

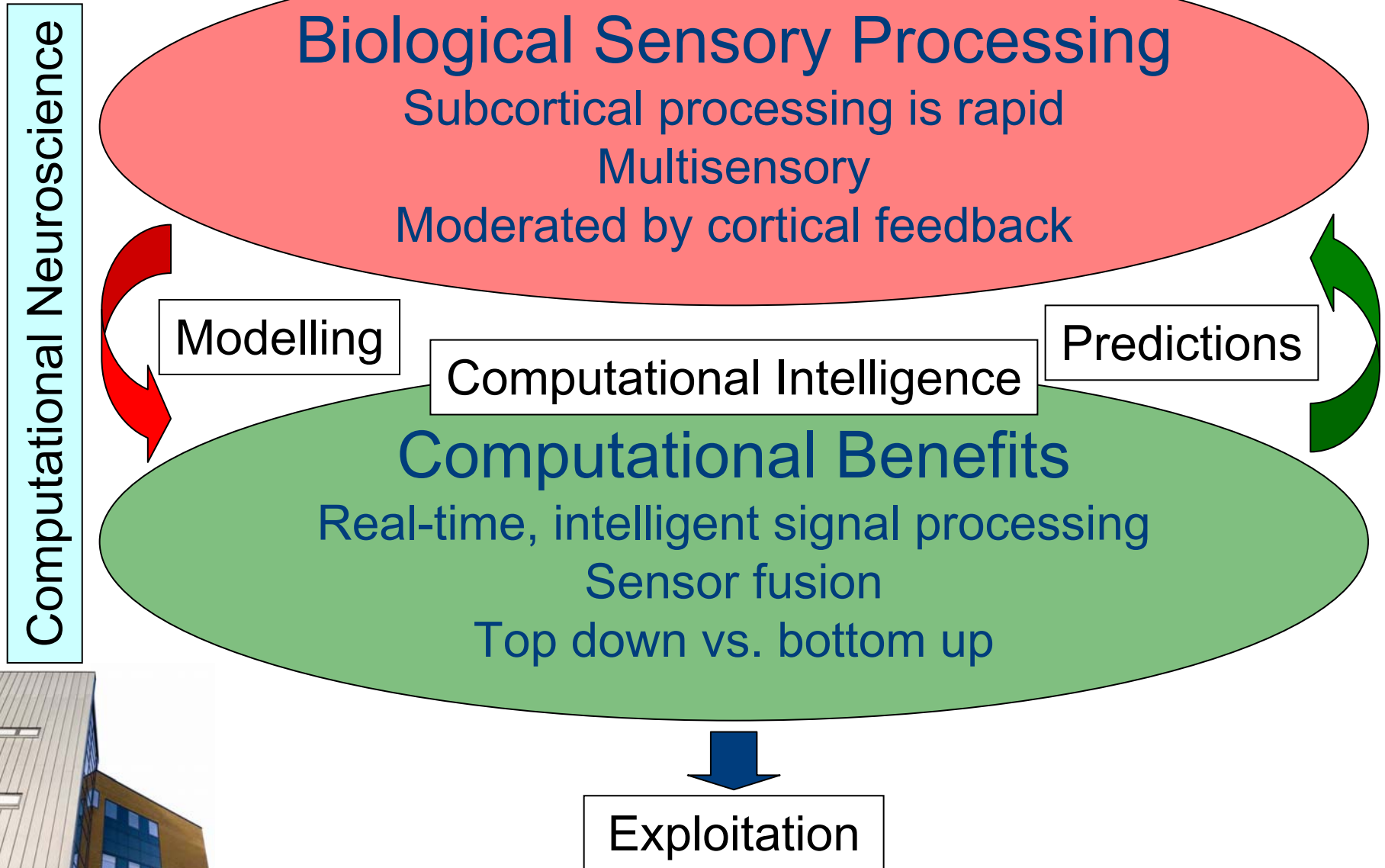
# Simulating the Effects of Cortical Feedback in the Superior Colliculus with Topographic Maps

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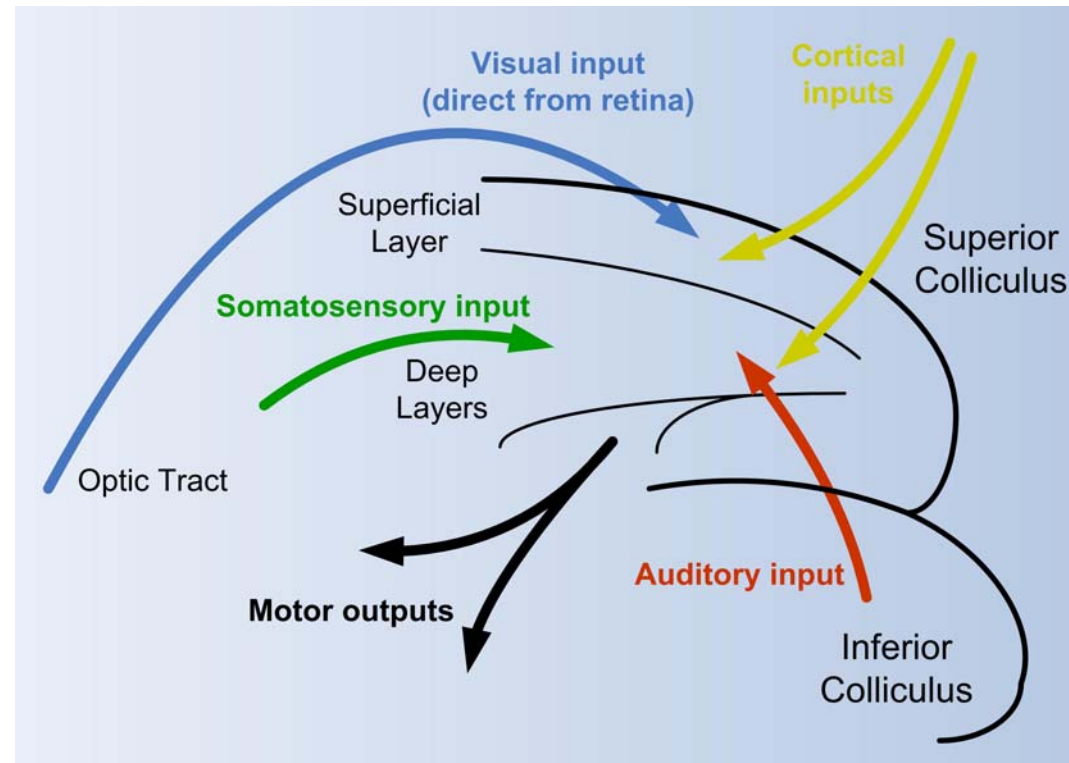


