Mind the (Computational) Gap

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Matthew Casey
Athanasios Pavlou
Anthony Timotheou
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Motivation

- "Are we there yet?" [1]
  - Cristianini's view on the state of computational intelligence (CI)
  - We have not achieved Turing's "intelligent machinery" dream [2]
  - But some impressive "data driven AI" [1:467]
  - Advocating a broader reference for intelligence
- Yet neuroscience has seen some impressive advances
  - Large-scale simulations of the human brain [3,4]
  - Mostly focused on the cortex (like Turing)
  - Can we still learn from computational neuroscience (CN)?
- Do large-scale CN models hold the key to "intelligence"?
  - There appears to be a computational gap between CN & CI
  - How can we apply these models and plug this gap?

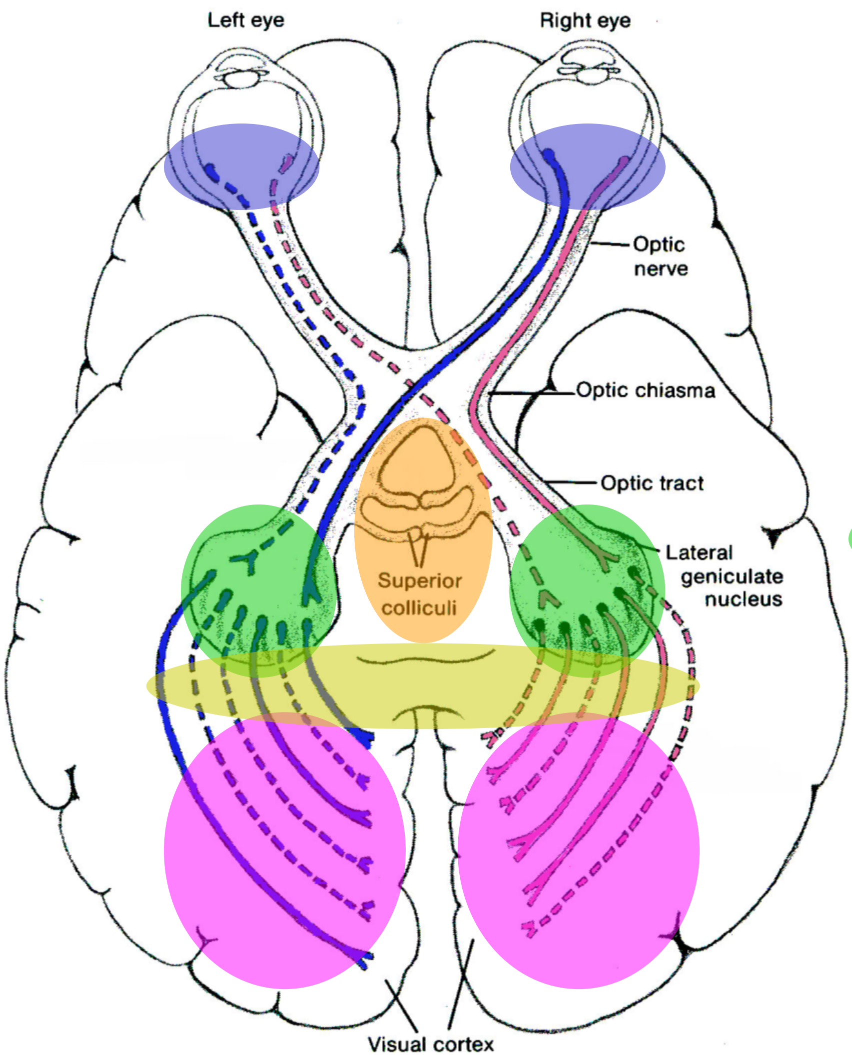
Aim

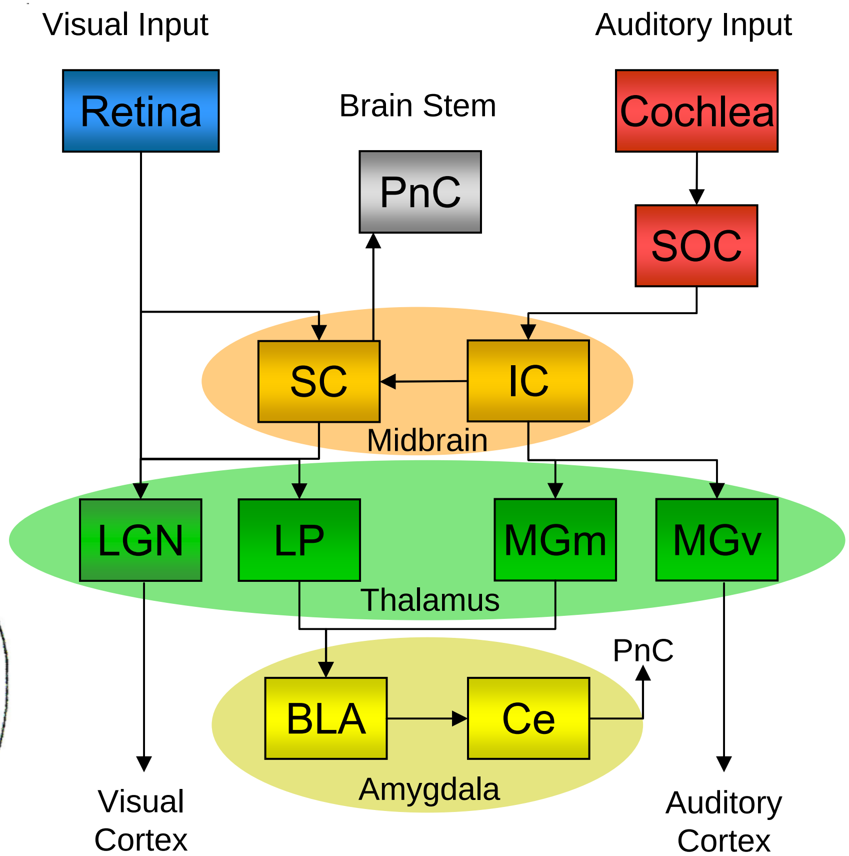
