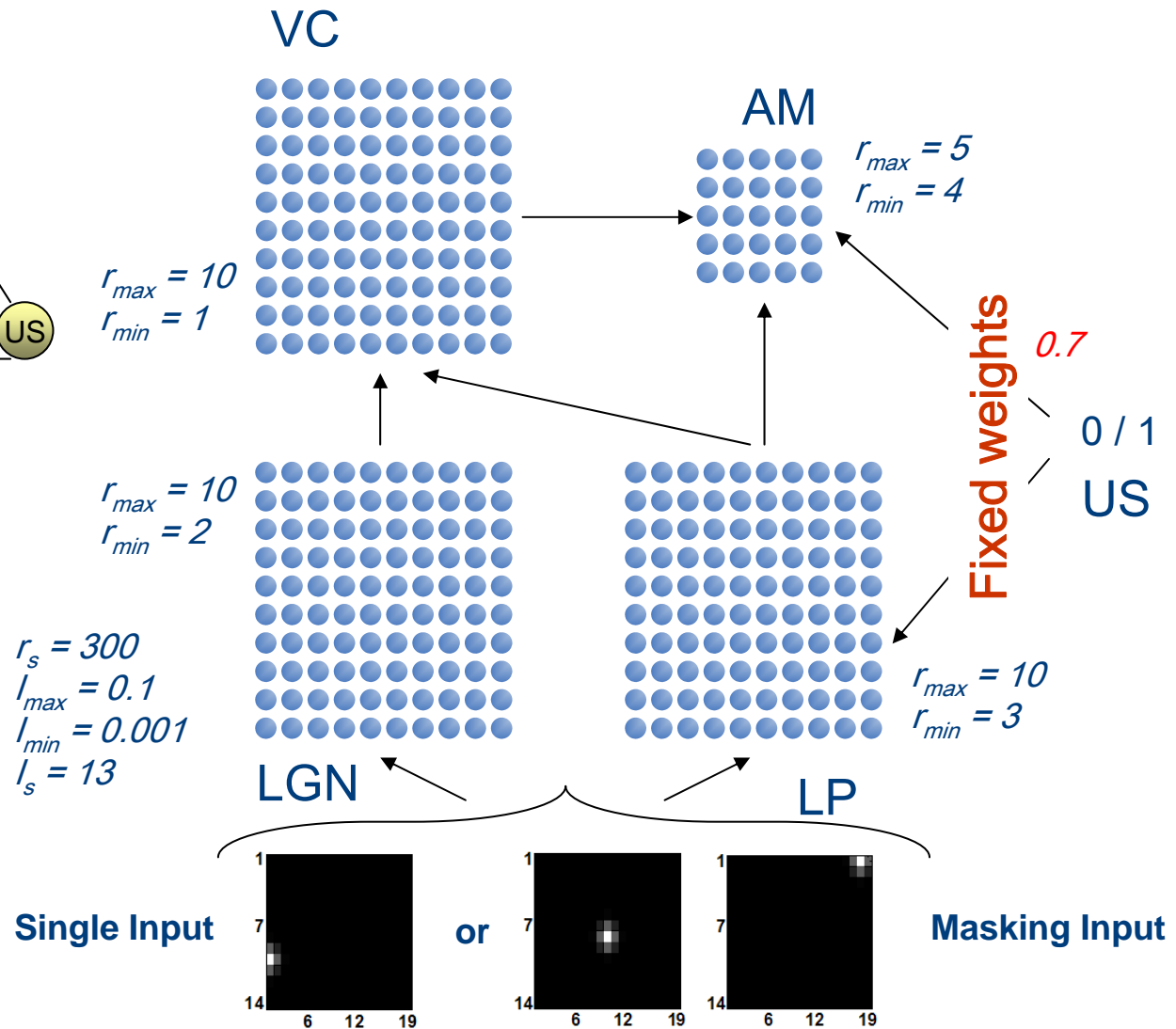
- Input x is a Gaussian at elevation i and azimuth j , where $\lambda = 1$, $\sigma = 10$

$$x_{ij} = \lambda e^{-\left(\frac{i^2 + j^2}{\sigma^2}\right)}$$

Model

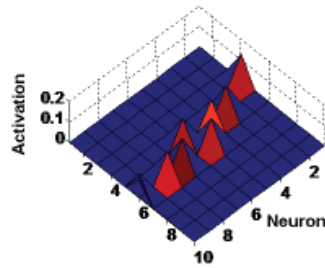
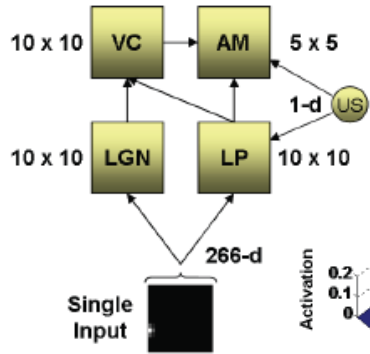