# Motivation



# Superior Colliculus

- Laminated structure in the midbrain [1,2]
  - Combines visual, auditory and somatosensory stimuli
  - Sensory alignment of topographic maps: multisensory space
- Causes gaze shifts
  - Prioritises
  - Multimodal stimuli
- Moderated integration
  - Cortical feedback [3]
  - Task context [4]?



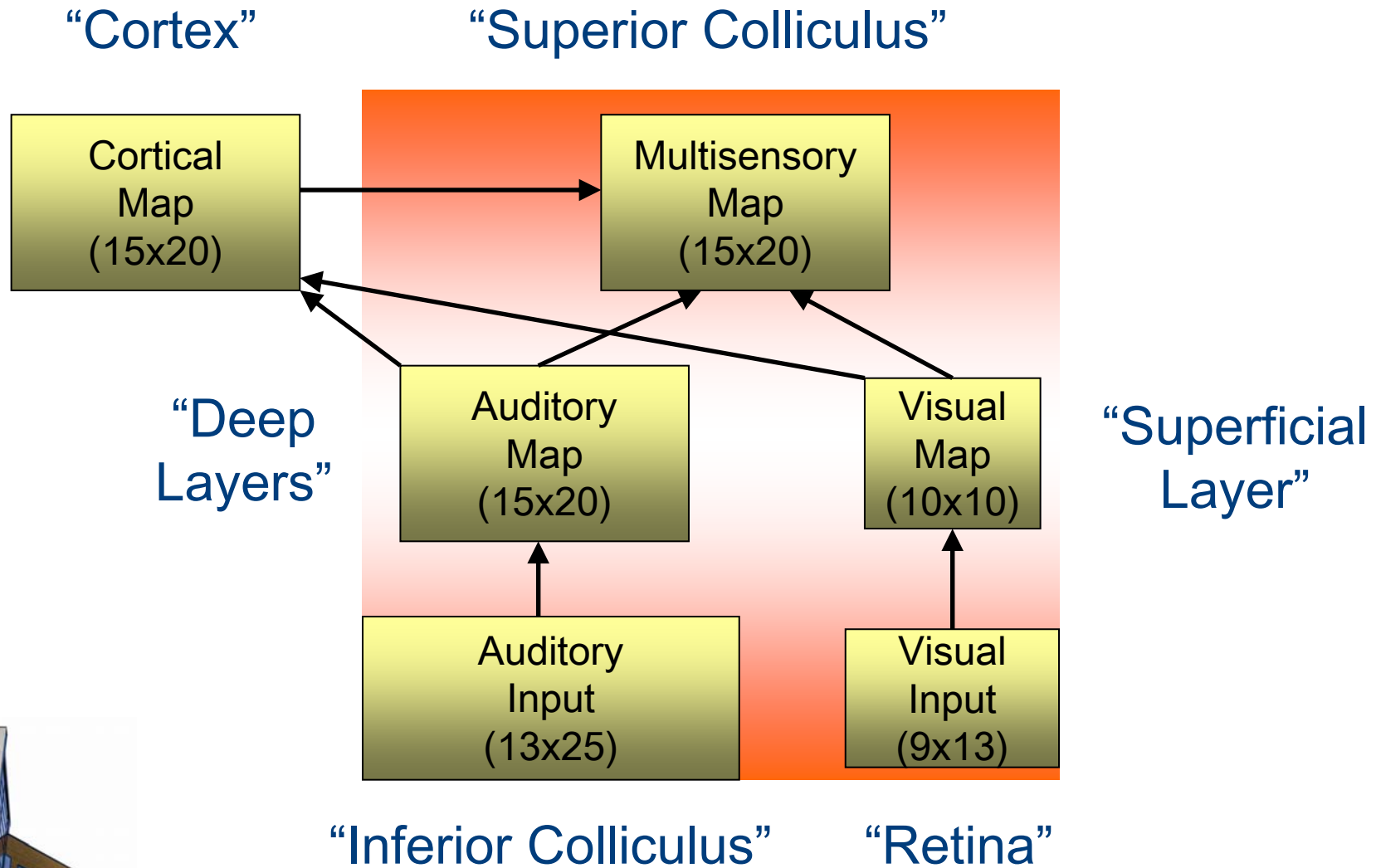


# Modelling the SC

- No existing model of the SC with all of the following:
  - Superficial layer (vision)
  - Deep layers (audition, somatosensory)
  - Multisensory output
  - Cortical feedback
- Models so far:
  - Have focused on the multisensory representation [8,9,11]
  - Integration of unisensory representations [7, 10,11]
  - Development [11,12]
- We present a behavioural model of the SC
  - Development of unisensory and multisensory representations
  - Demonstrates key properties of cortical feedback