- Large-scale models are impressive
  - But not connected with the real-world
- Can we develop large-scale models connected to the real world?
  - Useful for CN: behavioural models
  - Useful for CI: applying models of intelligence
- What do we need?
  - To focus on how to provide cortical models with input/output
- Focus on function below the cortex
  - Sensorimotor function: subcortical processing

Proof-of-concept

- Use an existing CN model and apply it to real-time inputs
  - Extract computational principles
  - Apply models to an example CI problem
- Which brain structures?
  - Subcortical visual processing
  - Link between senses and cortical processing
  - Extensive studies of key structures
  - Good example: superior colliculus
  - Using existing CN models (cf. [9,10])

Audio-Visual Subcortical Function

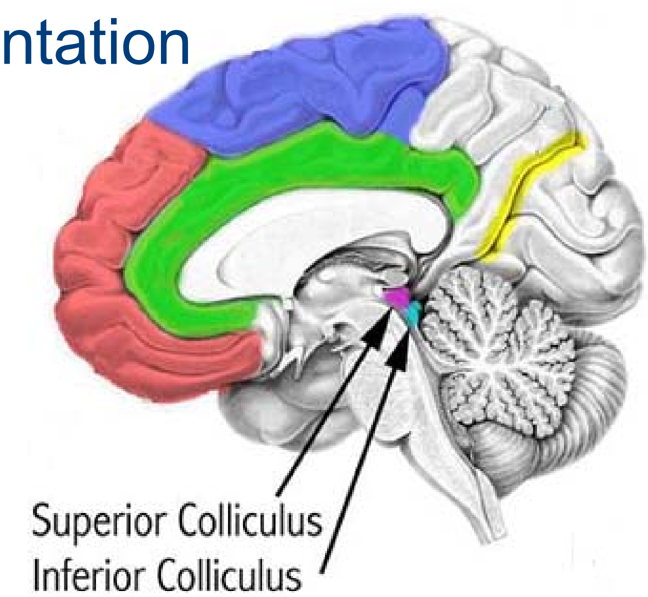




Constructed from [11,14,15,18]