- Pre-conditioning:
- Trained for 700 epochs
- Post-conditioning:
- Trained for 530 epochs

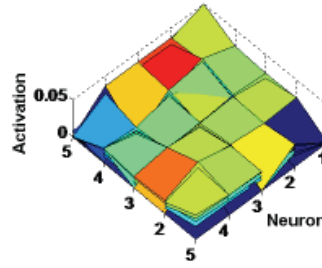


Evaluation: Organisation and Conditioning

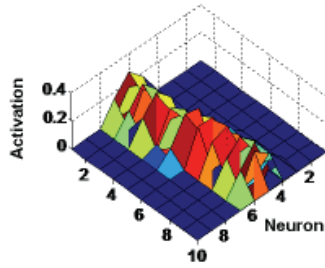
Pre-conditioning



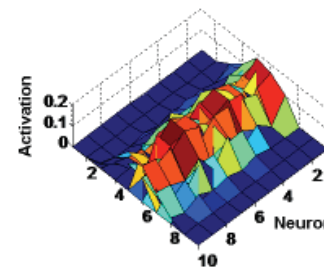
a) VC



b) AM

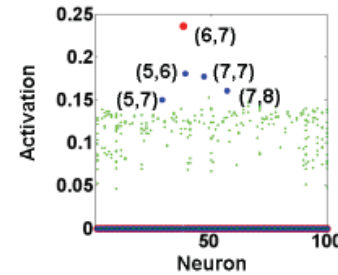


c) LGN

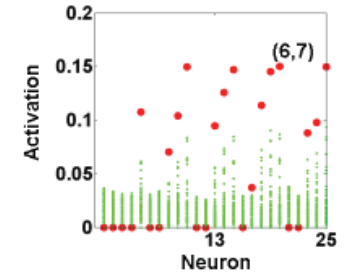


d) LP

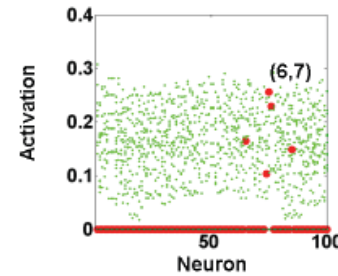
Post-conditioning on input (6, 7)



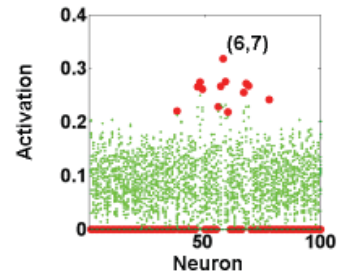
a) VC



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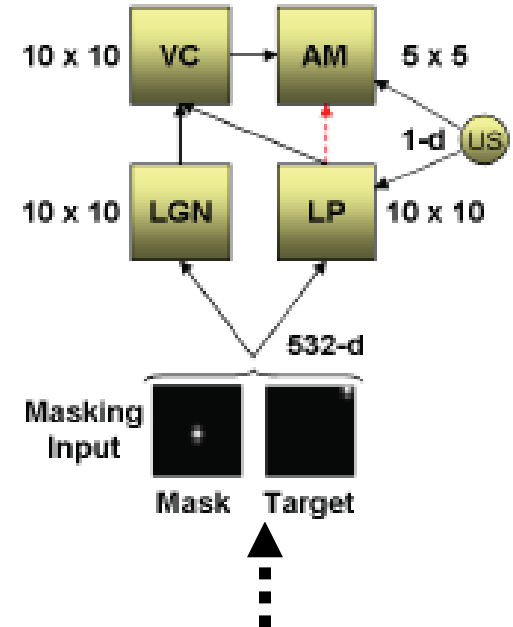


d) LP

- Topographic representation (for example, azimuth 0 and elevation [-65, 65])
- Co-ordinate alignment (LGN & LP to VC)
- Increased conditioned activation (with neighbors varying by radius)