# Approach: Behaviour Model

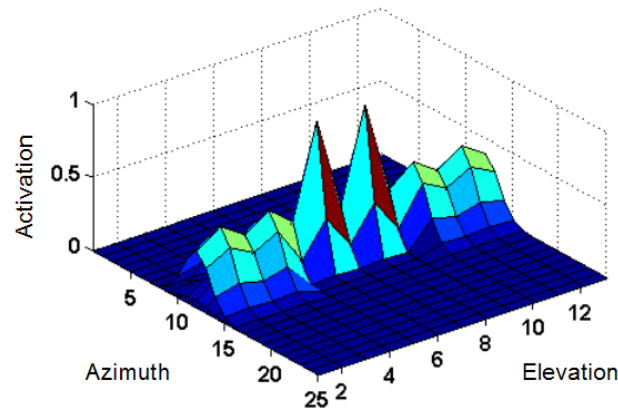


# Input Representation

- Abstract Gaussian blobs to represent spatial stimuli

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

- Dense and non-dense regions (fovea vs. peripheral)
- Auditory azimuth  $[-180^\circ, 180^\circ]$  and elevation  $[-90^\circ, 90^\circ]$



- Visual azimuth  $[-90^\circ, 90^\circ]$  and elevation  $[-65^\circ, 55^\circ]$

# Neural Model

- Topographic maps
  - Spatial representation [11]
  - Develops organisation
- Competitive learning
  - Hebbian association [13]
  - Maps trained in layers
- Integration
  - Map outputs as inputs
  - Unisensory → multisensory
  - Cortex → multisensory