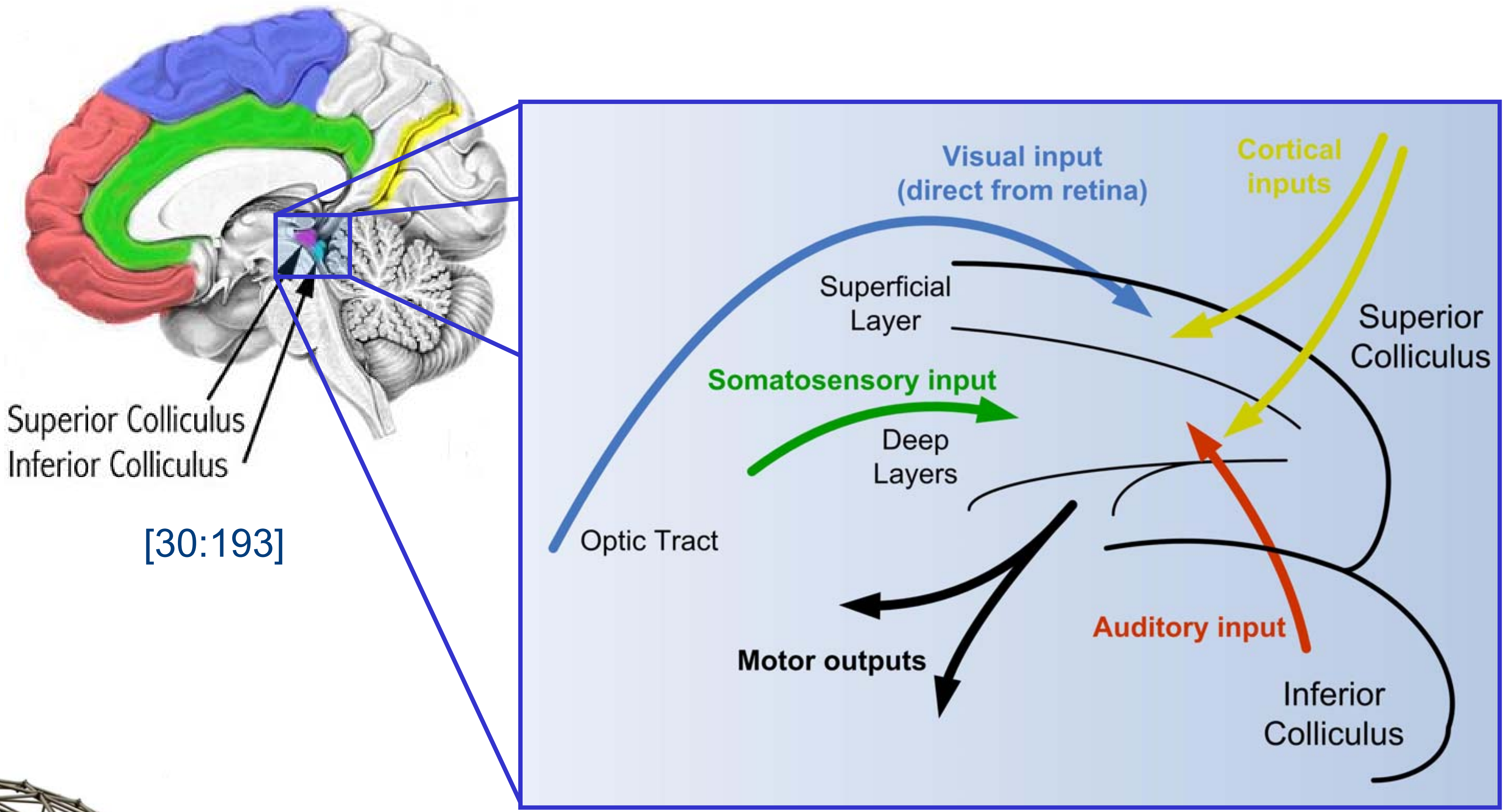
Superior Colliculus

- Laminated midbrain structure [13,21]
  - Combines visual, auditory and somatosensory stimuli
  - Sensory alignment of topographic maps
  - Develops a multisensory representation
- Causes gaze shifts
  - Prioritises to multimodal stimuli
  - Enhancement and suppression
- Integration is moderated
  - Cortical feedback [23]
  - Unisensory co-operation?