Evaluation: Masking

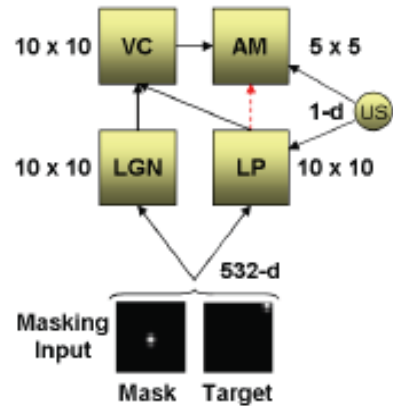
- Morris et al [9]:
 - Tested the existence of the sub-cortical pathway
 - Is there a response to a target even though it is not consciously perceived (**masked**)?
- Model
 - Contrast between the amygdala and cortex
 - What effect does the **direct connection** between the LP and the AM have?
- Two separate topologies
 - **With** direct connection from LP to AM
 - **Without** direct connection from LP to AM
 - Both trained from scratch
- Training and testing in accordance to Morris et al
 - **Habituation**: training on all inputs in identical pairs
 - **Conditioning**: continue training with US on subset
 - **Testing**: present unique **mask-target** pairings



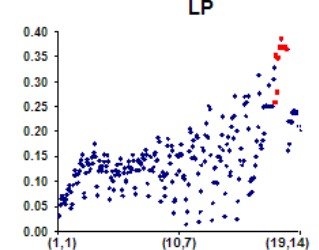
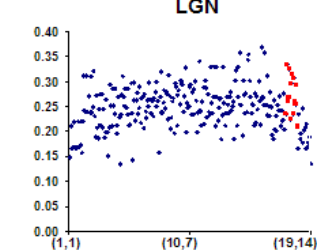
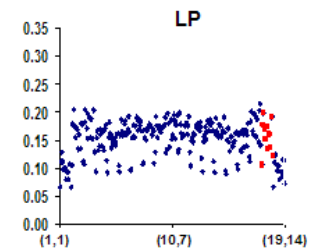
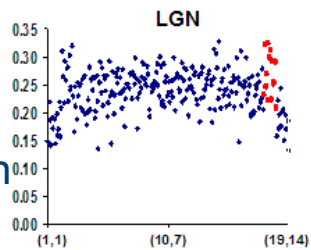
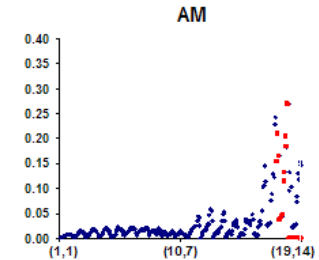
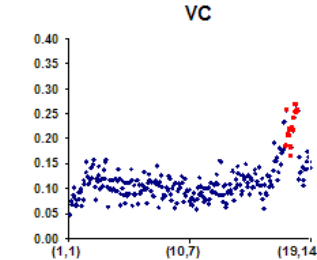
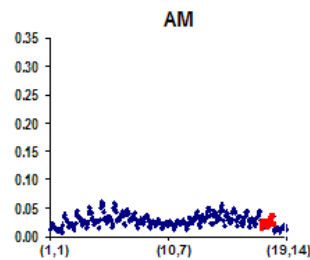
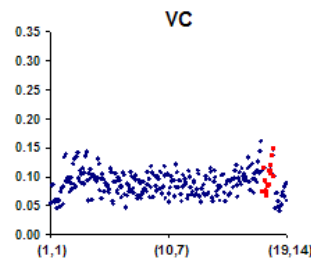
Example Mask-Target [9]



Habituation and Conditioning



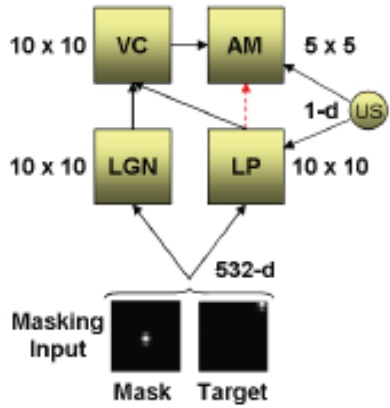
Habituation



Mask-mask or
target-target pairs:
maximum activation

- Maximum activation values for each of the 266 input stimuli
- Red dots correspond to the strip of 14 CS input pairs from (18,1) to (18, 14)
- Multiple conditioned stimuli
- Prior to conditioning, the AM activations of the CS do not show any increase
- After conditioning, the AM activations are higher for the CS