## 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

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

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

## Neighbourhood and learning rate

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

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



# What are we trying to show?

## 3. Feedback

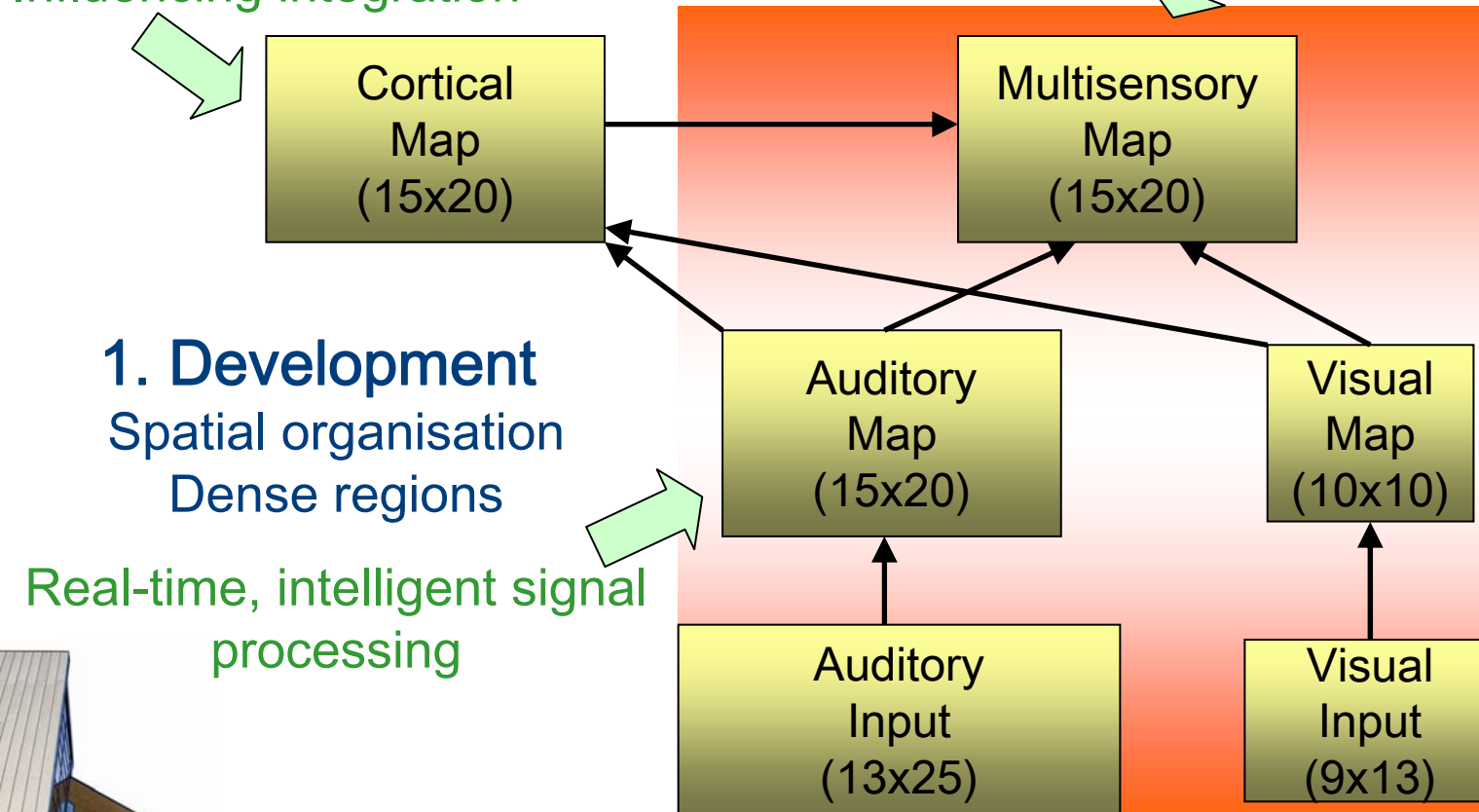
Enhancement and  
suppression

## 2. Integration

Coordinate alignment

Influencing integration

Sensor fusion

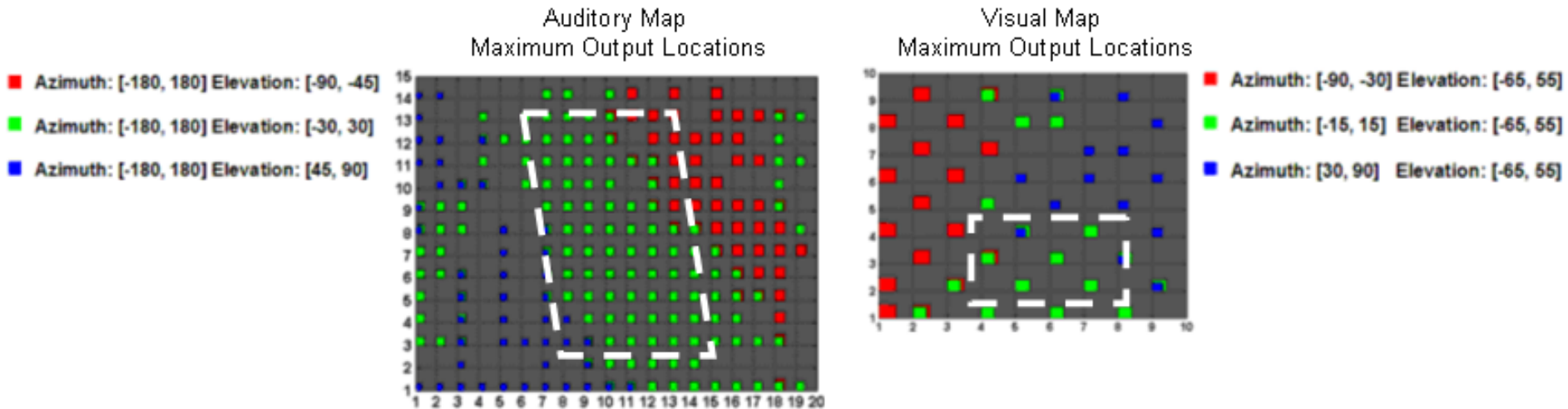


## 1. Development

Spatial organisation  
Dense regions

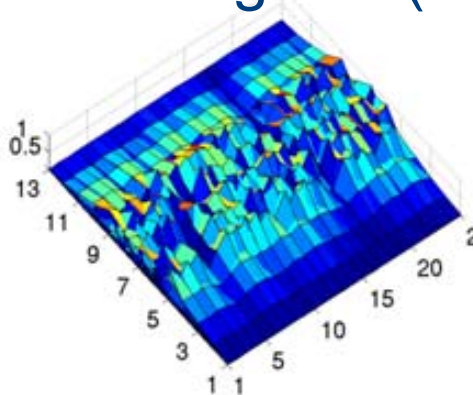
Real-time, intelligent signal  
processing

# 1. Spatial Organisation

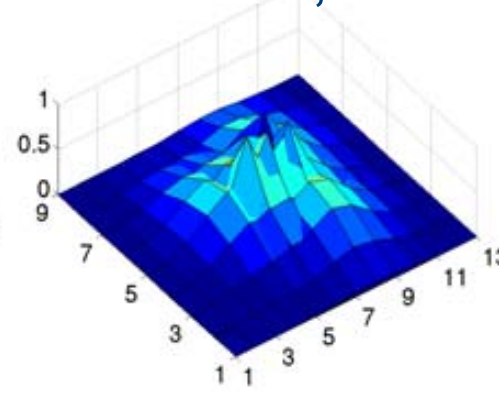


Testing on different examples shows spatial representation  
Larger dense regions (52% vs. 39%; 15% vs. 7%)

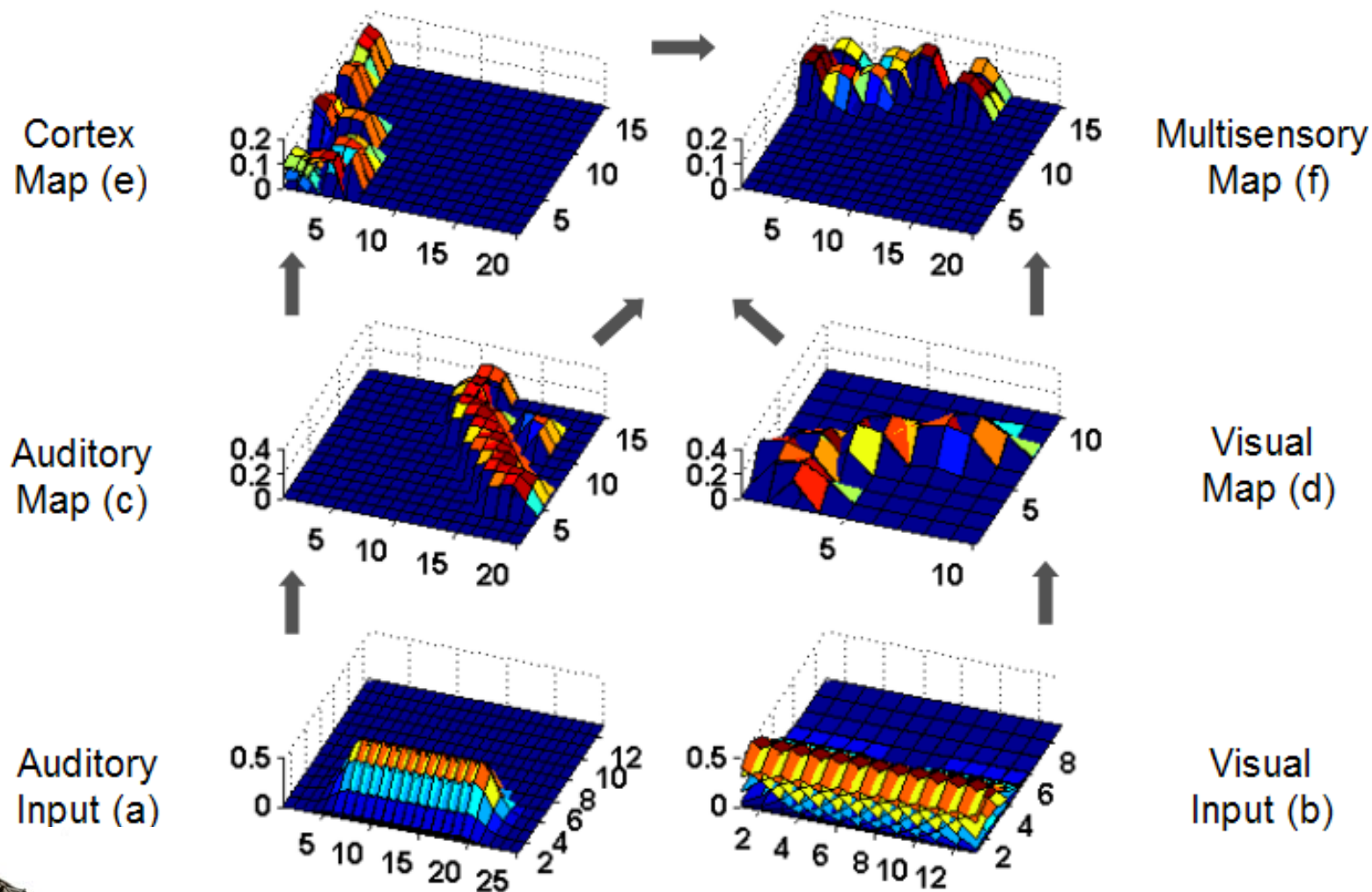
Example Auditory Inputs within  
Azimuth [-180, 180]  
Elevation [30, 30]  
(Dense Area)