[30:193]

Superior Colliculus



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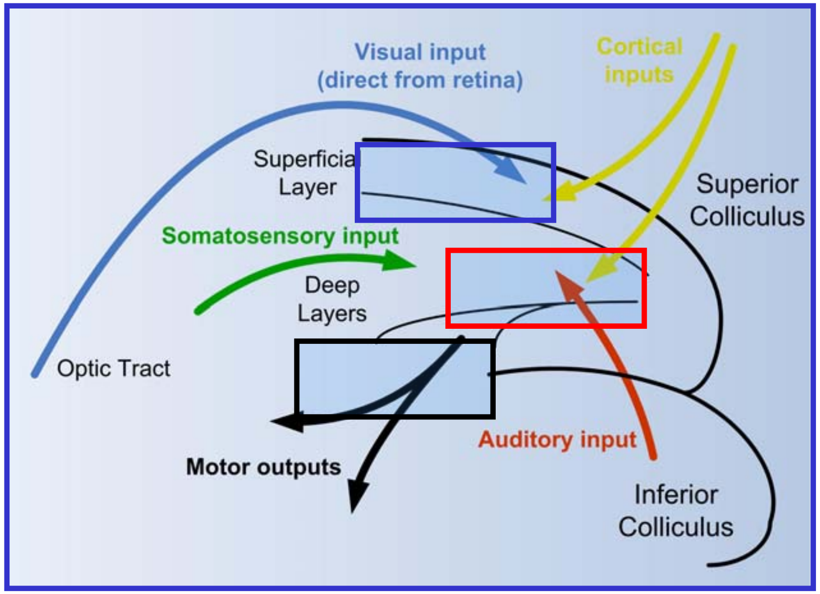
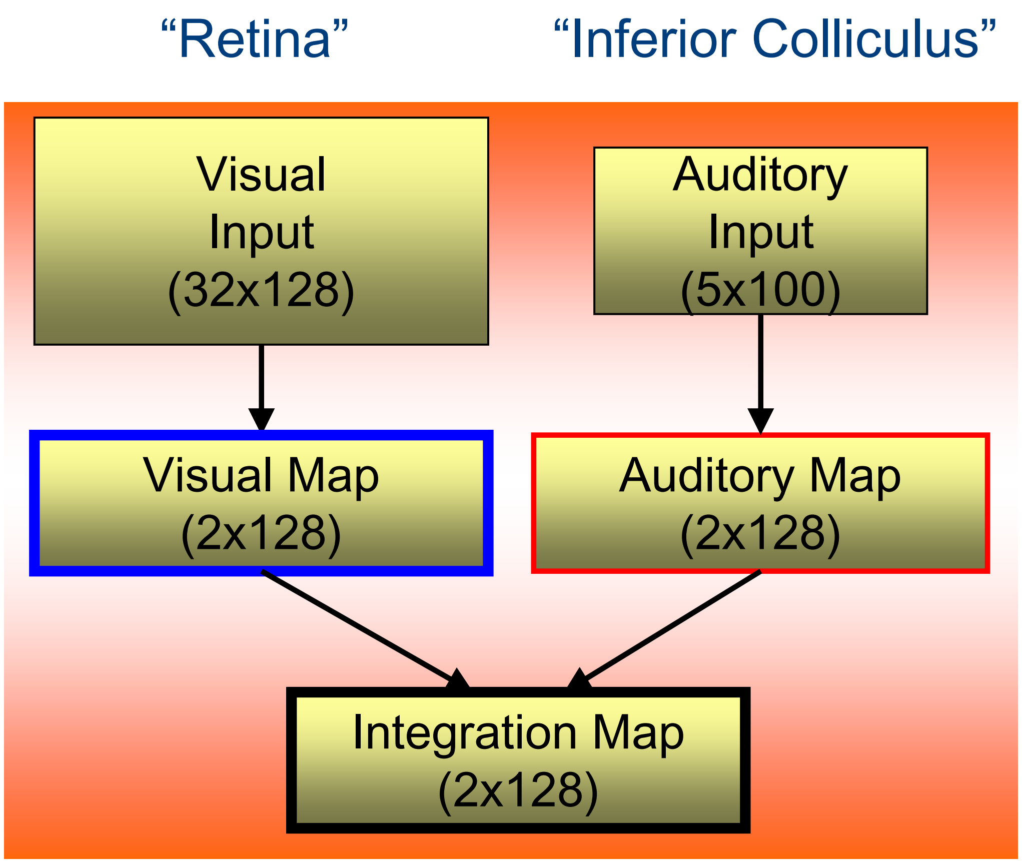
Computational Principles