Masking

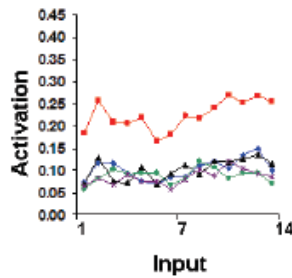


- ◆ Target: after habituation
- Target: after conditioning
- ▲ Mask-Target
- Mask: after habituation
- ✱ Mask: after conditioning

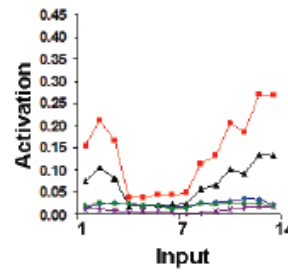
Mask-target pairs:
maximum activation

With LP to AM

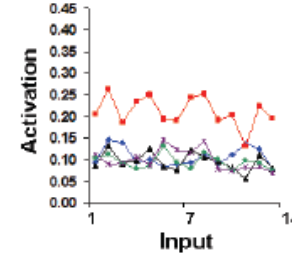
Without LP to AM



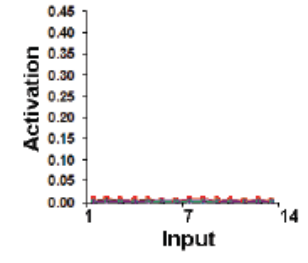
a) VC



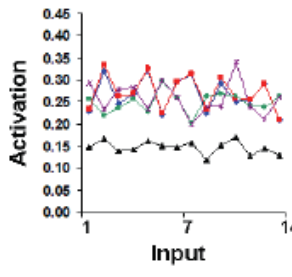
b) AM



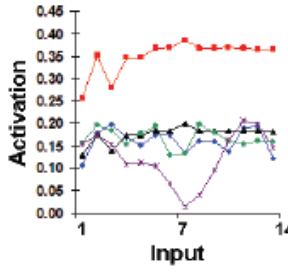
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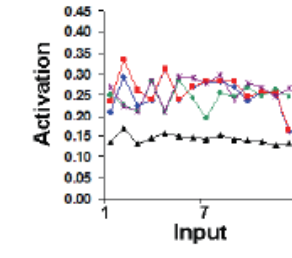
d) LP



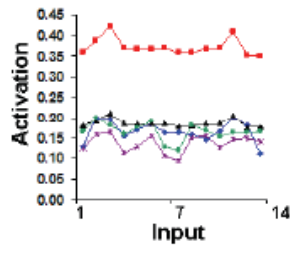
a) VC



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c) LGN



d) LP

Mask-target increased response:

- LP, VC and AM
- (LGN not conditioned on CS)

Mask-target increased response:

- LP and VC
- AM no response – requires LP

Conclusions

- We have modelled the amygdala's visual pathways:
 - Topographic modules: **sub-cortical** and **cortical**
 - Conditioning on **arbitrary** abstract 2-d visual input
- Reproduced observed neurobiological behavior:

Morris et al [9] findings:

- Right fusiform gyrus (temporal lobe) more active for unmasked faces than for masked
- Subjects reported no conscious perception of target when masked
- Yet skin conductance higher
- Sub-conscious perception

Simulation findings:

- VC shows activation for unmasked inputs but did not show significant activation for masked inputs
- Yet AM activations significantly higher
- LP to AM connection essential



Motivation



Fear is an important defence mechanism

Sub-conscious priming of the body to react to a threat

Conscious moderation of actions

Adaptive recognition of threats

Can we build an artificial system that can fear?

Test neuroscience hypotheses

Potential for wide application of adaptive threat detection

Relies on low-level sensory processing

Do we understand sub-cortical processing well enough?

Modelling sub-cortical processing is essential



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Follow-up work: scale and complexity for real images; pulse coding

Relies on low-level sensory processing

Do we understand sub-cortical processing well enough?

Modelling sub-cortical processing is essential

Follow-up work: model of the superior colliculus



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Thank you

Questions?

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