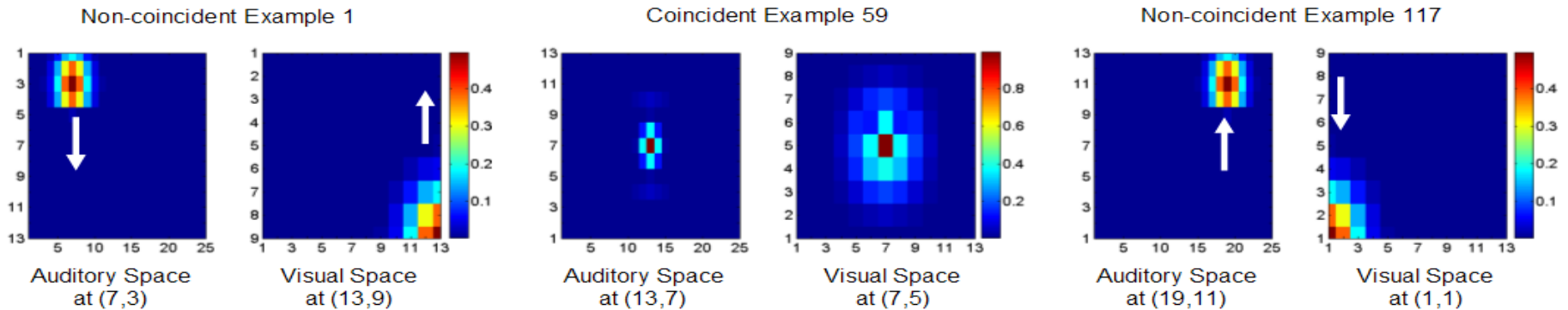
Example Visual Inputs within  
Azimuth [-15, 15]  
Elevation [-15, 15]  
(Dense Area)