Subcortical structures	Example
1. Develop	• Self-organisation
2. Adapt	• Through conditioning
3. Discriminate	• Albeit on crude stimuli
4. Operate rapid	• Express saccades 80ms [6]
5. Direct input/output	• Optic tract, plus others [19]
6. Multisensory	• Early stages of processing [21]
7. Essential for cortex	• Sensory routing to cortex, plus cortex-to-cortex [12,22,23]

Behaviour Model of the SC





Based upon our previous CN models [9,10]

Rate-coded Neural Model

- Topographic maps
  - Spatial representation [9]
  - Develops organisation
- Competitive learning
  - Hebbian association [18]
  - Maps trained in layers
- Integration
  - Map outputs as inputs
  - Unisensory → 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

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

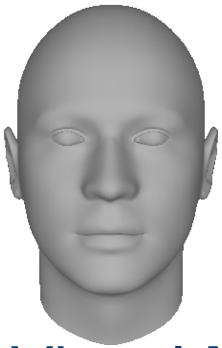
$$\epsilon(t) = l_{min} + (l_{max} - l_{min}) e^{-\left(\frac{(t/t_e)}{2l_s^2}\right)}$$

Speaker Localisation

- We are attempting to show that CN models can be connected to real-world inputs to apply their principles
- As a toy example we select speaker localisation
  - To locate a coincident facial and sound stimulus
  - Not aiming for state-of-the-art, but generic, adaptive solutions
- This will demonstrate:

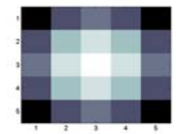
1. Develop	• Internal spatial representations
2. Adapt	
3. Discriminate	• Face silhouettes
4. Operate rapidly	• Real-time inputs (25 frames per second)
5. Direct input/output	• Sensory inputs, location output
6. Multisensory	• Video and audio
7. Essential for cortex	

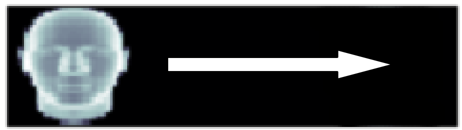
Training: Artificial Stimulus



FaceGen [27]

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



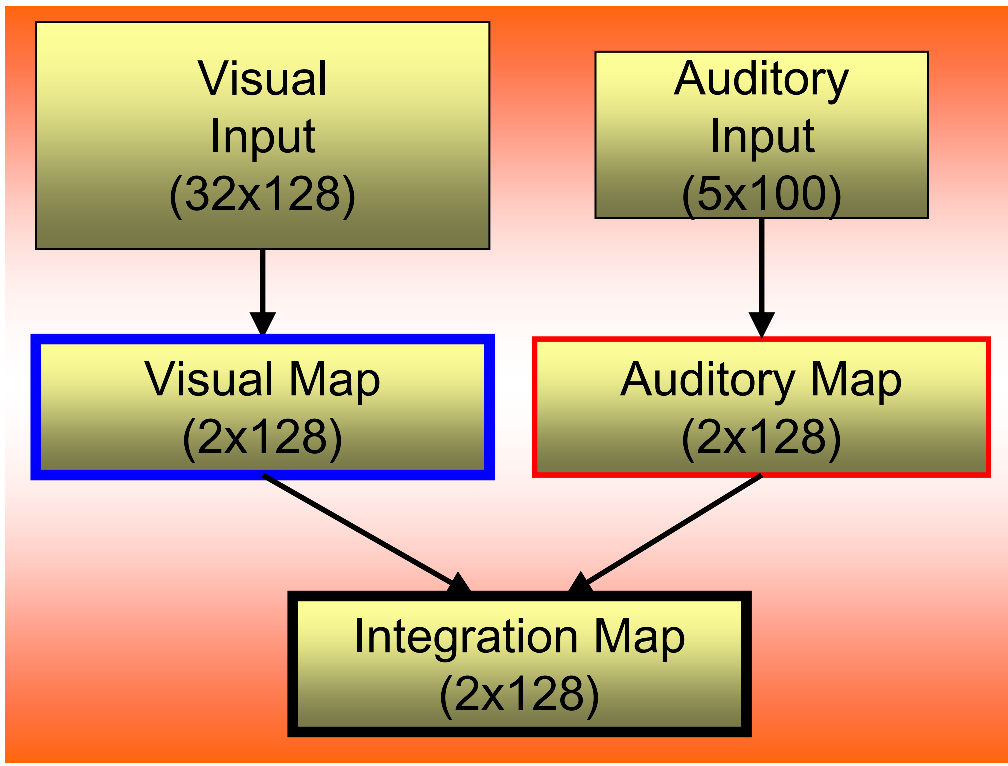


Visual Map

96 frames

Generic face

400 epochs



Auditory Map

96 frames

Gaussian blob

400 epochs

Develops a spatial representation of visual space, discriminates face silhouettes