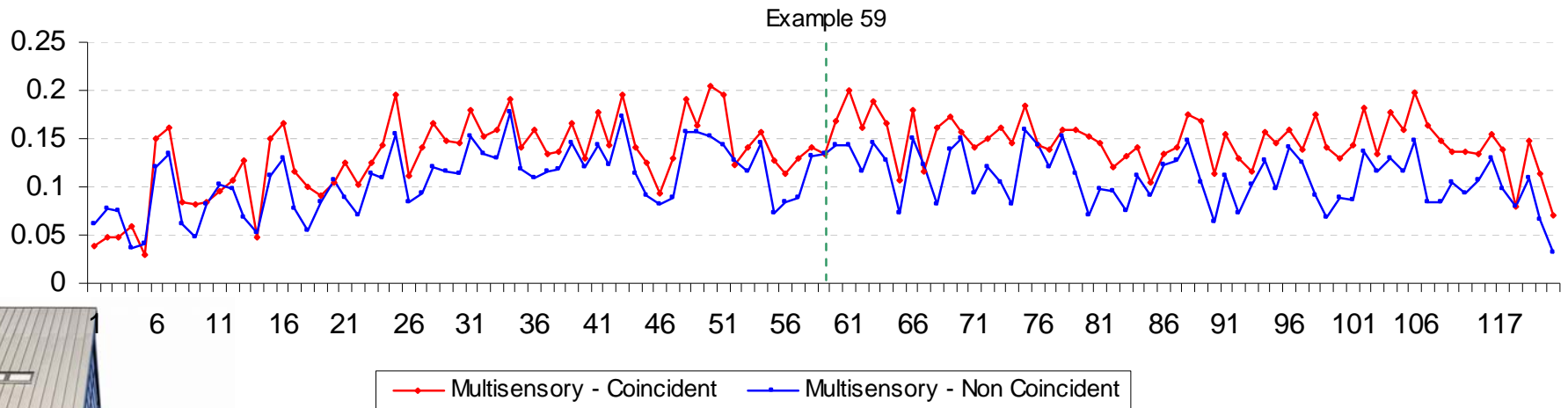
## 2. Coordinate Alignment



## 3a. Enhancement and Suppression

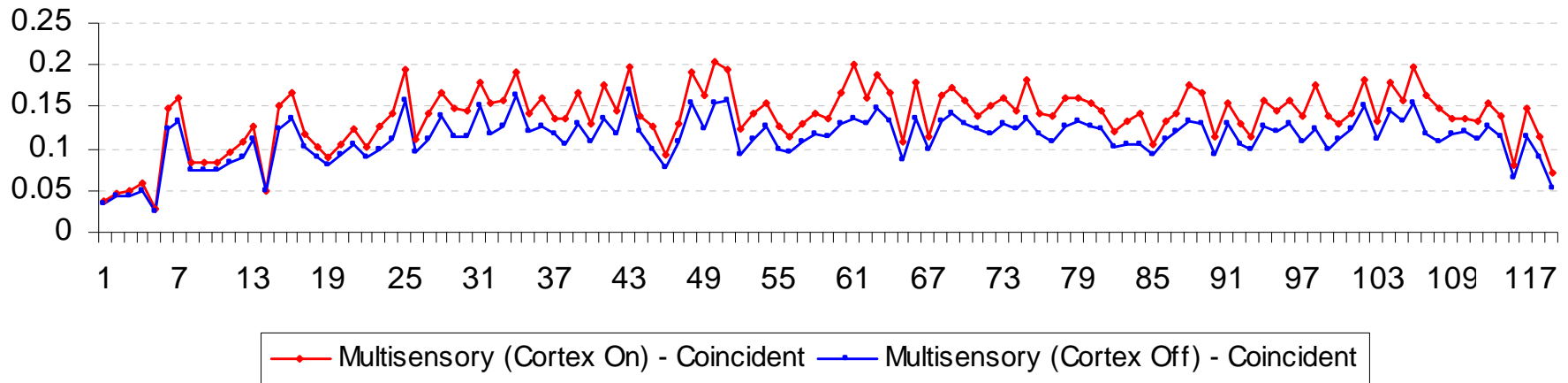


Enhancement: coincident higher activation (mean 0.138)  
 Suppression: non-coincident lower activation (mean 0.108)

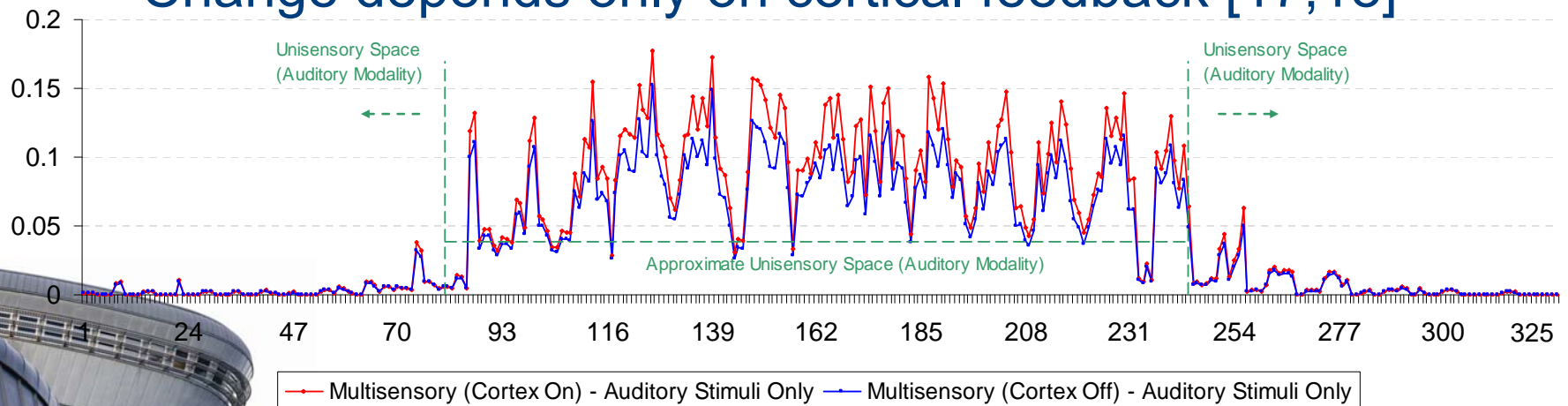




# 3b. Cortical Feedback



With cortical feedback, coincident activation mean 0.138  
 Without cortical feedback, coincident activation mean 0.112  
 Change depends only on cortical feedback [17,18]