Develops a spatial representation of auditory space

Integration of visual and auditory locations

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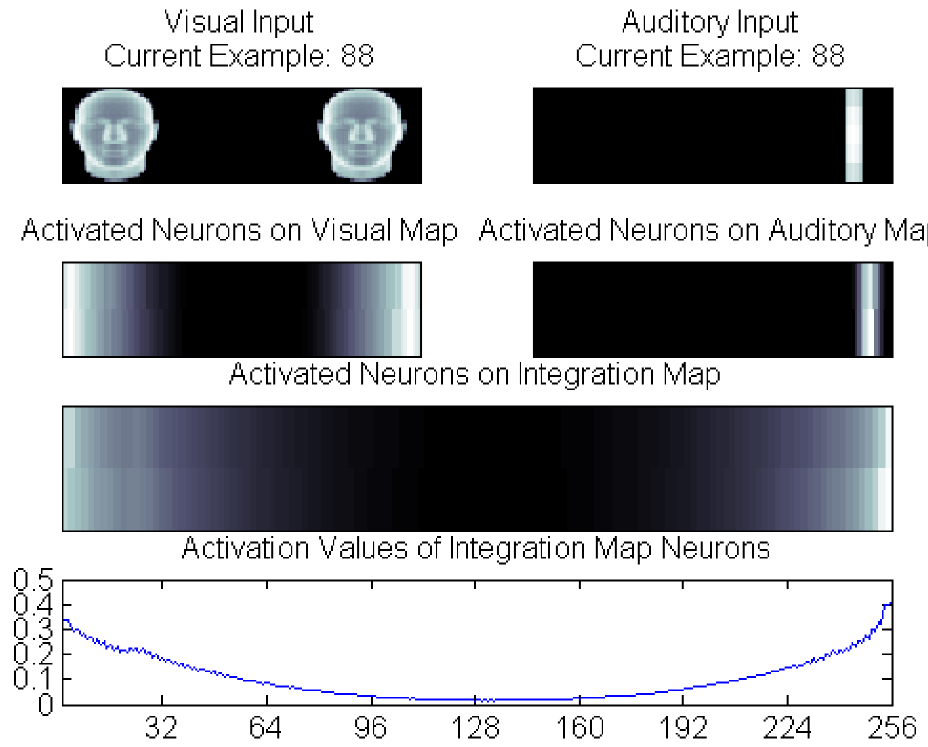
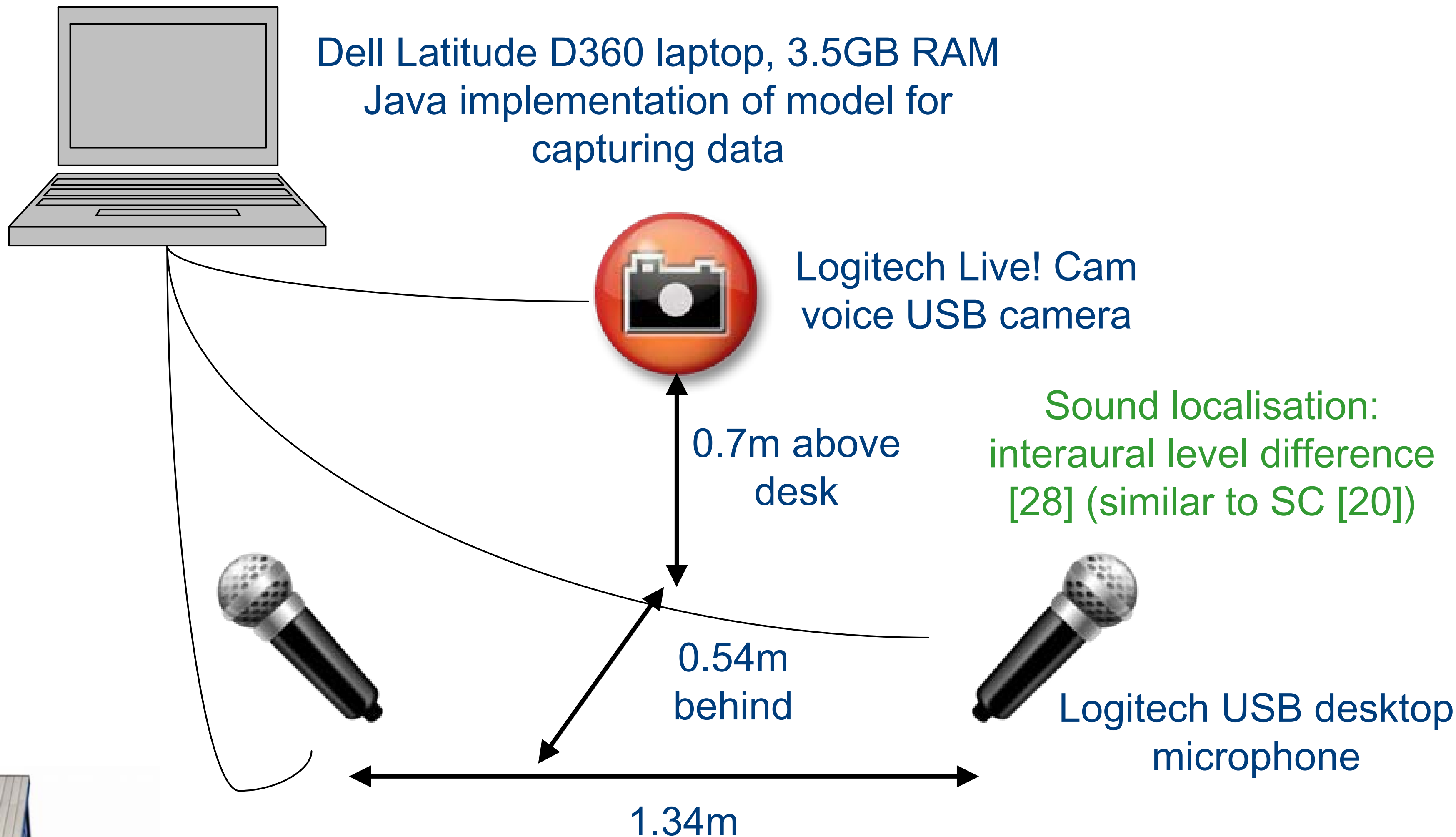
Model Development