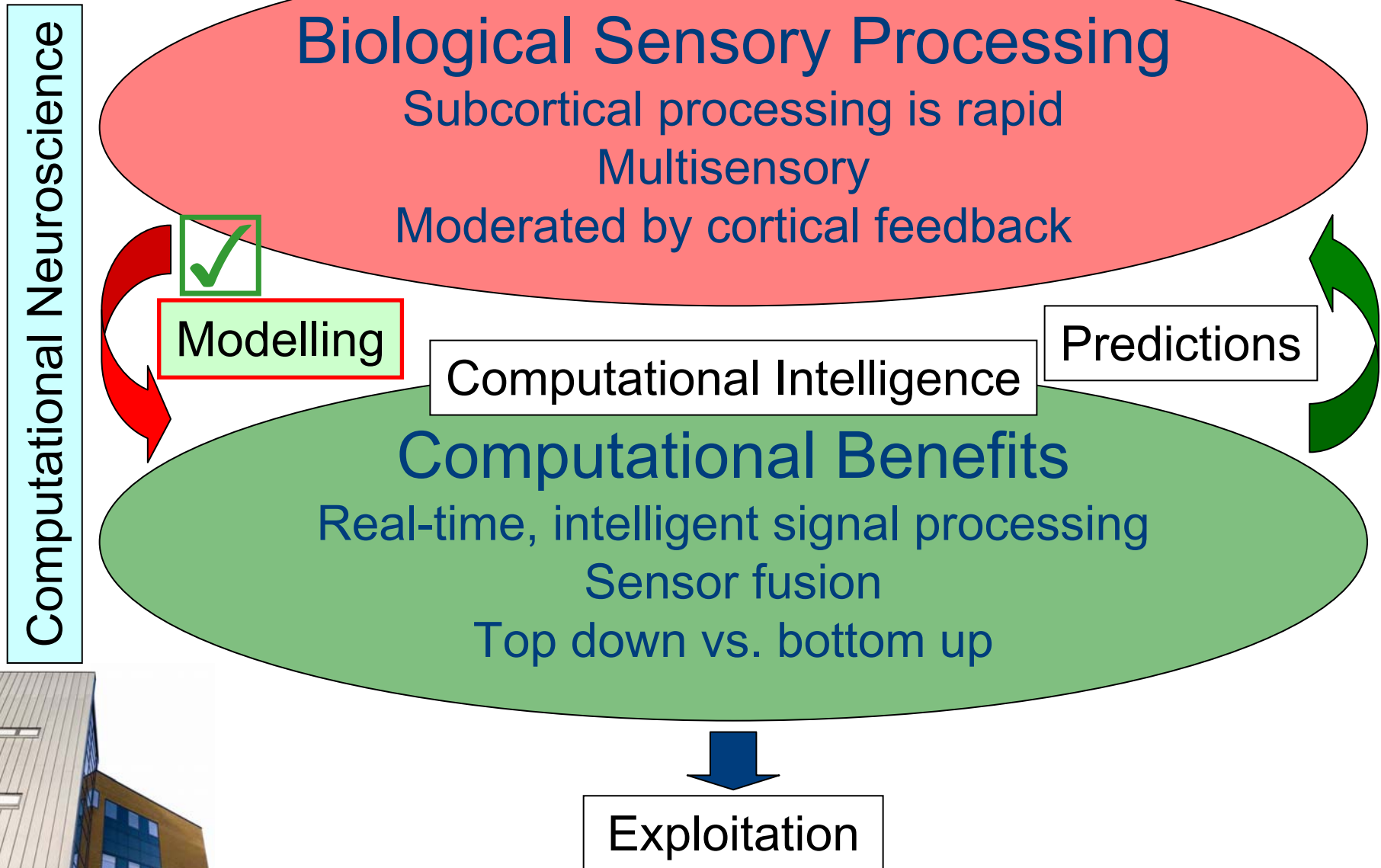


# Summary

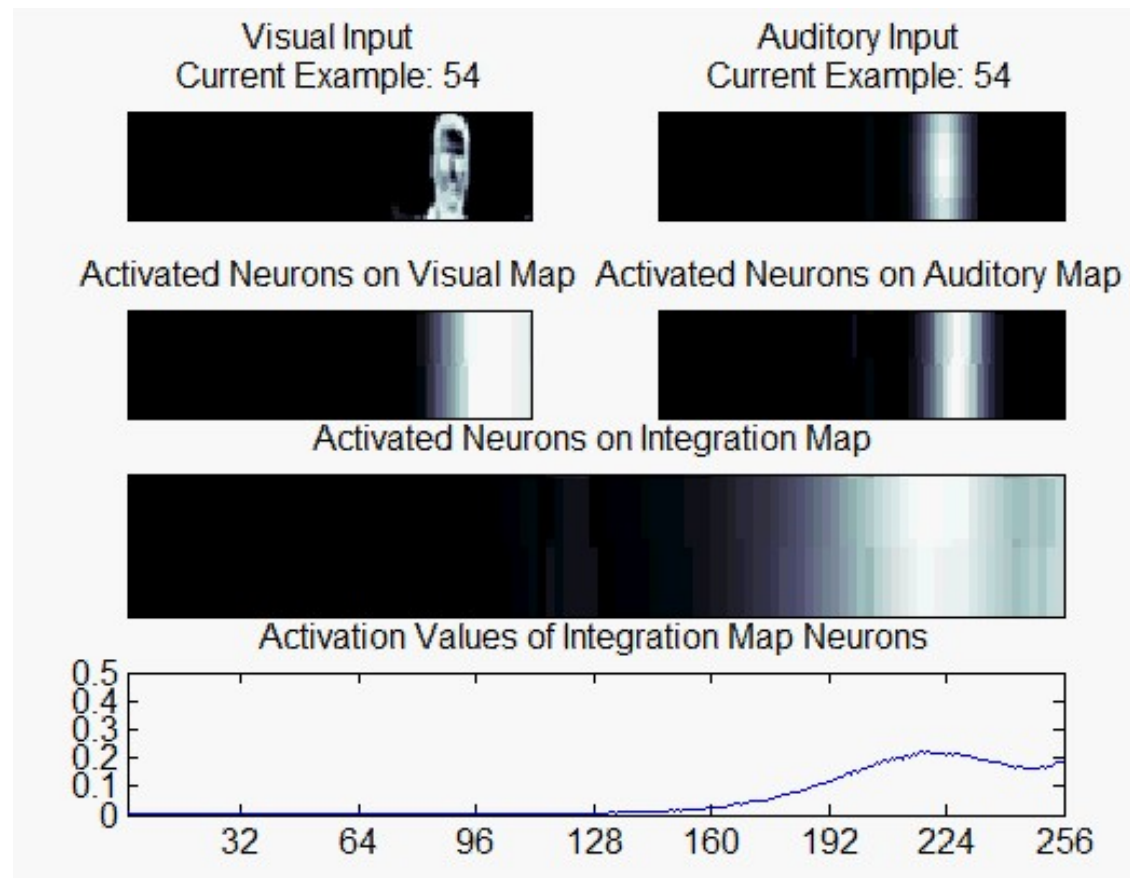
- Demonstrated
  - Complete functional representation of the SC
  - Unisensory, multisensory, cortical feedback
  - Development and sensory alignment
  - Enhancement and suppression
- Limitations:
  - Topographic organisation could be improved
  - Cortical feedback is simplistic
  - Abstract stimuli



# Motivation



# Exploitation: Taster



## Real-time visual and auditory integration:

- Rapid facial localisation
- Sound localisation (interaural level difference)
- Integration: real-time speaker localisation



# References

- [1] B.E.Stein and M.A.Meredith, *The Merging of the Senses*. Cambridge, MA.: A Bradford Book, MIT Press, 1993.
- [2] A.J.King, "The Superior Colliculus," *Current Biology*, vol. 14, pp. R335-R338, 2004.
- [3] B.E.Stein, W.Jiang and T.R.Stanford, "Multisensory Integration in Single Neurons of the Midbrain," G.A.Calvert, C.Spence, and B.E.Stein, Ed. Cambridge, MA.: A Bradford Book, MIT Press, 2004, pp. 243-264.
- [4] J.C.Alvarado, T.R.Stanford, B.A.Rowland, J.W.Vaughan and B.E.Stein, "Multisensory Integration in the Superior Colliculus Requires Synergy among Corticocollicular Inputs," *The Journal of Neuroscience*, vol. 29, pp. 6580-6592, 2009.
- [5] M.Corbetta and G.L.Shulman, "Control of Goal-directed and Stimulus-driven Attention in the Brain," *Nature Reviews Neuroscience*, vol. 3, pp. 215-229, 2002.
- [6] L.A.Notman, P.T.Sowden and E.Özgen, "The Nature of Learned Categorical Perception Effects: A Psychophysical Approach," *Cognition*, vol. 95, pp. B1-B14, 2005.
- [7] S.Grossberg, K.Roberts, M.Aguilar and D.Bullock, "A Neuronal Model of Multimodal Adaptive Saccadic Eye Movement Control by Superior Colliculus," *Journal of Neuroscience*, vol. 17, pp. 9706-9725, 1997.
- [8] T.J.Anastasio, P.E.Patton and K.Belkacem-Boussaid, "Using Bayes' Rule to Model Multisensory Enhancement in the Superior Colliculus," *Neural Computation*, vol. 12, pp. 1165-1187, 2000.
- [9] P.E.Patton and T.J.Anastasio, "Modeling Cross-Modal Enhancement and Modality-Specific Suppression in Multisensory Neurons," *Neural Computation*, vol. 15, pp. 783-810, 2003.
- [10] E.Magosso, C.Cuppini, A.Serino, G.Di Pellegrino and M.Ursino, "A Theoretical Study of Multisensory Integration in the Superior Colliculus by a Neural Network Model," *Neural Networks*, vol. 21, pp. 817-829, 2008.
- [11] M.C.Casey and A.Pavlou, "A Behavioral Model of Sensory Alignment in the Superficial and Deep Layers of the Superior Colliculus," in *Proceedings of the International Joint Conference on Neural Networks (IJCNN) 2008*, 2008, pp. 2751-2756.
- [12] J.Huo and A.Murray, "The Adaptation of Visual and Auditory Integration in the Barn Owl Superior Colliculus with Spike Timing Dependent Plasticity," *Neural Networks*, vol. 22, pp. 913-921, 2009.
- [13] J.L.Armony, D.Servan-Schreiber, J.D.Cohen and J.E.LeDoux, "Computational Modeling of Emotion: Explorations Through the Anatomy and Physiology of Fear Conditioning," *Trends in Cognitive Sciences*, vol. 1, pp. 28-34, 1997.
- [14] T.Kohonen, "Self-Organized Formation of Topologically Correct Feature Maps," *Biological Cybernetics*, vol. 43, pp. 59-69, 1982.
- [15] A.Pavlou, "Computational Modelling of Visual Fear Conditioning," Unpublished doctoral thesis, University of Surrey, Guildford, UK, 2009.
- [16] J.L.McClelland, A.Thomas, B.D.McCandliss and J.A.Fiez, "Understanding Failures of Learning: Hebbian Learning, Competition for Representational Space and Some Preliminary Experimental Data," J.Reggia, E.Ruppin, and D.Glanzman, Ed. The Netherlands: Elsevier Science BV, 1999, pp. 75-80.
- [17] J.C.Alvarado, T.R.Stanford, J.W.Vaughan and B.E.Stein, "Cortex Mediates Multisensory but not Unisensory Integration in Superior Colliculus," *Journal of Neuroscience*, vol. 27, pp. 12775-12786, 2007.
- [18] M.T.Wallace and B.E.Stein, "Cross-modal Synthesis in the Midbrain Depends on Input from Cortex," *Journal of Neurophysiology*, vol. 71, pp. 429-432, 1994.
- [19] B.A.Rowland, T.R.Stanford and B.E.Stein, "A Model of the Neural Mechanisms Underlying Multisensory Integration in the Superior Colliculus," *Perception*, vol. 36, pp. 1431-1443, 2007.
- [20] E.Izhikevich and G.M.Edelman, "Large-Scale Model of Mammalian Thalamocortical Systems," *Proceedings of the National Academy of Sciences of the USA*, vol. 105, pp. 3593-3598, 2008.



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Questions?

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