- Learnt spatial representations
  - Discriminates and locates (crude) faces
  - Locates abstract sound stimuli
  - Integrates locations
  - (Parameters [9])
- When coincident
  - Higher integrated activation



Experimental Set-up

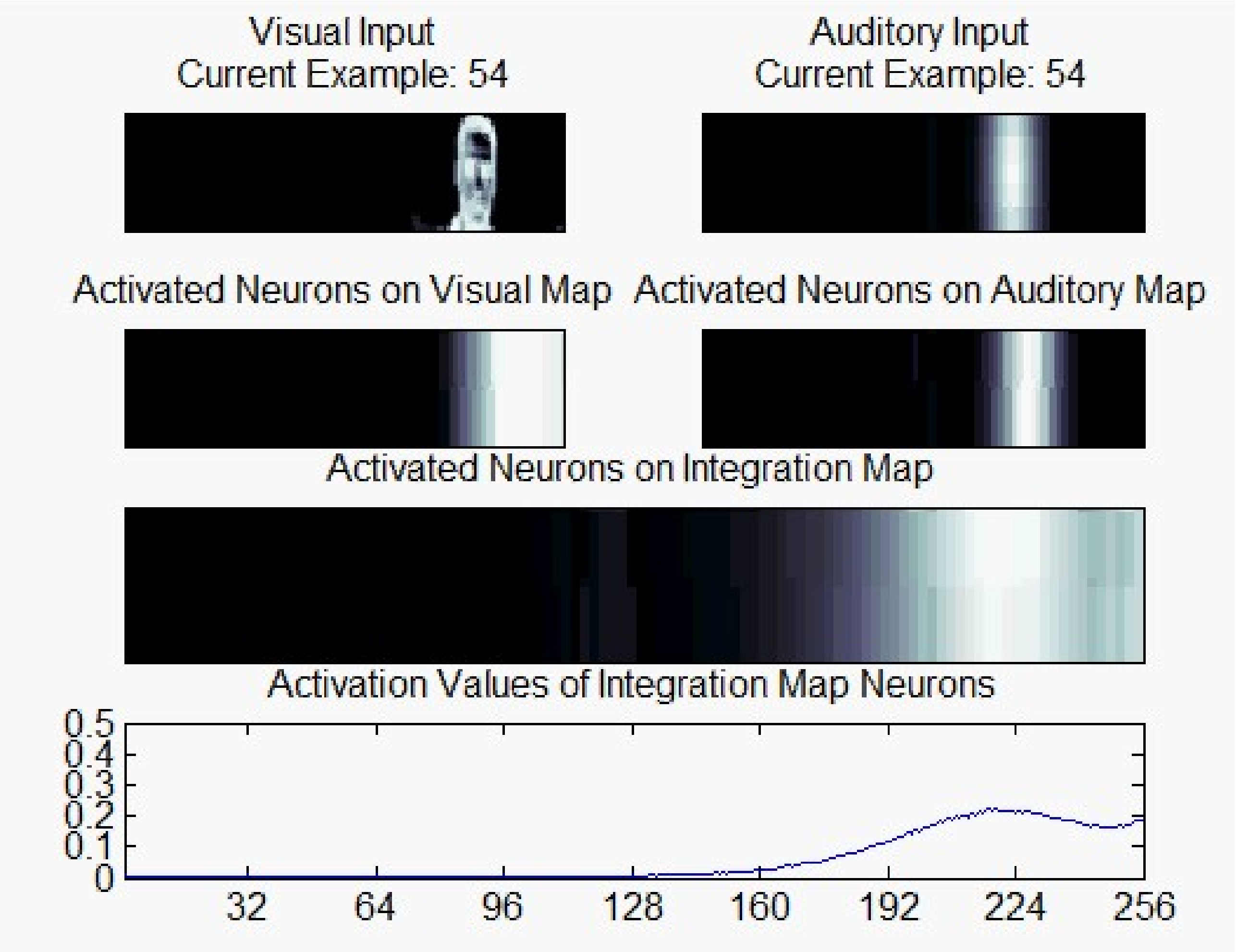


Independent sound source (pure tone) located 0.42m in front of microphones

Experiments

- Data
  - 325 example frames (13 seconds at 25 fps)
  - Various conditions: no faces, one face enters, another face enters, first leaves, last leaves, plus moving sound source
- Responses
  - Faces and sound localised at 25 fps
  - Integration response of 0.22 or above when coincident
- However
  - Crude discrimination of faces
  - Sound needs to be sufficiently loud and sustained

Example


Visual Input
Current Example: 54
Auditory Input
Current Example: 54
Activated Neurons on Visual Map
Activated Neurons on Auditory Map
Activated Neurons on Integration Map
Activation Values of Integration Map Neurons
0.5
0.4
0.3
0.2
0.1
0
32
64
96
128
160
192
224
256

Conclusion

- Can we develop large-scale real-world CN models?
  - To achieve this, we need CN models that can be connected to real-world inputs
- We demonstrated
  - How an existing CN model can be applied to real-time inputs
  - Simple speaker localisation to show crude discrimination
  - But generic and fast pattern recognition
- Limitations
  - Model uses less plausible rate-coded neurons: spiking needed
  - Need to increase the scale: link to cortical models
  - Simple localisation, hardware constrained, but functional
  - Ad-hoc computational principles identified
- Yet this shows how CN models can be applied to CI

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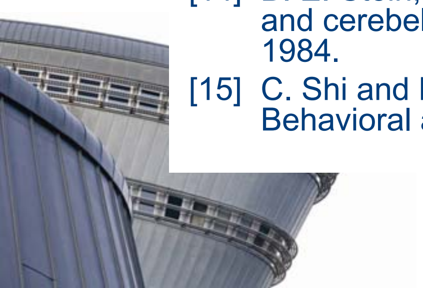

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Thank you

Questions?

T: +44 (0)1483 689635
F: +44 (0)1483 686051
m.casey@surrey.ac.uk